Walking Economy is Impaired in Older Men and Women with Type 2 Diabetes

Research Article

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Abstract

Objective: We compared the walking economy in older participants with and without type 2 diabetes.

Methods: Walking economy was determined in 115 older participants with type 2 diabetes and 130 older control participants without diabetes by continuously measuring oxygen uptake during a treadmill test in which the work rate was at a constant speed of 2 mph and a grade of 0% for a duration of 10 minutes. Participants also completed a Balke treadmill protocol for the determination of peak oxygen uptake, defined as the highest oxygen uptake value attained during the final work stage attained. Fractional utilization was then calculated as the walking economy oxygen uptake divided by peak oxygen uptake, expressed as a percentage.

Results: Compared to those without diabetes, participants with type 2 diabetes were older (p=0.042), had higher prevalence of men (p=0.034), obesity (p=0.010), chronic kidney disease (p=0.020), peripheral artery disease (p=0.024), and had a higher body mass index (p=0.025), and waist/hip ratio (p=0.006). After adjusting for these variables, the participants with diabetes had higher walking economy (p<0.001), fractional utilization (p<0.001), and lower peak oxygen uptake (p<0.001) than those without diabetes (p<0.001).

Conclusions: Older men and women with type 2 diabetes are less economical when they ambulate at a given speed than compared to control participants without diabetes, independent of their greater co-morbid burden. The impaired walking economy in the diabetic participants is further magnified by their lower aerobic fitness, thereby leading to a higher fractional utilization of oxygen consumed during a given walking task.

Keywords: Ambulation; Exercise; Mobility; Oxygen Consumption; Women.

Introduction

The global prevalence of diabetes mellitus in adults is 9%, affecting 415 million adults in 2015 which is expected to increase to nearly 642 million by 2040 [1]. People over the age of 60 have a disproportionately high prevalence, as approximately 35% of all cases worldwide (135 million) are older adults [2]. Type 2 diabetes mellitus represents up to 95% of these cases [3], and is associated with high burden of comorbid conditions, such as peripheral neuropathy, nephropathy, retinopathy, cardiovascular complications, and a high mortality rate that exceeds 5 million per year [2]. Not surprisingly, 12% of global health expenditure is spent on diabetes [2].

The ability to ambulate well is important in maintaining functional independence in older adults. Walking economy, defined as the oxygen uptake during ambulation, is a key aspect in sustaining ambulatory activities [4]. Impaired walking economy is reflective of high oxygen uptake during a given ambulatory task, and may be a consequence of an altered gait pattern [5-7]. The clinical relevance of poor walking economy is that ambulation is performed at a higher intensity of exercise, particularly when combined with lower aerobic capacity, thereby potentially leading to faster fatigue, limited mobility, and lower daily physical activity. Older adults with diabetes have impairments in spatial and temporal gait characteristics, such as decreased gait velocity, shorter step length, and increased step width, stance time, and double-support time.

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[8-10], all of which may impair walking economy. Additionally, individuals with diabetes have higher prevalence of cardiovascular comorbid conditions, lower physical activity and leg strength, and higher body mass index, which are additional factors that may impact ambulation [10]. However, surprisingly little information is available on the impact of diabetes on walking economy in older adults.

The purpose of this study was to compare the walking economy in older participants with and without type 2 diabetes. We hypothesized that compared to those without type 2 diabetes, participants with diabetes would have worse walking economy, defined as a higher oxygen uptake during walking at a given pace. Furthermore, walking at a constant pace would be performed at a higher fractional utilization (i.e., relative exercise intensity) in the participants with type 2 diabetes due to the combination of having a higher walking economy value and a lower maximal oxygen uptake.

Methods

Participants

Approval and Informed Consent: The institutional review board at the University of Oklahoma Health Sciences Center approved the procedures of this study. Written informed consent was obtained from each participant at the beginning of investigation.

Recruitment: Individuals with and without type 2 diabetes who were ≥ 50 years of age, and who were able to walk independently without a walking aid [11] were recruited to participate in this study. The participants were recruited by distributing informational flyers in clinics at the University of Oklahoma Medical Center and in various locations in the Oklahoma City area, and by media advertising in local newspapers and in campus-wide email messages.

Medical Screening: Participants were evaluated during a medical history and physical examination. Demographic information, height, weight, body mass index, waist and hip circumferences, cardiovascular risk factors, co-morbid conditions, blood samples, and a list of current medications were obtained.

Definitions of Clinical Characteristics: Obesity was defined by a body mass index ≥ 30 [12], and abdominal obesity was defined by a waist circumference ≥ 102 cm in men and ≥ 94 cm in women [12]. Hypertension was defined by having at least one of the following conditions: a systolic blood pressure ≥ 140 mmHg, a diastolic blood pressure ≥ 90 mmHg, or currently taking antihypertensive medications [13]. Dyslipidemia was defined by having at least one of the following conditions: a cholesterol value ≥ 200 mg/dl, a triglyceride value ≥ 150 mg/dl, a low-density lipoprotein level ≥ 130 mg/dl, a high-density lipoprotein level < 40 mg/dl in men and < 50 mg/dl in women, or currently taking lipid-lowering medications [14]. Peripheral artery disease was determined by measuring the ankle and brachial systolic blood pressures after 10 minutes of supine rest, as previously described [15], and was defined by an ankle/brachial index value < 0.90 [16]. Coronary artery disease was defined by having at least one of the following conditions: a history of coronary percutaneous transluminal angioplasty, coronary stents, coronary artery bypass graft, myocardial infarction, or symptoms of exertional angina. Cerebrovascular disease was defined by having one of the following conditions: a history of carotid stents, coronary endovascular angioplasty, coronary bypass graft, stroke, or transient ischemic attacks. Chronic kidney disease was determined using the four variable modification of diet in renal disease equation, and was defined as having an estimated glomerular filtration rate < 60 ml/min per 1.73 m² [17].

Inclusion and Exclusion Criteria: Participants were included in the type 2 diabetes group if they met either or both of the following criteria: fasting plasma glucose ≥ 126 mg/dl [2], and/or current use of diabetes medications such as oral medications and/or insulin [18]. Individuals were included in the non-diabetic control group if they met both of the following criteria: fasting plasma glucose < 100 mg/dl, and not taking diabetes medications [3]. Individuals in either group were excluded from participating for the following reasons: (a) fasting plasma glucose between 100 and 125 mg/dl and not on diabetes medications, (b) any condition that would contraindicate performing exercise tests according to the American College of Sports Medicine [19], (c) active cancer, (d) stage 5 chronic kidney disease (end stage), as defined by an estimated glomerular filtration rate < 15 ml/min per 1.73 m² [17], (e) abnormal liver function [19], and (f) lower extremity ulcerations. A total of 115 participants with type 2 diabetes and 130 participants without diabetes were deemed eligible for this investigation.

Outcome Measurements

Peak Acrobic Power: Oxygen uptake, respiratory quotient, and ventilation were measured continuously with a Medical Graphics VO2000 metabolic system (Medical Graphics Inc, St. Paul, MN) during a Balke treadmill protocol. The participants performed this test consisting of a constant walking speed of 3.4 mph, beginning at an initial incline of 2% grade and increasing an additional 2% grade every two minutes until exhaustion. Heart rate was recorded at the completion of each minute of exercise, and blood pressure was measured during the final minute of each 2-minute work stage. The highest oxygen uptake obtained during the final minute of exercise was recorded as the peak oxygen uptake, expressed in ml·kg⁻¹·min⁻¹. The final values obtained during the test for respiratory quotient, ventilation, heart rate, and blood pressure were recorded as peak values. The test-retest intraclass reliability coefficient for peak oxygen uptake in our laboratory is R = 0.95, and the coefficient of variation is 3.4%.

Walking Economy Treadmill Test: This test was the experimental protocol used to obtain the primary outcome measure of walking economy (oxygen uptake expressed as ml·kg⁻¹·min⁻¹). Participants performed the walking economy treadmill test in which the work rate was at a constant speed of 2 mph and a grade of 0% for a duration of 10 minutes [20]. Oxygen uptake, respiratory quotient, and ventilation were measured continuously throughout the test with the Medical Graphics VO2000 metabolic system. Heart rate was recorded at the end of each minute of exercise, and blood pressure was obtained every other minute during the test. To better ensure that the participants had reached a metabolic steady-state level, the minute values of oxygen uptake, respiratory quotient, and ventilation were averaged over the final three minutes of the exercise test. Heart rate and blood pressure were calculated as the average values obtained during minute 8.
and minute 10 of the test. The test-retest intraclass reliability coefficient for walking economy in our laboratory is $R = 0.92$, and the coefficient of variation is 3.8%.

**Statistical Analyses**

All statistical analyses were performed using the Statistical Package for the Social Sciences software – SPSS version 23 (IBM Corp, New York, USA). Continuous variables were summarized as mean and standard deviation, whereas categorical variables were summarized as relative frequency. Unpaired t-tests for the continuous variables and chi-square tests for the categorical variables were used to assess whether differences in the clinical characteristics existed between the groups with and without type 2 diabetes. One-factor analysis of covariance (ANCOVA) was used to compare walking economy and the other metabolic and cardiovascular measurements during submaximal and peak exercise, after adjusting for clinical characteristics that were significantly different between the two groups (age, sex, body mass index, waist/hip ratio, obesity, and peripheral artery disease). Residual analysis was performed, homoscedasticity was analyzed by graphical analysis (scatterplot) and adherence to the normal distribution was tested using the Kolmogorov-Smirnov test. All analyses were performed with a two-tailed significance level of 0.05.

**Results**

The clinical characteristics of the participants with and without type 2 diabetes are displayed in Table 1. Compared to the controls, the participants with diabetes were older ($p = 0.042$), had higher prevalence of men ($p = 0.034$), obesity ($p = 0.010$), chronic kidney disease ($p = 0.020$), and peripheral artery disease ($p = 0.024$), and they had a higher body mass index ($p = 0.025$), and waist/hip ratio ($p = 0.006$).

The peak exercise performance measurements of participants with and without type 2 diabetes are shown in Table 2. After adjustment for age, sex, body mass index, waist/hip ratio, obesity, chronic kidney disease, and peripheral artery disease, the peak oxygen uptake was lower in the participants with diabetes than in the controls ($p < 0.001$). None of the other measures obtained at peak exercise were significantly different between the two groups.

The submaximal exercise performance measurements of participants with and without type 2 diabetes are shown in Table 3. After adjustment for age, sex, body mass index, waist/hip ratio, obesity, chronic kidney disease, and peripheral artery disease, the participants with diabetes had higher values for walking economy ($p < 0.001$), fractional utilization ($p < 0.001$), and systolic blood pressure during submaximal exercise than in the controls.

**Discussion**

The novel findings of this investigation were that after adjusting for greater co-morbid burden, participants with type 2 diabetes had impaired walking economy, lower peak oxygen uptake, and higher fractional utilization than compared to those without diabetes.

**Walking Economy in Type 2 Diabetes**

Walking economy during ambulation represents the metabolic cost of exercise. Less economical walking, measured by higher

| Variables                        | Control Group (n = 130) | Diabetes Group (n = 115) | P Value |
|----------------------------------|-------------------------|--------------------------|---------|
| Age (years)                      | 66 (9)                  | 69 (6)                   | 0.042   |
| Mass (kg)                        | 82.3 (14.4)             | 86.9 (18.4)              | 0.088   |
| Body Mass Index                  | 28.3 (4.3)              | 30.2 (6.2)               | 0.025   |
| Waist/hip ratio                  | 0.91 (0.08)             | 0.95 (0.06)              | 0.006   |
| HOMA-IR (mg/dL)                  | 3.3 (3.8)               | 4.6 (4.1)                | < 0.001 |
| HbA1c                            | 4.61 (1.13)             | 7.15 (1.40)              | < 0.001 |
| Race (% Caucasian)               | 55                      | 54                       | 0.182   |
| Sex (% Male)                     | 41                      | 57                       | 0.034   |
| Current Smoking (% yes)          | 30                      | 27                       | 0.680   |
| Hypertension (% yes)             | 62                      | 73                       | 0.156   |
| Dyslipidemia (% yes)             | 72                      | 78                       | 0.529   |
| Obesity (% yes)                  | 26                      | 47                       | 0.010   |
| Abdominal Obesity (% yes)        | 36                      | 51                       | 0.075   |
| Peripheral Artery Disease (% yes)| 12                      | 33                       | 0.024   |
| Coronary Artery Disease (% yes)  | 31                      | 38                       | 0.765   |
| Cerebrovascular Accident (% yes) | 9                       | 7                        | 0.599   |
| Chronic Kidney Disease (% yes)   | 11                      | 35                       | 0.020   |
| Chronic Obstructive Pulmonary Disease (% yes) | 8 | 9 | 0.800 |
| Dyspnea (% yes)                  | 42                      | 56                       | 0.105   |
oxygen uptake at a constant work rate, indicates that exercise is performed at a higher percentage of exercise capacity, thereby reducing the tolerance to sustain ambulation [4]. Our participants with type 2 diabetes had an 11% higher walking economy than those with diabetes as they walked at a given pace of 2 mph during a submaximal treadmill test. This finding indicates that older men and women with type 2 diabetes require a greater amount of oxygen to ambulate at an absolute exercise intensity that is representative of many activities of daily living, which may limit their ability to sustain exercise, impair their physical function, and reduce their physical activity level.

**Potential Mechanisms**

There are several potential mechanisms for the impaired (i.e., higher) walking economy in the diabetic group. Because the participants with type 2 diabetes performed the walking task at a much higher relative intensity, they may have had a greater recruitment of fast-twitch motor units, which would increase oxygen uptake during exercise [24, 25]. Additionally, muscle denervation may impair optimal motor unit recruitment during exercise [26], thus making exercise less efficient. Indeed, impairment in peripheral nerve function in older individuals with diabetes partially explains their worse physical function compared to non-diabetic controls [27]. Furthermore, individuals with diabetes have slower oxygen kinetics during the onset of exercise [21], which may lead to an oxygen deficit and reduced efficiency in performing subsequent exercise, as evident by an increase in the slow component of oxygen uptake during a constant exercise work load [4]. Finally, older individuals with diabetes have alterations in spatiotemporal gait characteristics compared to non-diabetic controls, such as decreased gait velocity, shorter step length, greater step width, and increased stance time and double-support.

Table 2. Peak exercise performance measurements of participants with and without type 2 diabetes. Values are means (SD).

| Variables                     | Control Group (n = 130) | Diabetes Group (n = 115) | P Value |
|-------------------------------|-------------------------|--------------------------|---------|
| Maximal Oxygen Uptake         | 21.9 (2.7)              | 14.5 (3.2)               | < 0.001 |
| Maximal Respiratory Quotient  | 0.99 (0.11)             | 0.96 (0.08)              | 0.181   |
| Maximal Ventilation           | 48.6 (21.4)             | 44.7 (11.1)              | 0.251   |
| Heart Rate                    | 124 (24)                | 118 (20)                 | 0.099   |
| Systolic Blood Pressure       | 192 (30)                | 199 (28)                 | 0.175   |
| Diastolic Blood Pressure      | 92 (13)                 | 90 (14)                  | 0.219   |

* Adjusted for age, sex, body mass index, waist/hip ratio, obesity, chronic kidney disease, and peripheral artery disease.

Table 3. Submaximal exercise performance measurements of participants with and without type 2 diabetes. Values are means (SD).

| Variables           | Control Group (n = 130) | Diabetes Group (n = 115) | P Value |
|---------------------|-------------------------|--------------------------|---------|
| Walking Economy     | 10.7 (1.3)              | 11.9 (1.2)               | < 0.001 |
| Fractional Utilization | 0.49 (0.15)           | 0.82 (0.15)              | < 0.001 |
| Heart Rate          | 108 (20)                | 106 (18)                 | 0.519   |
| Systolic Blood Pressure | 176 (26)              | 189 (32)                 | 0.032   |
| Diastolic Blood Pressure | 88 (12)               | 84 (15)                  | 0.186   |
| Ventilation         | 33.6 (9.8)              | 33.0 (8.2)               | 0.762   |
| Respiratory Quotient | 0.86 (0.08)            | 0.86 (0.05)              | 0.879   |

* Adjusted for age, sex, body mass index, waist/hip ratio, obesity, chronic kidney disease, and peripheral artery disease.
time [8-10]. These spatiotemporal alterations have not only been observed in older diabetics with peripheral neuropathy [28], but also in those without peripheral neuropathy [29, 30], suggesting that type 2 diabetes may result in central damage to the vestibular, somatic, and autonomic systems from impaired microcirculation, or that a compensatory strategy is adopted for greater stability and balance at the expense of gait speed [1].

Limitations

Several limitations exist for this study. Participants were volunteers and therefore may represent those who were more interested in their health, who had better transportation to our research center, and who had better health than individuals who did not volunteer. The cross-sectional design comparing those with and without diabetes does not indicate causality. Furthermore, these results are only generalizable to older men and women with type 2 diabetes, who are overweight-to-mildly obese, and who have a high prevalence of hypertension and dyslipidemia. Despite these limitations, this study had a good representation of men and women, and Caucasians and African-Americans. Thus, we believe the findings in the present investigation are generalizable to a large number of older men and women with type 2 diabetes who have concomitant cardiovascular risk factors.

Conclusion and Clinical Significance

We conclude that older men and women with type 2 diabetes are less economical when they ambulate at a given speed than compared to control participants without diabetes, independent of their greater co-morbid burden. The impaired walking economy in the diabetic participants is further magnified by their lower aerobic fitness, thereby leading to a higher fractional utilization of oxygen consumed during a given walking task. The clinical significance of impaired walking economy in older men and women with type 2 diabetes is that ambulation is completed at a higher metabolic intensity, which may limit their ability to sustain exercise.

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