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SHORT REPORT

Assessment of energy expenditure using doubly labeled water, physical activity by accelerometer and reported dietary intake in Japanese men with type 2 diabetes: A preliminary study

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ABSTRACT
The aim of the present study was to determine the total energy expenditure, physical activity and dietary intake of men with type 2 diabetes mellitus and control participants without type 2 diabetes mellitus who were matched for age and body mass index. The participants in the present study were 12 well-controlled type 2 diabetes mellitus patients and 10 controls, aged 40–75 years, with a body mass index <30 kg/m^2. Total energy expenditure under free-living conditions was assessed using the doubly labeled water method, and physical activity was measured using a triaxial accelerometer. Dietary intake was assessed using a self-recorded food intake diary during the measurement period. Participants were instructed to record their dietary intake over 3 days, including 2 weekdays. Total energy expenditure was not significantly different between the groups (P = 0.153), nor were energy (P = 0.969) or macronutrient intakes. In conclusion, when age and body mass index are matched, total energy expenditure and self-reported energy intake are not significantly different between type 2 diabetes mellitus patients and healthy controls.

INTRODUCTION
Nutritional therapy is the initial approach for all diabetes patients, and it is very important to prevent the development of type 2 diabetes mellitus complications and to maintain bodyweight[1]. Therefore, the calculation of the estimated energy requirements of patients with type 2 diabetes mellitus is necessary to design meal plans for individual patients. In Japan, target energy intakes, which are provided for patients with type 2 diabetes mellitus or for those who are obese, are often calculated by multiplying the standard body mass (corresponding to a body mass index [BMI] of 22.0 kg/m^2) by a coefficient determined by the amount of physical activity (PA) undertaken (25–35 kcal/kg/day)[2]. This method focuses on weight reduction rather than glycemic control and the accurate calculation of estimated energy requirements. However, there is almost no evidence for the energy requirements of daily life for patients with type 2 diabetes mellitus.

The doubly labeled water (DLW) method is considered the gold standard for the assessment of total energy expenditure (TEE) in daily life and could be used to estimate energy requirements. The evaluation of TEE using the DLW method for patients with type 2 diabetes mellitus could provide useful information for the design of appropriate individualized diabetes treatment programs. In fact, patients with type 2 diabetes mellitus in the Japan Diabetes Complication Study consumed an energy-restricted diet that contained 400–500 kcal fewer per day than Japanese men in the general population[3]. Higher levels of PA are also important for diabetes prevention. Previous studies carried out in Turkey and France have reported that patients with type 2 diabetes mellitus undertake lower levels of PA (assessed using TEE or step count) than healthy

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individuals[4,5]. However, the actual eating habits and PA of Japanese adults with type 2 diabetes mellitus are unknown.

The aim of the present study was to investigate differences in TEE, PA and dietary intake between patients with type 2 diabetes mellitus and non-diabetic individuals.

METHODS

The study participants were Japanese type 2 diabetes mellitus patients and healthy controls. The study protocol was explained, and written informed consent was obtained from all participants. The study protocol was approved by the ethics committee of the National Institute of Health and Nutrition (20120803-02, 2012.8.3). This study conformed to the provisions of the Declaration of Helsinki.

Details of the methodology are given in Data S1. TEE was assessed using the DLW method, as described previously[6]. Although not all participants (type 2 diabetes mellitus $n = 9$, control $n = 5$), measured basal metabolic rate (BMR) was evaluated early in the morning. Daily PA was measured using a triaxial accelerometer (Activity Style Pro HJA-350IT; Omron Healthcare, Kyoto, Japan)[7]. The mean values for all measured variables were calculated over 7 days to assess PA under free-living conditions. Participants wore the accelerometer on their waist, except while sleeping or bathing, for 2 weeks from the date of DLW administration. To calculate energy intake (in kcal) and the intake of fat, protein and carbohydrates (in grams), each participant completed a self-recorded food intake diary after the measurement period. Participants were instructed to record their dietary intake over 3 days (2 weekdays and 1 weekend day). Blood samples were obtained from an antecubital vein in the morning after a 12-h overnight fast. All data are presented as mean ± standard deviation. Student's t-test was used to compare measurements between the type 2 diabetes mellitus and non- type 2 diabetes mellitus groups. Significance levels for statistical tests were set at $P < 0.05$.

RESULTS

The age, anthropometric parameters, blood pressure and most of the blood parameters, except glycated hemoglobin, glucose and homeostasis model assessment of β-cell function, were not significantly different between the type 2 diabetes mellitus and non- type 2 diabetes mellitus groups (Table 1). Energy expenditure, PA and dietary intake data are shown in Table 2. TEE, TEE per weight, step count, the duration of the sedentary period and the duration of PA were not significantly different between the groups. Energy ($P = 0.969$) and macronutrient intakes were also not significantly different between the groups. The ratio of total energy intake to TEE was not significantly different between the groups (type 2 diabetes mellitus 0.87 ± 0.15 vs non-type 2 diabetes mellitus 0.95 ± 0.25; $P = 0.325$). BMR, TEE and PA level data for nine type 2 diabetes mellitus patients and five controls, in whom BMR could be measured, are given in the Supporting Information.

Table 1 | Characteristics of participants

	Type 2 diabetes mellitus (n = 12) Mean ± SD	Control (n = 10) Mean ± SD	P-value
Age (years)	55 ± 7	55 ± 7	0.869
Height (cm)	168.5 ± 6.7	170.0 ± 6.2	0.603
Weight (kg)	68.4 ± 7.2	67.9 ± 3.4	0.851
BMI (kg/m^2)	24.0 ± 1.8	23.6 ± 1.8	0.545
Percentage of body fat (%)	25.4 ± 5.2	22.9 ± 4.9	0.268
Fat-free mass (kg)	50.2 ± 5.2	51.1 ± 3.5	0.662
Fat mass (kg)	17.3 ± 4.7	15.2 ± 3.6	0.269
Systolic blood pressure (mmHg)	135 ± 14	130 ± 15	0.434
Diastolic blood pressure (mmHg)	85 ± 11	80 ± 10	0.249
AST (U/L)	19 ± 4	22 ± 5	0.149
ALT (U/L)	18 ± 7	23 ± 10	0.152
γGTP (U/L)	35 ± 20	25 ± 12	0.196
Total cholesterol (mg/dL)	175 ± 16	206 ± 29	0.005
HDL cholesterol (mg/dL)	57 ± 11	57 ± 12	0.997
Triglyceride (mg/dL)	108 ± 103	96 ± 56	0.749
Free fat acid (mEq/L)	0.5 ± 0.2	0.5 ± 0.1	0.620
C-peptide (ng/dL)	1.1 ± 0.3	1.1 ± 0.3	0.939
HbA1c (%) NGSP	6.4 ± 0.5	5.6 ± 0.3	<0.001
Insulin (μU/mL)†	2.9 ± 1.2	3.7 ± 1.2	0.177
Glucose (mg/dL)	117 ± 16	92 ± 8	<0.001
HOMA-IR	0.9 ± 0.4	0.8 ± 0.3	0.907
HOMA-β	21 ± 9	48 ± 23	0.002
Duration of diabetes (years)	6 ± 4		
Medication (n)			
Dipeptidyl peptidase-4 inhibitor	4		
Sulfonylurea	5		
Metformin	4		
Alpha-glucosidase inhibitor	1		
Glinide	1		
None	4		

†The number of control participants was nine persons. γGTP, γ-glutamyltransferase; ALT, alanine aminotransferase; AST, aspartate aminotransferase; BMI, body mass index; HbA1c, glycated hemoglobin; HDL, high-density lipoprotein; HOMA-β, homeostasis model assessment of β-cell function; HOMA-IR, homeostasis model assessment of insulin resistance; NGSP, National Glycohemoglobin Standardization Program; SD, standard deviation.

DISCUSSION

The present study compared TEE, PA and dietary intake between patients with type 2 diabetes mellitus and healthy controls with matched BMI, and found that none of these were significantly different.

Recent studies carried out using metabolic Holter monitors (sensor armbands) have shown that diabetes patients have lower TEE and PA than healthy individuals[4,5]. However, a

Table 2 | Comparison of daily energy expenditure and intake between patients with type 2 diabetes mellitus and control participants

	Type 2 diabetes mellitus (*n* = 12) Mean ± SD	Control (*n* = 10) Mean ± SD	*P*-value
Energy expenditure			
Total energy expenditure (kcal/day)	2,490 ± 379	2,284 ± 243	0.153
Total energy expenditure (kcal/day/kg weight)	36.5 ± 5.0	33.7 ± 3.7	0.156
Physical activity			
Step counts (steps/day)	9,647 ± 2,809	9,591 ± 2,016	0.958
Sedentary time (min/day)	552 ± 109	546 ± 125	0.906
Light-intensity activity time (min/day)	323 ± 107	305 ± 110	0.698
Moderate-intensity activity time (min/day)	72 ± 23	76 ± 27	0.721
Vigorous-intensity activity time (min/day)	0 ± 0	1 ± 1	0.437
Moderate- to vigorous-intensity activity time (min/day)	72 ± 24	76 ± 27	0.698
Energy intake			
Energy intake (kcal/day)	2,140 ± 430	2,133 ± 381	0.969
Protein (g/day)	89 ± 22	87 ± 28	0.859
Fat (g/day)	69 ± 16	73 ± 16	0.548
Carbohydrate (g/day)	234 ± 56	247 ± 59	0.605
Protein (%)	16.7 ± 3.0	16.1 ± 3.5	0.672
Fat (%)	29.0 ± 4.2	30.7 ± 3.3	0.293
Carbohydrate (%)	54.4 ± 5.4	53.2 ± 5.1	0.607

metabolic chamber study showed that patients with type 2 diabetes mellitus have a higher BMR and 24-h energy expenditure than healthy individuals[8,9]. However, these results might be affected by differences in fasting blood glucose level, because a level >180 mg/dL affects metabolic rate[10], whereas a level <180 mg/dL does not[11]. Ucok *et al.*[4] showed that fasting blood glucose is inversely correlated with TEE and PA, and might be affected by high fasting blood glucose (183 ± 87 mg/dL). In addition, the differences in step count (present study vs Fagour *et al.*[5], 9,647 ± 2,809 vs 7,400 ± 3,387 steps/day) and BMI (24.0 ± 1.8 vs Ucok *et al.*[4] 29.9 ± 3.7 and Fagour *et al.*[5] 30.2 ± 5.2 kg/m^2) between participants in the present study and previous studies might also have had an effect on the results. Thus, further studies are required.

In the present study, energy intake also was not significantly different between the type 2 diabetes mellitus and non-type 2 diabetes mellitus groups (2,140 ± 430 vs 2,133 ± 381 kcal/day; *P* = 0.969). In contrast, among 807 Japanese patients with type 2 diabetes mellitus, energy intake assessed using a food questionnaire containing details of reported meal frequency and portion size was 400–500 kcal/day lower than that of healthy Japanese individuals in the same age group[3]. The difference between self-recorded measurement and the use of a food frequency questionnaire might influence the total energy intake data. In the present study, recorded energy intake was lower than TEE, but no significant difference was found between the groups (the ratio of total energy intake to TEE for the type 2 diabetes mellitus and non-type 2 diabetes mellitus groups was 0.87 ± 0.15 and 0.95 ± 0.25, respectively; *P* = 0.325). Although there was apparently greater underreporting of dietary intake by type 2 diabetes mellitus patients, this difference was not statistically significant, but this might have been due to insufficient statistical power, so further research is necessary.

The present study had a few limitations. The study sample comprised type 2 diabetes mellitus patients whose blood glucose control was successful, so few patients met the inclusion criteria. Thus, the results of this study might be not be reflected in the wider diabetic population, and there might have been sampling bias. Clearly, further studies of larger cohorts of participants are needed to confirm the present findings.

In conclusion, if age and BMI are matched, and PA is similar, total energy expenditure and self-reported energy intake are not significantly different between well-controlled type 2 diabetes mellitus patients and healthy controls. However, the sample size of the current study is small, and thus further studies are required to confirm these findings.

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DISCLOSURE

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1 | Detail of Methods and Results.