JDI Journal of Diabetes Investigation Open access
Official Journal of the Asian Association for the Study of Diabetes
ORIGINAL ARTICLE

Appropriate physical activity and dietary intake achieve optimal metabolic control in older type 2 diabetes patients

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Keywords
Dietary intake, Older diabetes patients, Physical activity

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J Diabetes Invest 2014; 5: 418–427

doi: 10.1111/jdi.12164

ABSTRACT

Aims/Introduction: The aim of the present study was to investigate an appropriate level of physical activity and optimal dietary intake in older type 2 diabetes patients.

Materials and Methods: The cross-sectional study enrolled 210 older type 2 diabetes patients. Participants were interviewed to obtain information on physical activity, 24-h dietary recall and typical weekly dietary patterns. Anthropometric measurements, and biochemical analysis of blood and urine were determined.

Results: Moderate physical activity (either moderate leisure-time physical activity or moderate physical activity level) and diet with protein intake of ≥0.8 g/kg/day were associated with lower glycated hemoglobin and triglyceride, higher high-density lipoprotein, lower waist circumference, body mass index and body fat, as well as better serum magnesium and albumin levels in older diabetic patients. In contrast, inadequate protein intake was correlated with higher glycated hemoglobin, triglyceride, body fat percentage, waist circumference and body mass index. In addition, high physical activity with inadequate protein and magnesium intake might exacerbate magnesium deficiency, resulting in poor glycemic control in older diabetic patients. Furthermore, low physical activity and inadequate protein intake were linked with poor glycemic control, and lower high-density lipoprotein, and higher triglyceride, body fat percentage, waist circumference and body mass index.

Conclusions: Moderate physical activity and adequate dietary protein intake (≥0.8 g/kg/day) might be the optimal recommendation for better metabolic control in older adults with type 2 diabetes.

INTRODUCTION

Type 2 diabetes is a major metabolic disease, and its prevalence is increasing dramatically worldwide, particularly in aging populations[1,2]. It is generally accepted that this upward trend is mainly attributable to a sedentary lifestyle and an unhealthy diet[3]. A healthy diet, adequate physical activity (PA) and appropriate medications are important in health management of older type 2 diabetes patients[4]. These factors are thought to be important for achieving optimal blood glucose and lipid levels, maintaining appropriate blood pressure, reducing bodyweight, and preventing or delaying diabetes-related complications, including nephropathy, in this population[5]. Indeed, conventional and novel blood glucose-lowering drugs have been developed that provide better outcomes in these patients[6]. However, there is currently no consensus in the literature regarding recommendations for appropriate PA and dietary intake that would result in optimal metabolic parameters in older type 2 diabetes patients.

Regular physical activity is a modifiable factor for reducing blood glucose levels and cardiovascular risk factors in type 2 diabetes patients[7,8]. The American College of Sports Medicine (ACSM) and the USA Department of Health and Human Ser-

Received 27 June 2013; revised 29 August 2013; accepted 1 September 2013

vices (DHHS) recommend that all adults carry out aerobic PA at least 3 days/week with no more than two consecutive days, comprising approximately 150 min/week of moderate-intensity aerobic PA or 75 min/week of vigorous aerobic PA, or an equivalent combination of the two for health benefits[9,10]. A study also showed that aerobic exercise alone or combined with resistance training can improve metabolic control in type 2 diabetes[11]. However, most relevant guidelines and studies are only concerned with leisure-time PA or exercise[8,10], and there is less emphasis on non-leisure-time PA, which comprises the majority of overall PA for older adults[12]. Thus, the total amount of might be underestimated, which could confound the relationship between PA and metabolic control in older diabetic patients. Furthermore, excessive PA could be harmful to health[13,14]. A recent study has established that long-term excessive endurance exercise might induce adverse cardiovascular effects[13]. Physical exercise might deplete magnesium when magnesium intake is inadequate, and could therefore exacerbate magnesium deficiency and impair energy metabolism efficiency[14].

Low magnesium intake was associated with metabolic syndrome and depression among elderly type 2 diabetes patients in our previous study[15]. Adequate magnesium intake might be beneficial in diabetes prevention and management[15–17]. A higher intake of carbohydrates and a lower consumption of total fat are associated with good glycemic control in middle-aged and older people with diabetes[18]. Diets with increased protein have been evaluated for weight loss, and have been shown to reduce hyperglycemia and improve cardiovascular risk factors[19]. Increased protein and reduced carbohydrates could improve glycemic regulation, body composition and lipid profile in type 2 diabetes patients[19]. However, high protein intakes have long been known to accelerate nephropathy, which is frequently observed in elderly and diabetic populations[20,21]. To date, the minimum requirement of adequate protein intake in older type 2 diabetes is ill defined.

The objective of the present cross-sectional study was to determine appropriate PA and dietary intake in older type 2 diabetes patients. PA and dietary intake data were obtained from questionnaires. Anthropometric values, as well as biochemical determinations of blood and urine samples, were analyzed.

MATERIALS AND METHODS

Patients

Type 2 diabetes patients aged 65 years and older were enrolled in the present cross-sectional study. The patients lived in rural areas of central Taiwan, and most of them had a simple, stable lifestyle and had typical eating habits. The study design has been described previously in detail[15]. After excluding patients with a history of heart failure, cirrhosis, current malignancy, chronic renal failure or signs of serious deterioration in comprehension or memory, a total of 210 patients were included in the study (CCHIRB#090419).

Biochemical Determination

Biochemical determination including glycated hemoglobin (HbA1c), fasting and postprandial plasma glucose, high-density lipoprotein cholesterol (HDL), triglyceride, magnesium, albumin and estimated glomerular filtration rate (eGFR) were made. Assessment of glycemic control using HbA1c referred to the definitions of the National Glycohemoglobin Standardization Program (NGSP) and American Diabetes Association (ADA)[22,23]. The recommended glycemic goals for non-pregnant adults is HbA1c <7.0%. HbA1c ≥7% is defined as not good glycemic control. HbA1c ≥8% is defined as poor glycemic control. In addition, the recommended goals for lipid control are HDL >50 mg/dL in females and >40 mg/dL in males, and triglyceride <150 mg/dL[24]. Hypomagnesemia was defined as serum magnesium <0.75 mmol/L[25]. The definition of chronic kidney disease (CKD) stages was based on guidelines for the management of CKD[26].

Anthropometric Measurements

Anthropometric measurements included height, weight, blood pressure, waist circumference and body composition. The recommended goal for blood pressure control is <130/80 mmHg[24]. The Department of Health, Executive Yuan, Taiwan, has defined waist circumference ≥90 cm for men and ≥80 cm for women as abdominal adiposity. Body mass index (BMI) was also calculated (weight [kg]/height [m^2]). BMI exceeding 27 results in a dramatically elevated mortality risk[27]. Percentage of body fat was estimated with bioelectrical impedance analysis using TBF-410 (TANITA, Tokyo, Japan). Females with a body fat percentage >30% and males with a body fat percentage >25% were categorized as obese.

Physical Activity

Assessment of PA was based on a slightly modified version of the method used in a Finnish study[28]. Briefly, occupational PA was categorized as follows: (i) light: physically very easy, seated office work; (ii) moderate: work including standing and walking; and (iii) active: work including walking and lifting, or heavy manual labor. Daily commuting was categorized as follows: (i) using motorized transportation, or no work; (ii) walking or bicycling 1–2 min; and (iii) walking or bicycling >30 min. Self-reported leisure-time PA was classified as follows: (i) low: almost completely inactive, or doing only some minor physical activity; (ii) moderate: some moderate-intensity aerobic PA for 150–300 min/week or vigorous aerobic PA for 75–150 min/week; and (iii) high: moderate-intensity aerobic PA for >300 min/week or vigorous aerobic PA for >150 min/week[9,29]. Physical activities were evaluated and categorized as follows: (i) low PA, defined as light levels of occupational activity, commuting (<1 min) and leisure-time PA; (ii) moderate PA, defined as only one of the three types of moderate to high PA; and (iii) high PA, defined as two or three types of moderate to high PA[28].

Dietary Assessment

Patients' eating habits were assessed based on 24-h dietary recall and typical weekly dietary pattern, which were collected by interview with a registered dietitian[18,30]. Energy and nutrient intake were analyzed using the Taiwan Nutrition Database and the E-Kitchen nutritional analysis software (Nutritional Chamberlain Line, Professional Edition, version 2001/2003; E-Kitchen Inc, Taichung, Taiwan)[31]. The patients were divided into four subgroups according to protein intake: ≤ 0.60, 0.61–0.79, 0.80–1.00, and >1.00 g/kg/day[32,33]. The following equations were used to determine energy requirement and balance: estimated energy requirement (EER) for an older adult was calculated from resting metabolic rate (RMR; = reference RMR × reference bodyweight) and physical activity level (PAL). The Taiwan Resting Energy Expenditure (REE) for people aged 65 years and older is 21.88–21.67 kcal/kg/day for men or 20.44–20.23 kcal/kg/day for women. EER for older adults (kcal/day) = REE × PAL. Energy balance = energy intake – ER (kcal/day). Magnesium intake <5 mg/kg/day was defined as magnesium deficiency[34].

Statistical Analysis

Data were analyzed by one-way ANOVA for continuous variables, and by chi-squared-test for categorical variables. Partial correlation analysis was applied to determine the correlations of dietary intake with metabolic parameters. Multiple regression analysis was applied to determine the relationships of PA and protein intake with metabolic parameters, body fat, magnesium status, and nutrition status. All statistical procedures were carried out using SPSS (version 17.0) statistical software (SPSS Inc., Chicago, IL, USA). A *P*-value less than 0.05 was considered statistically significant.

RESULTS

The baseline characteristics of the 210 older type 2 diabetes patients are presented in Table 1. There were significant differences in age, hypertension medication and exercise status among the three groups ($P < 0.001$).

Physical Activity

Patients with moderate PA had lower HbA1c than those with high PA ($P < 0.05$, as shown in Table 2). Furthermore, patients with moderate PA had higher HDL and lower triglyceride than those with low PA ($P < 0.05$). Patients in the high PA subgroup had lower waist circumference and triglyceride than those in the low PA subgroup ($P < 0.05$). However, the high PA subgroup had higher HbA1c and lower serum magnesium than those of the other two subgroups ($P < 0.05$). In addition, PA was marginally correlated with BMI ($P = 0.060$). Physical activity was not significantly associated with fasting plasma glucose, postprandial plasma glucose or blood pressure.

Table 1 | Baseline characteristics of the 210 older adults with type 2 diabetes based on physical activity status

Variables	Physical activity levels			*P*
	Low (*n* = 48)	Moderate (*n* = 83)	High (*n* = 79)	
Age (years)*,†‡	74.0 ± 6.0	73.6 ± 5.5	70.0 ± 3.9	<0.001
Sex				
Male	18 (37.5)	35 (42.2)	45 (57.0)	0.059
Female	30 (62.5)	48 (57.8)	34 (43.0)	
Education				
Primary school and below	42 (87.5)	76 (91.6)	70 (88.6)	0.324
Junior or senior high school	3 (6.3)	6 (7.2)	8 (10.1)	
University	3 (6.3)	1 (1.2)	1 (1.3)	
Duration of diabetes (years)	10.0 ± 6.9	12.0 ± 7.3	10.3 ± 8.2	0.227
Diabetes medication				
Oral hypoglycemic drug	30 (62.5)	58 (69.9)	59 (74.7)	0.348
Insulin and oral hypoglycemic drug	18 (37.5)	26 (30.1)	20 (25.3)	
Lipid-lowering medication				
No medication	12 (25.0)	30 (36.1)	19 (24.1)	0.186
Oral medication	36 (75.0)	53 (63.9)	60 (75.9)	
Hypertension medication				
No medication	16 (33.3)	23 (27.7)	43 (54.4)	0.002
Oral medication	32 (66.7)	60 (72.3)	36 (45.6)	
Exercise (daily or almost daily)	5 (10.4)	78 (94.0)	48 (60.8)	<0.001

Comparisons of categorical data among different physical activities were analyzed by χ^2-test. Data are number (*n*), percent (%) and significant difference ($P < 0.05$). Comparisons of age among different physical activities were carried out by one-way ANOVA followed by Scheffe's multiple comparisons test. Data are means ± standard deviation. Significant difference ($P < 0.05$). Multiple comparisons: *Significant differences between low and moderate PA. †Significant differences between low and high PA. ‡Significant differences between moderate and high PA.

Table 2 | Relationships of physical activity with metabolic parameters, body composition, magnesium status, nutrition indicators and dietary intake

Variables	Physical activity levels			*P*
	Low (*n* = 48)	Moderate (*n* = 83)	High (*n* = 79)	
Metabolic parameters*				
HbA1c (%)†	7.3 ± 0.2	7.2 ± 0.1	7.8 ± 0.2	0.032
Fasting plasma glucose (mg/dL)	126.6 ± 5.9	134.5 ± 4.6	142.4 ± 4.9	0.132
Postprandial plasma glucose (mg/dL)	187.3 ± 9.4	183.8 ± 7.3	191.4 ± 7.8	0.771
Triglycerides (mg/dL)‡,§	162.1 ± 11.3	128.2 ± 9.3	131.2 ± 9.4	0.004
HDL cholesterol (mg/dL)‡	39.9 ± 2.4	46.5 ± 2.0	44.9 ± 2.0	0.010
Systolic blood pressure	132.4 ± 2.9	134.5 ± 2.4	135.6 ± 2.4	0.565
Diastolic blood pressure	74.0 ± 2.6	76.6 ± 2.2	76.6 ± 2.1	0.508
Waist circumference (cm)§	95.4 ± 1.8	91.8 ± 1.5	90.1 ± 1.5	0.015
BMI (kg/m^2)	25.9 ± 0.7	24.7 ± 0.6	24.2 ± 0.6	0.060
Body composition				
Free fat mass (kg)¶	44.4 ± 0.8	44.8 ± 0.6	45.6 ± 0.6	0.456
Fat mass (kg)*,§	20.5 ± 1.5	17.6 ± 1.2	16.3 ± 1.2	0.020
Body fat percentage (%)>25 for men or >30 for women (obese)	30 (62.5)	49 (59.0)	30 (38.0)	0.007
Magnesium status				
Serum Mg (mmol/L)†,**	0.80 ± 0.01	0.80 ± 0.01	0.76 ± 0.01	0.019
Serum Mg <0.75 mmol/L (hypomagnesemia)	13 (27.1)	26 (31.3)	39 (49.4)	0.015
Nutrition indicators				
Serum albumin (mg/dL)††	4.00 ± 0.04	4.08 ± 0.03	3.96 ± 0.04	0.068
Energy balance (kcal/day)†‡§	89 ± 319	−197 ± 404	−456 ± 439	<0.001
Dietary intake‡‡				
Energy intake (kcal/kg)‡,§	23.0 ± 1.1	26.4 ± 0.8	27.5 ± 0.9	0.007
Protein intake (g/kg)	0.72 ± 0.04	0.85 ± 0.03	0.82 ± 0.04	0.065
Carbohydrate (% of energy)	59.7 ± 1.2	59.7 ± 0.9	62.6 ± 1.0	0.081
Fat (% of energy)	27.7 ± 1.1	27.5 ± 0.8	25.5 ± 0.8	0.177
Magnesium intake (mg/kg)‡,§	2.9 ± 0.2	3.8 ± 0.2	3.8 ± 0.2	0.003

Comparisons of categorical data among different physical activities were analyzed by χ^2-test. Data are number (*n*), percent (%) and significant difference ($P < 0.05$). Relationships of physical activity with metabolic parameters, body composition, magnesium status, nutrition indicators, and dietary intake were examined by multiple linear regression analysis followed by Bonferroni's multiple comparisons test. Data are adjusted mean ± standard error (SE). Significant difference ($P < 0.05$). *Adjusted for sex, age, energy intake, macronutrient intake, smoking, alcohol consumption and medication. †Significant differences between moderate and high PA. ‡Significant differences between low and moderate PA. §Significant differences between low and high PA. ¶Adjusted for sex, age, energy intake and protein intake. **Adjusted for sex, age, and magnesium intake. ††Adjusted for sex, age, high-sensitivity C-reactive protein, energy intake, and protein intake. ‡‡Adjusted for sex and age. Multiple comparisons: BMI, body mass index; HbA1c, glycated hemoglobin; HDL, high-density lipoprotein.

The low PA subgroup had lower energy and magnesium intake than those in the high and moderate PA subgroups ($P < 0.05$). However, patients with low PA had a greater positive energy balance than those with high or moderate PA ($P < 0.001$). Furthermore, the low PA subgroup had a higher body fat percentage than that of the high PA subgroup ($P < 0.05$). There were no differences in energy and protein intake between the high and moderate PA groups. However, patients with high PA had a greater negative energy balance compared with those of the other two subgroups ($P < 0.001$). In addition, PA was marginally correlated with serum albumin ($P = 0.068$), protein intake ($P = 0.065$) and carbohydrate consumption ($P = 0.081$). Patients in the moderate PA subgroup tended to have higher serum albumin.

Dietary Intake

After adjusting for sex, age, physical activity level, smoking and alcohol consumption, negative correlations were found between protein intake and HbA1c ($r = -0.149$; $P = 0.032$), waist circumference ($r = -0.220$; $P = 0.002$), BMI ($r = -0.322$; $P < 0.001$) and body fat percentage ($r = -0.289$; $P < 0.001$). Magnesium intake was positively correlated with protein intake ($r = 0.636$; $P < 0.001$). Energy, carbohydrate and fat intake were not significantly correlated with HbA1c, blood lipids, blood pressure, waist circumference, or body fat percentage.

The subgroup with protein intake of 0.80–1.00 g/kg/day showed lower HbA1c than those with protein intake of ≤0.60 and 0.61–0.79 g/kg/day ($P < 0.05$), as shown in Table 3. The subgroup with protein intake of >1.00 g/kg/day had lower triglyceride than those with protein intake of ≤0.60 and 0.61–

Table 3 | Relationships of protein intake levels with metabolic parameters, body fat, serum magnesium, and serum albumin and dietary intake

Variables	Protein intake levels (g/kg)				*P*
	≤0.60 (*n* = 52)	0.61–0.79 (*n* = 63)	0.80–1.00 (*n* = 48)	>1.00 (*n* = 47)	
Metabolic parameters*					
HbA1c (%)	8.0 ± 0.3	7.7 ± 0.2	7.0 ± 0.2	7.1 ± 0.3	0.012
Fasting plasma glucose (mg/dL)	142.3 ± 8.7	132.4 ± 7.2	123.1 ± 7.8	129.2 ± 8.9	0.310
Postprandial plasma glucose (mg/dL)	198.6 ± 13.8	183.5 ± 11.4	188.8 ± 12.3	172.2 ± 14.1	0.453
Triglycerides (mg/dL)	163.4 ± 12.4	148.4 ± 9.8	138.3 ± 10.6	111.6 ± 12.1	0.015
HDL cholesterol (mg/dL)	39.0 ± 2.6	44.3 ± 2.1	44.5 ± 2.2	46.0 ± 2.6	0.138
Systolic blood pressure	138.3 ± 3.2	133.7 ± 2.6	134.3 ± 2.8	131.7 ± 3.2	0.412
Diastolic blood pressure	79.3 ± 2.9	76.3 ± 2.3	74.4 ± 2.6	74.0 ± 2.9	0.510
Waist circumference (cm)	101.1 ± 1.8	94.0 ± 1.4	88.6 ± 1.6	84.7 ± 1.8	<0.001
BMI (kg/m^2)	28.3 ± 0.7	26.0 ± 0.6	23.1 ± 0.6	21.9 ± 0.7	<0.001
Body composition					
Free fat mass (kg)†	45.1 ± 0.9	44.2 ± 0.7	45.2 ± 0.8	45.2 ± 1.0	0.734
Fat mass (kg)*	24.1 ± 1.5	20.2 ± 1.2	14.6 ± 1.3	12.2 ± 1.5	<0.001
Body fat percentage (%)‡	33.0 ± 1.4	30.6 ± 1.2	25.2 ± 1.3	23.3 ± 1.5	<0.001
Body fat percentage (%) >25 for men or >30 for women (obese)	37 (71.2)	40 (63.5)	18 (37.5)	14 (29.8)	<0.001
Magnesium status					
Serum Mg (mmol/L)§	0.79 ± 0.01	0.76 ± 0.01	0.80 ± 0.01	0.80 ± 0.02	0.062
Serum Mg <0.75 mmol/L (Hypomagnesemia)	19 (36.5)	30 (47.6)	13 (27.1)	16 (34.0)	0.155
Serum albumin (mg/dL)‡	3.97 ± 0.05	4.06 ± 0.04	4.02 ± 0.05	3.99 ± 0.06	0.410
Dietary intake¶					
Energy intake (kcal/kg)	18.7 ± 0.7	23.4 ± 0.7	28.6 ± 0.8	34.3 ± 0.8	<0.001
Carbohydrate (% of energy)	66.1 ± 1.1	60.2 ± 1.0	58.3 ± 1.1	57.1 ± 1.2	<0.001
Fat (% of energy)	23.7 ± 1.0	27.5 ± 0.9	28.3 ± 1.0	28.4 ± 1.1	0.002
Magnesium intake (mg/kg)	2.4 ± 1.2	3.3 ± 0.2	3.6 ± 0.2	4.9 ± 0.2	<0.001

Comparisons of categorical data among different physical activities were analyzed by χ^2-test. Data are number (*n*), percent (%) and significant difference ($P < 0.05$). Relationships of protein intake with metabolic parameters, body composition, serum magnesium and serum albumin were examined by multiple regression analysis. Data are adjusted mean ± standard error. Significant difference ($P < 0.05$). *Adjusted for sex, age, physical activity levels, smoking, alcohol consumption, energy, carbohydrate and fat intake, and medication. †Adjusted for sex, age, physical activity, and energy intake. ‡Adjusted for sex, age, physical activity, and magnesium intake. §Adjusted for sex, age, high-sensitivity C-reactive protein, and energy intake. ¶Adjusted for sex, age, and physical activity. BMI, body mass index; HbA1c, glycated hemoglobin; HDL, high-density lipoprotein.

0.79 g/kg/day ($P < 0.05$). The subgroup with protein intake of 0.61–0.79 g/kg/day had lower waist circumference, BMI and body fat than those with protein intake of ≤0.60 g/kg/day ($P < 0.05$). The subgroups with protein intake of 0.80–1.00 and >1.00 g/kg/day had lower waist circumference BMI, and body fat than those with protein intake of ≤0.60 and 0.61–0.79 g/kg/day ($P < 0.05$). There were no significant differences in HbA1c, triglyceride, waist circumference, BMI, free fat mass, and body fat percentage between the subgroup with protein intake of 0.80–1.00 and the >1.00 g/kg/day subgroup. In addition, serum magnesium was marginally correlated with protein intake ($P = 0.062$).

Energy, carbohydrate, fat and magnesium intake were significantly correlated with protein intake ($P \leq 0.002$). Energy intake was increased with increase of protein intake ($P < 0.001$). The subgroup with protein intake of ≤0.60 g/kg/day had a higher carbohydrate intake and lower fat intake (% of energy), and a lower magnesium intake compared with those of the other three subgroups ($P \leq 0.008$ and 0.003, respectively).

Physical Activity and Protein Intake

Combined PA with protein intake was correlated with HbA1c, triglyceride, waist circumference, BMI, body fat percentage, magnesium status and energy balance ($P < 0.05$), as shown in Table 4. Combined PA with protein intake was marginally correlated with fasting plasma glucose ($P = 0.072$), HDL ($P = 0.057$), serum magnesium ($P = 0.056$) and serum albumin ($P = 0.056$). Patients were stratified into six subgroups based on PA levels and protein intake: (i) group A had low PA, and protein intake <0.8 mg/kg; (ii) group B had low PA and protein intake ≥0.8 mg/kg; (iii) group C had moderate PA, and protein intake <0.8 mg/kg; (iv) group D had moderate PA, and ≥0.8 mg/kg; (v) group E had high PA, and protein intake <0.8 mg/kg; (vi) group F had high PA, and protein intake ≥0.8 mg/kg. Group E had higher HbA1c than those in groups B, C, D and F ($P < 0.05$). Groups D and F had lower triglyceride than that in group A. Groups D and F also had lower waist circumference, BMI, and body fat percentage than those in the A, C, and E groups ($P < 0.05$). In addition, the

Table 4 | Relationship of physical activity and protein intakes with metabolic parameters, body composition, magnesium status, and nutrition indicators, and dietary intake

Variables	Physical activity levels/protein intake (g/kg/day)						*P*
	Group A (Low/<0.8) (*n* = 34)	Group B (Low/≥0.8) (*n* = 14)	Group C (Moderate/<0.8) (*n* = 42)	Group D (Moderate/≥0.8) (*n* = 41)	Group E (High/<0.8) (*n* = 39)	Group F (High/≥0.8) (*n* = 40)	
Metabolic parameters*							
HbA1c (%)	7.6 ± 0.3	7.2 ± 0.4	7.4 ± 0.2	7.1 ± 0.2	8.4 ± 0.2	7.2 ± 0.2	<0.001
Fasting plasma glucose (mg/dL)	124.0 ± 8.7	137.6 ± 12.2	136.7 ± 8.0	124.9 ± 8.2	149.8 ± 8.3	130.8 ± 8.1	0.072
Postprandial plasma glucose (mg/dL)	193.0 ± 13.9	175.9 ± 19.5	181.3 ± 12.9	181.6 ± 13.1	196.8 ± 13.2	185.9 ± 13.0	0.850
Triglycerides (mg/dL)	167.9 ± 12.4	151.0 ± 16.9	135.8.0 ± 11.4	118.0 ± 11.3	144.6 ± 11.7	119.8 ± 11.5	0.009
HDL (mg/dL)	38.7 ± 2.6	41.3 ± 3.5	45.9 ± 2.4	47.0 ± 2.4	43.5 ± 2.4	45.9 ± 2.4	0.057
Systolic blood pressure	132.5 ± 3.2	130.3 ± 4.5	135.0 ± 3.0	133.0 ± 3.0	134.0 ± 3.0	137.4 ± 3.0	0.673
Diastolic blood pressure	74.8 ± 2.9	71.2 ± 4.1	77.2 ± 2.7	75.6 ± 2.8	75.7 ± 2.7	77.5 ± 2.7	0.738
Waist circumference (cm)	96.1 ± 1.9	93.7 ± 2.7	95.0 ± 1.7	87.6 ± 1.8	93.8 ± 2.7	85.9 ± 1.8	<0.001
BMI (kg/m^2)	26.6 ± 0.7	24.9 ± 1.0	26.5 ± 0.7	22.7 ± 0.7	26.1 ± 0.7	22.2 ± 0.7	<0.001
Body composition							
Free fat mass (kg)†	43.2 ± 1.0	46.9 ± 1.5	44.9 ± 0.9	44.5 ± 0.9	45.6 ± 0.9	45.7 ± 1.0	0.251
Body fat percent (%)	31.8 ± 1.5	28.4 ± 2.0	31.1 ± 1.4	24.6 ± 1.4	29.7 ± 1.4	23.3 ± 1.4	<0.001
Magnesium status							
Mg intake (mg/kg)‡	2.5 ± 1.4	3.5 ± 1.2	3.0 ± 1.4	4.5 ± 1.6	3.1 ± 1.1	4.4 ± 1.9	<0.001
Serum Mg (mmol/L)§	0.79 ± 0.02	0.81 ± 0.03	0.78 ± 0.02	0.82 ± 0.02	0.75 ± 0.02	0.78 ± 0.02	0.056
Serum Mg <0.75 mmol/L (Hypomagnesemia)	10 (29.4)	3 (21.4)	18 (42.9)	8 (19.5)	21 (53.8)	18 (45.0)	0.015
Nutrition indicators							
Serum albumin (mg/dL)¶	4.01 ± 0.05	3.97 ± 0.08	4.04 ± 0.05	4.11 ± 0.05	4.02 ± 0.05	3.90 ± 0.05	0.056
Energy balance (kcal/day)‡	−11.3 ± 59.4	273.7 ± 92.6	−413.5 ± 53.5	1.3 ± 54.0	−694.2 ± 56.6	−200.8 ± 54.9	<0.001
Dietary intake‡							
Energy intake (kcal/kg)	20.7 ± 1.0	28.7 ± 1.6	21.1 ± 0.9	32.1 ± 0.9	22.2 ± 1.0	32.4 ± 0.9	<0.001
Fat (% of energy)	26.9 ± 1.2	29.5 ± 1.9	25.8 ± 1.1	29.2 ± 1.1	24.6 ± 1.2	26.3 ± 1.1	0.065
Carbohydrate (% of energy)	61.4 ± 1.4	55.7 ± 2.1	62.5 ± 1.2	56.7 ± 1.3	64.8 ± 1.3	60.6 ± 1.3	<0.001
Mg intake (mg/kg)	2.5 ± 1.4	3.5 ± 1.2	3.0 ± 1.4	4.5 ± 1.6	3.1 ± 1.1	4.4 ± 1.9	<0.001

Comparisons of categorical data among different physical activities levels and protein intakes were analyzed by χ^2-test. Data are number (*n*), percent (%) and significant difference ($P < 0.05$). Relationships of physical activity and protein intake with metabolic parameters, body composition, serum magnesium, and serum albumin were examined by multiple regression analysis. Data are adjusted mean ± standard error. Significant difference ($P < 0.05$). *Adjusted for sex, age, smoking, alcohol consumption, energy intake (kcal/day) and medication. †Adjusted for sex, age, and energy intake (kcal/kg). ‡Adjusted for sex and age. §Adjusted for sex age, and magnesium intake. ¶Adjusted for sex, age, high-sensitivity C-reactive protein, and energy intake. BMI, body mass index; HbA1c, glycated hemoglobin; HDL, high-density lipoprotein.

D group had higher serum magnesium than that in the E group ($P < 0.05$), and tended to have higher serum albumin levels.

DISCUSSION

Older type 2 diabetes patients with moderate PA (either moderate leisure-time PA or moderate PA lifestyle) and who had a diet with protein intake ≥0.8 g/kg/day were found to have optimal HbA1c, triglyceride, HDL, waist circumference, BMI, body fat, serum magnesium, and albumin. Inadequate protein intake was associated with higher HbA1c, triglyceride, body fat percentage, waist circumference and BMI. Moderate PA with inadequate protein intake appeared to be correlated with higher body fat percentage, waist circumference and BMI. High PA with inadequate protein and magnesium intake might exacerbate magnesium deficiency, resulting in poor glycemic control in older diabetic patients. Furthermore, patients with low PA and inadequate protein intake had poor glycemic control, lower HDL, as well as higher triglyceride, body fat percentage, waist circumference and BMI.

In general, PA recommendations for persons with type 2 diabetes are the same as the exercise guidelines provided by the ACSM and the USA DHHS, which suggest that all adults carry out aerobic PA at least 3 days/week with no more than two consecutive days, comprising approximately 150 min/week of moderate-intensity aerobic PA or 75 min/week of vigorous aerobic PA, or an equivalent combination of the two for health benefits[9,10]. Aerobic exercise alone or combined with resistance training improves glycemic control, lowers blood pressure and blood lipids, and reduces waist circumference in type 2 diabetes patients[11]. The present data showed patients with moderate leisure-time PA had lower HbA1c and triglyceride, and higher HDL compared with those who had high or low leisure-time PA. In addition, the present study showed 4.8% of rural older adults with diabetes in Taiwan do moderate manual labor, whereas 36.1% working in agriculture (31.4%) or fisheries (4.7%) do high manual labor. Among rural older adults with diabetes in the USA, 34.0% do gardening or yard work[35]. Rural older adults with diabetes in Taiwan might have a slightly higher PA than that of their counterparts in the USA. Therefore, in order to understand the relationship between PA and metabolic control, it is important to investigate not only leisure-time PA, but also the total amount of PA. Indeed, our data showed that overall PA was associated with metabolic control, body fat and magnesium status. Patients with moderate PA had lower HbA1c and triglyceride, higher HDL, and better serum magnesium and albumin than those with low or high PA. In patients with type 2 diabetes who carry out moderate PA or exercise, blood glucose utilization by muscles usually exceeds hepatic glucose production, and thus blood glucose levels tend to decrease[36]. Furthermore, lipid profiles could benefit more from moderate exercise intensity than from high intensity PA or high exercise intensity[37]. The present data suggest that moderate PA or leisure-time PA is more beneficial for metabolic control than high PA in older patients with type 2 diabetes.

Increased protein and reduced carbohydrates could improve metabolic control in patients with type 2 diabetes[19]. Low fat and/or high carbohydrate intake are associated with good glycemic control in middle-aged and elderly diabetic patients[18]. In the present study, carbohydrate and fat intakes were not significantly associated with metabolic control. Our data on protein intake were consistent with data from some reviews and studies that indicated higher protein in the diet could benefit metabolic control in type 2 diabetes patients[19,38]. The present findings showed that the beneficial effects in terms of lower HbA1c and triglyceride, increased HDL levels, and reduced waist circumference, BMI, and body fat were about the same in the subgroups with protein intake 0.8–1.0 and >1.0 g/kg/day. A protein intake <0.8 g/kg/day is insufficient to meet the protein requirements of most elderly[32]. Conversely, higher protein intakes have been known to accelerate nephropathy, which is frequently observed in elderly and diabetic populations[20,21]. The Recommended Dietary Allowance (RDA) for protein is 0.8 g/kg/day in the general population[33]. A protein intake of 1.0 g/kg/day was recommended for the elderly in the 2011 Taiwan Dietary Reference Intakes (DRI) guidelines. Some guidelines recommend increasing RDA to 1.0–1.3 g/kg/day in older adults[39]. In addition, the clinical practice guidelines suggest that RDA of dietary protein for people with diabetes and chronic kidney disease (CKD), stages 1–4, should be 0.8 g/kg/day[40]. Our data suggest that the minimum requirement for adequate protein intake might be 0.8 g/kg/day for maintenance of good metabolic control in older diabetic patients. Appropriate protein intake was approximately 0.8–1.0 g/kg/day for older type 2 diabetes patients with CKD stages 1–3. Furthermore, our data showed lower protein intake tended to be associated with lower magnesium intake and serum magnesium. Although other nutrients might also be correlated with metabolic control, our data suggest that inadequate protein and magnesium intake could cause or result from metabolic abnormalities in older adults with type 2 diabetes.

One of the major findings in the present study was that moderate PA and a diet with adequate protein (≥0.8 g/kg/day) might help older diabetic patients achieve better metabolic control. The 20% of older diabetic patients who did moderate PA and maintained a diet with adequate protein had lower HbA1c and triglyceride, higher HDL, reduced weight and body fat, and better serum magnesium and albumin. In contrast, moderate PA with inadequate protein intake seemed to be linked with higher body fat percentage, waist circumference and BMI. Moderate PA appeared to be more beneficial for metabolic control than high PA[36,37]. Adequate dietary protein intake could improve metabolic control and reduce bodyweight[19]. Indeed, the percentages of older diabetic patients who had HbA1c <7.0% in three out of four HbA1c tests carried out over the past year in groups A, B, C, D, E, and F were 38.2, 42.9, 52.4, 53.7, 25.6, and 42.5% ($P = 0.002$), respectively. Patients in group D (moderate PA and a diet with adequate protein) achieved optimal metabolic control.

Excessive PA and inadequate dietary intake might be harmful to health[13,32,41]. In the present study, 19% of older type 2 diabetes patients who engaged in high physical activity and ingested adequate protein showed moderate metabolic controls. Conversely, another 19% of older type 2 diabetes patients who engaged in high physical activity, but had inadequate protein, had a higher HbA1c, lower magnesium intake and serum magnesium, higher waist circumference, BMI and body fat, and a noticeable negative energy balance compared with those who engaged in high physical activity and ingested adequate protein. The beneficial effects of higher protein intake might include increased satiety[42], increased thermogenesis[43], sparing of muscle protein loss[44], enhanced glycemic control[45] and improved body composition[19,45]. However, excessive energy expenditure could increase the protein required to compensate for the energy deficiency[46]. In addition, the present data showed that patients with high PA had higher HbA1c than those with moderate or low PA. There was no significant difference in magnesium intake between patients with high and moderate PA. Patients with low PA had lower magnesium intake. However, those with high PA had higher prevalence of hypomagnesemia. Furthermore, our data showed prevalence rates of poor glycemic control (HbA1c $\geq$7.0%) in hypomagnesemic patients with low, moderate, and high PA were 53.8, 46.2, and 66.7%, respectively. In the high PA subgroup, the prevalence of poor glycemic control in patients with and without hypomagnesemia was 66.7 and 50%, respectively. A study by Grylls *et al.*[47] showed that older diabetic patients with relatively high-intensity PA had higher HbA1c than those with low PA. High-intensity PA or a relatively low insulin concentration might trigger elevations in glucose to counter regulatory hormone levels, increase hepatic glucose production and lower glucose uptake, resulting in an increase in blood glucose levels[48,49]. Furthermore, PA could deplete magnesium and impair metabolism efficiency when magnesium intake is insufficient[14,50]. Metabolic abnormalities are associated with hypomagnesemia in diabetic patients[51]. The present data suggest that high PA with inadequate protein and magnesium intake could exacerbate magnesium deficiency, resulting in poor glycemic control in older type 2 diabetes patients. Older type 2 diabetes patients who engage in high PA should ingest adequate amounts of protein and magnesium in order to improve their metabolic control and magnesium status.

It is generally accepted that regulation of dietary intake and energy expenditure are impaired in older adults, which might lead to malnutrition or obesity and impair metabolic outcome[41,52,53]. In the present study, 16% of older diabetic patients who engaged in low levels of PA, and had lower protein and magnesium intakes had poor glycemic control, lower HDL, and higher triglyceride, body fat percentage, waist circumference, and BMI. Indeed, Iijima *et al.*[54] suggested that lower PA is a strong predictor of cardiovascular events in elderly patients with type 2 diabetes. Our data suggest that older type 2 diabetes patients with low PA should try to carry out and maintain moderate PA, and ingest adequate amounts of protein.

There were several limitations in the present study. First, the analyses were highly dependent on self-reported PA and dietary intake data. It is possible that overestimation, underestimation and poor recall might have confounded the results[30]. Fortunately, these rural-dwelling, elderly type 2 diabetes patients tended to have similar, simple lifestyle and eating habits. The majority of our patients on farms or fisheries were able to report the quantity and quality of their food. Thus, 24-h recall might be adequate for this type of population, and can provide complete and sufficient information[18]. Furthermore, questionnaires were used to assess typical weekly dietary patterns to ensure the dietary data were consistent[30]. Second, the study participants were typical rural-dwelling, elderly type 2 diabetic patients. Our data show that moderate PA and diet with adequate protein and magnesium might improve metabolic control, which is in line with data reported in other studies[16,17,19,38]. Thus, we believe that the present results are generalizable to non-rural patient populations with type 2 diabetes. Third, energy balance for an older adult was calculated from energy intake and estimated energy requirement. This might be unable to very accurately reflect the actual energy balance. Finally, although appropriate PA and protein intake could improve metabolic control in older type 2 diabetes patients, a further standardized intervention might benefit clinical outcomes in a prospectively designed study.

In conclusion, the present data suggest that moderate PA and a diet with protein intake $\geq$0.8 g/kg/day could be an optimal choice for better metabolic control in older type 2 diabetes patients. High PA might exacerbate magnesium deficiency, resulting in poor glycemic control when protein and magnesium intake is inadequate. Unfortunately, just 20% of the present patients had moderate PA and a diet with adequate protein. Of the patients with high PA, just 10% ingested adequate protein and magnesium. Clinicians should educate older type 2 diabetes patients about the importance of engaging in moderate PA regularly, and ingesting adequate protein and magnesium.

ACKNOWLEDGMENTS

This study was supported in part by a grant (the CCH project 93150 Erlin Community Investigation Project) from Changhua Christian Hospital, Taiwan. We thank Dr Jia-zhen Lu and the clinic medical staff for their enthusiastic support. The authors also thank Mr Kuang-Hsi Chang (Biostatistics Task Force, Department of Medical Research, Taichung Veterans General Hospital, Taichung, Taiwan) for his assistance. The authors have no conflicts of interest.

REFERENCES

1. U.S. Centers for Disease Control and Prevention. Number and Percentage of U.S. Population with Diagnosed Diabetes. http://www.cdc.gov/diabetes/statistics/prev/national/figbyage.htm. Accessed 4 June 2012.

2. Wild S, Roglic G, Green A, *et al.* Global prevalence of diabetes: estimates for the year 2000 and projections for 2030. *Diabetes Care* 2004; 27: 1047–1053.
3. Walker KZ, O'Dea K, Gomez M, *et al.* Diet and exercise in the prevention of diabetes. *J Hum Nutr Diet* 2010; 23: 344–352.
4. Rizvi AA. Management of diabetes in older adults. *Am J Med Sci* 2007; 333: 35–47.
5. Huang ES, Liu JY, Moffet HH, *et al.* Glycemic control, complications, and death in older diabetic patients- The Diabetes and Aging Study. *Diabetes Care* 2011; 34: 1329–1336.
6. Kleefstra N, van Hateren KJ, Houweling ST, *et al.* New blood glucose-lowering drugs in type 2 diabetes: a review of the literature. *Ned Tijdschr Geneeskd* 2010; 154: A886.
7. Espeland M, Pi-Sunyer X, Blackburn G, *et al.* Reduction in weight and cardiovascular disease risk factors in individuals with type 2 diabetes – one-year results of the Look AHEAD trial. *Diabetes Care* 2007; 30: 1374–1383.
8. Sigal RJ, Kenny GP, Wasserman DH, *et al.* Physical activity/exercise and type 2 diabetes: a consensus statement from the American Diabetes Association. *Diabetes Care* 2006; 29: 1433–1438.
9. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, *et al.* American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc* 2009; 41: 1510–1530.
10. U.S. Department of Health and Human Services. 2008. Physical Activity Guidelines for Americans. [article online]. http://www.health.gov/paguidelines/guidelines/default.aspx. Accessed December 2010.
11. Chudyk A, Petrella RJ. Effects of exercise on cardiovascular risk factors in type 2 diabetes- a meta-analysis. *Diabetes Care* 2011; 34: 1228–1237.
12. Dong L, Block G, Mandel S. Activities contributing to total energy expenditure in the United States: results from the NHAPS study. *Int J Behav Nutr Phys Act* 2004; 1: 4.
13. O'Keefe JH, Patil HR, Lavie CJ, *et al.* Potential adverse cardiovascular effects from excessive endurance exercise. *Mayo Clin Proc* 2012; 87: 587–595.
14. Nielsen FH, Lukaski HC. Update on the relationship between magnesium and exercise. *Magnes Res* 2006; 19: 180–189.
15. Huang JH, Lu YF, Cheng FC, *et al.* Correlation of magnesium intake with metabolic parameters, depression and physical activity in elderly type 2 diabetes patients: a cross-sectional study. *Nutr J* 2012; 11: 41.
16. Dong JY, Xun P, He K, *et al.* Magnesium intake and risk of type 2 diabetes: meta-analysis of prospective cohort studies. *Diabetes Care* 2011; 34: 2116–2122.
17. Rodriguez-Moran M, Guerrero-Romero F. Oral magnesium supplementation improves insulin sensitivity and metabolic control in type 2 diabetic subjects: a randomized double-blind controlled trial. *Diabetes Care* 2003; 26: 1147–1152.
18. Xu J, Eilat-Adar S, Loria CM, *et al.* Macronutrient intake and glycemic control in a population-based sample of American Indians with diabetes: the Strong Heart Study. *Am J Clin Nutr* 2007; 86: 480–487.
19. Layman DK, Clifton P, Gannon MC, *et al.* Protein in optimal health: heart disease and type 2 diabetes. *Am J Clin Nutr* 2008; 87: 1571S–1575S.
20. Uribarri J, Tuttle KR. Advanced glycation end products and nephrotoxicity of high-protein diets. *Clin J Am Soc Nephrol* 2006; 1: 1293–1299.
21. Meek RL, Leboeuf RC, Saha SA, *et al.* Glomerular cell death and inflammation with high-protein diet and diabetes. *Nephrol Dial Transplant* 2013; 28: 1711–1720.
22. Kashiwagi A, Kasuga M, Araki E, *et al.* International clinical harmonization of glycated hemoglobin in Japan: from Japan Diabetes Society to National Glycohemoglobin Standardization Program values. *J Diabetes Invest* 2012; 3: 39–40.
23. American Diabetes Association. Standards of medical care in diabetes—2011. *Diabetes Care* 2011; 34(Suppl 1): S11–S61.
24. Kurukulasuriya LR, Sowers JR. Therapies for type 2 diabetes: lowering HbA1c and associated cardiovascular risk factors. *Cardiovasc Diabetol* 2010; 9: 45.
25. Arnaud MJ. Update on the assessment of magnesium status. *Br J Nutr* 2008; 99(Suppl 3): S24–S36.
26. Levey AS, Coresh J. Chronic kidney disease. *Lancet* 2012; 379: 165–180.
27. Hwang LC, Chen SC, Tjung JJ, *et al.* Body mass index as a predictor of mortality in older people in Taiwan. *Int J Gerontol* 2009; 3: 39–46.
28. Hu G, Eriksson J, Barengo NC, *et al.* Occupational, commuting, and leisure-time physical activity in relation to total and cardiovascular mortality among Finnish subjects with type 2 diabetes. *Circulation* 2004; 110: 666–673.
29. World Health Organization. 2011. Global Recommendations on Physical Activity for Health. http://www.who.int/dietphysicalactivity/pa/en/index.html. Accessed December 2010.
30. Thompson FE, Byers T. Dietary assessment resource manual. *J Nutr* 1994; 124(11 Suppl): 2245S–2317S.
31. Huang MC, Hsu CC, Wang HS, *et al.* Prospective randomized controlled trial to evaluate effectiveness of registered dietitian-led diabetes management on glycemic and diet control in a primary care setting in Taiwan. *Diabetes Care* 2010; 33: 233–239.
32. Evans WJ. Protein nutrition, exercise and aging. *J Am Coll Nutr* 2004; 23(6 Suppl): 601S–609S.
33. Trumbo P, Schlicker S, Yates AA, *et al.* Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. *J Am Diet Assoc* 2002; 102: 1621–1630.
34. Institute of Medicine FaNB. Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D and

Fluoride. National Academy Press, Washington, DC, 1997; 71–145.

35. Arcury TA, Snively BM, Bell RA, *et al*. Physical activity among rural older adults with diabetes. *J Rural Health* 2006; 22: 164–168.
36. Sigal RJ, Kenny GP, Wasserman DH, *et al*. Physical activity/exercise and type 2 diabetes. *Diabetes Care* 2004; 27: 2518–2539.
37. Lira FS, Yamashita AS, Uchida MC, *et al*. Low and moderate, rather than high intensity strength exercise induces benefit regarding plasma lipid profile. *Diabetol Metab Syndr* 2010; 2: 31.
38. Gannon MC, Nuttall FQ, Saeed A, *et al*. An increase in dietary protein improves the blood glucose response in persons with type 2 diabetes. *Am J Clin Nutr* 2003; 78: 734–741.
39. Paddon-Jones D, Short KR, Campbell WW, *et al*. Role of dietary protein in the sarcopenia of aging. *Am J Clin Nutr* 2008; 87: 1562S–1566S.
40. Stall S. Protein recommendations for individuals with CKD stages 1-4. *Nephrol Nurs J* 2008; 35: 279–282.
41. Ritz P. Factors affecting energy and macronutrient requirements in elderly people. *Public Health Nutr* 2001; 4: 561–568.
42. Nickols-Richardson SM, Coleman MD, Volpe JJ, *et al*. Perceived hunger is lower and weight loss is greater in overweight premenopausal women consuming a low-carbohydrate/high-protein vs high-carbohydrate/low-fat diet. *J Am Diet Assoc* 2005; 105: 1433–1437.
43. Marliss EB, Vranic M. Intense exercise has unique, effects on both insulin release and its roles in glucoregulation – implications for diabetes. *Diabetes* 2002; 51: S271–S283.
44. Riddell MC, Perkins BA. Type 1 diabetes and vigorous exercise: applications of exercise physiology to patient management. *Can J Diabetes* 2006; 30: 63–71.
45. Bohl CH, Volpe SL. Magnesium and exercise. *Crit Rev Food Sci Nutr* 2002; 42: 533–563.
46. Corica F, Corsonello A, Ientile R, *et al*. Serum ionized magnesium levels in relation to metabolic syndrome in type 2 diabetic patients. *J Am Coll Nutr* 2006; 25: 210–215.
47. Grylls WK, McKenzie JE, Horwath CC, *et al*. Lifestyle factors associated with glycaemic control and body mass index in older adults with diabetes. *Eur J Clin Nutr* 2003; 57: 1386–1393.
48. Parker B, Noakes M, Luscombe N, *et al*. Effect of a high-protein, high-monounsaturated fat weight loss diet on glycemic control and lipid levels in type 2 diabetes. *Diabetes Care* 2002; 25: 425–430.
49. Layman DK, Boileau RA, Erickson DJ, *et al*. A reduced ratio of dietary carbohydrate to protein improves body composition and blood lipid profiles during weight loss in adult women. *J Nutr* 2003; 133: 411–417.
50. Farnsworth E, Luscombe ND, Noakes M, *et al*. Effect of a high-protein, energy-restricted diet on body composition, glycemic control, and lipid concentrations in overweight and obese hyperinsulinemic men and women. *Am J Clin Nutr* 2003; 78: 31–39.
51. Soenen S, Westerterp-Plantenga MS. Protein induced sparing of fat free mass in energy balance. *Int J Obes* 2008; 32: S70.
52. Roberts SB, Rosenberg I. Nutrition and aging: changes in the regulation of energy metabolism with aging. *Physiol Rev* 2006; 86: 651–667.
53. Rolls BJ, Dimeo KA, Shide DJ. Age-related impairments in the regulation of food intake. *Am J Clin Nutr* 1995; 62: 923–931.
54. Iijima K, Iimuro S, Shinozaki T, *et al*. Lower physical activity is a strong predictor of cardiovascular events in elderly patients with type 2 diabetes mellitus beyond traditional risk factors: the Japanese elderly diabetes intervention trial. *Geriatr Gerontol Int* 2012; 12: 77–87.