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Association between Resting Metabolic Rate (RMR), Respiratory Quotient (RQ) and Dietary Energy Density (DED) in overweight and obese women

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Summary. *Aim*: Dietary Energy Density (DED) defined as the energy content of foods (kJ or kcal) per unit weight of foods (g) that has an important effect in the regulation of energy intake, weight reduction, weight maintenance and waist circumference but its function in resting metabolic rate (RMR) is less understood. Therefore, we wanted to investigate the association between resting metabolic rate (RMR), respiratory quotient (RQ) and DED in overweight and obese women. *Methods:* A total of 301 overweight and obese women were included in the current comparative cross-sectional study. Body composition was measured using body composition analyzer. RMR was measured by means of indirect calorimetry. The usual food intake of people over the past year evaluated through the use of a semi-quantitative food frequency questionnaire. We calculate ED from food only as energy (kcal) and it was divided by the total weight of the food (g) excluding nonenergetic beverages. *Results*: Between low and high energy density of diets there is statistically significant difference in age, carbon dioxide uptake (VCO_2), RMR/Kg body weight (RMR/Kg), RMR/body surface area (RMR/BSA) ($P > 0.0001$), RMR and RQ ($P = 0.01$). Furthermore, there is a significant relationship between the DED and RMR/Kg body weight ($P > 0.0001$) and finally in the regression model after adjusted for age, fat free mass and physical activity, the association of DED and RMR/Kg body weight was still significance ($p<0.05$; 95% CI= 0.86-1.69). *Conclusion*: The findings of this study suggest that there is a positive relationship between RMR, RQ and DED.

Key words: dietary energy density, resting metabolic rate, respiratory quotient, obesity, overweight

Introduction

Obesity is one of the major risk factor of health (1) that led to increased metabolic complications of obesity including type 2 diabetes, metabolic syndrome, impaired glucose tolerance, insulin resistance, hyperglycemia, cardiovascular diseases and cancer (2). Previous studies have shown that the prevalence of obesity is increasing significantly, as approximately 600 million people were obese throughout the word in 2014 (3) and it will increase almost 7-10% among adult in 2020 (4). However, weight maintenance has determine by whole energy intake, (3) managing the energy density of diets is a novel approach to reduction of body weight (5).

Energy density (ED) has an important effect in the regulation of energy intake (EI), (6) indeed EI will decrease by reducing of a diet (7). ED of diets defined as the energy content of foods (kJ or kcal) per unit weight of foods (g) (8). Diets with lower ED include whole grains, vegetables, fruits, low-fat dairies and lean meats (9). Lower ED has a beneficial effect on weight reduction, weight maintenance and waist circumference, (1, 10) also it prevents from passive over-eating, abdominal obesity, weight gain and, excessive adiposity, (10) but its relationship with RMR is less known.

RMR usually have the largest component of daily energy requirements (approximately 65 to 70%), (11) and it consists of RMR, physical activity and the thermic effect of food (12). Some studies have shown the association between RMR and the level of some hormones in the body. Recent studies have demonstrated that there is mediatory effect of vaspin and adiponectin with RMR through visceral fat and fat mass (13, 14). RMR is associated with fat-free mass (FFM), fat mass (FM), leptin, adiponectin, vaspin and body weight (15-17).

According to the results of previous studies, we want to see the relationship between RMR, RQ and DED.

Methods

A total of 301 overweight and obese women were included in the current comparative cross-sectional study. For all the participants who were 301 overweight and obese women, body weight (BW) and body height (BH) were measured to determine the body mass index (BMI), expressed as BMI = BW (kg)/BH (m^2). The study participants were chosen according to our defined inclusion criteria, namely, aged 17-56 years, an absence of any acute or chronic inflammatory disease, no history of hypertension, no alcohol or drug abuse, and not being pregnant. Accordingly, individuals who had a history of any condition affecting inflammatory markers, such as known cardiovascular disease, thyroid diseases, malignancies, current smoking, diabetes mellitus, sustained hypertension, heart failure, acute or chronic infections, and hepatic or renal diseases were excluded from the study. All participants were provided with written informed consent before taking part in the study.

We measured the RMR by indirect calorimetry (spirometer METALYZERR 3B-R3, Cortex Biophysik GmbH, Leipzig, Germany). Gas ventilation and exchange was calibrated prior to each examination. CO_2 evaluated by an infrared sensor and O_2 evaluated by an amperometric solid electrolyte sensor. O_2 and CO_2 recorded through breath-by-breath.

We utilized an ergonomically designed mask, that the air is conducted through the volume flow sensor. The RMR was evaluation through the amount of O_2 and CO_2. The RMR was assessed in the morning after a 10 to 12 hours fasting. We declared that participants avoid caffeine or alcohol consumption and severe exercise for a 24 hours before the RMR evaluation. The RMR was measured for 0.5 hours, after performing steady state and supine position in a quiet room. The RMR was determined through the Harris–Benedict equation, which considers weight, height, and age for participants.

Body composition such as weight, BMI, FM, FFM and waist to hip ratio (WHR) were acquired by using a bioelectrical impedance analyzer (BIA) InBody 770 scanner (Inbody Co., Seoul, Korea). The BIA calculated the amount and proportion of FFM and FM by the flow of an electrical signal that flows more efficiently through both hands and feet. According to the manufacturer's instructions they have to remove extra clothes such as shoes, coat and sweater. They have to remove metal utensils, such as earing, ring and watch. The examination takes nearly 20 seconds, and the result is shown.

The usual food intake of people over the past year will be evaluated halfway through the use of the Food Frequency Questionnaire (FFQ) (18). Dietary intake data were analyzed using the NUTRITIONIST 4 (First Data Bank, San Bruno, CA) food analyzer. We used the method of Ledikwe et al (19) to determine the ED of the diets. This method calculates ED from food only as energy (kcal)/weight of food (g) excluding nonenergetic beverages.

All statistical analysis was performed using the IBM SPSS version 22.0 (SPSS, Chicago, IL, USA). Normal distribution of data was checked by Kolmogorov-Smirnov test. Independent sample t-test was used for assessed differences between groups with high and low ED. Pearson correlation was used to the assessed correlation between energy density and variables. Linear regression was used to assess the association of RMR/Kg body weight and ED and its components. The differences between groups re-analyses by linear regression to adjust the confounder effect. Four models were constructed: Model 1 was crud, model 2 was adjusted for age, model 3 adjusted for age and FFM and in model 4 adjusted for age, FFM and physical activity. Results of linear regression were presented as β±SE, T-value and 95% confidence intervals (CIs) compared with the DED.

Results

Anthropometrical and clinical characteristics of participants

Anthropometrical and clinical characteristics of women are presented in Table 1. The mean age, height, weight of the study participants was 36.49 (SD=8.38) years, 161.38 (SD=5.90) cm, 80.89 (SD=12.45) kg, respectively. The minimum, maximum, and mean BMI measurements for the participants were 24.20, 49.60, and 31.04, respectively (Table 1).

Correlation between Dietary energy density and studied variables

Total of participants was categorized based on the low and high energy density diets that they consumed and divided into two groups (group 1 n= 146; group 2 n= 145) (Table 2). Our cut point for categorization of participants based on energy density was 0.93. Participants with energy density less than 0.93 were in group 1 and participants with energy density greater than 0.93 were in group 2. The result of the study revealed that there was statistically significant differ-

Table 1. Characteristics of study population

Variables	Minimum	Maximum	Mean	Std. Deviation
Age (years)	17.00	56.00	36.49	8.38
Weight (kg)	59.50	136.60	80.89	12.45
Height (cm)	142.00	179.00	161.38	5.90
BMI (kg/m^2)	24.20	49.60	31.04	4.31
RMR (kcal/day)	952.00	248a0.00	1574.96	259.71
RMR/Kg (kcal/day/kg)	9.30	32.50	19.59	3.09
V.CO$_2$ (ml/min)	0.01	0.30	0.19	0.03
V.O$_2$ (ml/min)	0.14	0.36	0.22	0.03
RQ	0.73	0.99	0.85	0.04
Fat mass (kg)	19.40	74.20	34.04	8.69
Fat free mass (kg)	35.30	67.70	46.80	5.64

n: 301. BMI body mass index, RMR resting metabolic rate, Vco_2 Carbon dioxide consumption, Vo_2 Oxygen consumption, RQ respiratory quotient

Table 2. Correlation between Dietary energy density and studied variables

	Dietary energy density		
Variables	**Low (n= 145) Mean ± Std. Deviation**	**High (n= 146) Mean ± Std. Deviation**	**P-value***
Age (years)	38.66 ± 7.74	34.35 ± 8.71	<0.0001
Weight (kg)	81.02 ± 13.00	80.41 ± 11.44	0.67
Height (cm)	160.89 ± 5.49	161.68± 6.32	0.25
BMI (kg/m^2)	31.30 ± 4.59	30.80 ± 4.04	0.32
RMR (kcal/day)	1538.25 ± 248.11	1614.77 ± 265.49	0.01
RMR/Kg (kcal/day/kg)	19.12 ±2.75	20.17 ± 3.37	<0.0001
V.O$_2$ (ml/min)	0.22 ± 0.03	0.23 ± 0.03	0.01
V.CO$_2$ (ml/min)	0.18 ± 0.03	0.19 ± 0.03	<0.0001
RQ	0.85 ± 0.04	0.85 ± 0.03	0.01
Fat mass (kg)	34.31 ± 9.21	33.70 ± 8.12	0.54
Fat free mass (kg)	46.78 ± 5.62	46.77 ± 5.55	0.99
Waist to hip ratio	0.93 ± 0.05	1.56 ± 7.56	0.31
Waist circumference (cm)	99.07 ± 10.48	98.85 ± 9.62	0.85

*n: 301. BMI body mass index, RMR resting metabolic rate, Vco_2 Carbon dioxide consumption, Vo_2 Oxygen consumption, RQ respiratory quotient. * P-value <0.05 is significant.*

ence on age, VO_2, VCO_2, RMR/Kg body weight (P <0.0001), RMR and RQ (P = 0.01). However, there was no significant difference in age, weight, BMI, FM, FFM, waist-hip ratio and waist circumference among the two groups (P > 0.05) (Table 2).

Correlation between dietary energy density and variables

Pearson bivariate correlation was used to find the correlation between DED and variables. Correlation and significance level between variables and DED were investigated in participants (Table 3). The result of the study revealed that there is positive correlation and statistically significant difference on RQ (P= 0.01; r = 0.14) and there is negative correlation and statistically significant difference on age (P <0.0001; r = -0.24) (Table 3).

Correlation between RMR/Kg and dietary energy density

In order to be more specific, we also studied the relationship between RMR/Kg body weight and DED. In this study, the correlation between RMR/Kg body weight and DED was investigated (Table 4). According to the results, there is a significant relationship between the DED and RMR/Kg body weight (P <0.0001) in crude model. After the DED was Adjusted for age the relationship remained significant (P <0.01) (model 1). Then the DED was adjusted for age and FFM, there was a significant correlation between the DED and RMR/Kg body weight (P<0.0001) (model 2). Finally, the DED was Adjusted for age, FFM and physical activity, there was still a significant correlation between the DED and RMR/Kg body weight (P <0.05) (model 3) (Table 4). Our study showed that for one-unit increase in DED, the RMR/Kg body weight is increased 0.89 percent.

Correlation between food groups with low and high energy density

Then, we assessed the correlation between dietary groups and DED (Table 5). There was a relationship between consumption of refined grain, fruits, vegetables, tea, coffee (P<0.0001), animal fat (P<0.05) and DED. In a diet with a high DED, consumption of refined grain, animal fat, tea and coffee was high and consumption of fruits, vegetables was low (Table 5).

Table 3. Correlation between dietary energy density and variables

	Dietary energy density	
Variables	**r**	**P-value***
Energy density	1	
Age (years)	-0.24	<0.0001
Weight (kg)	0.00	0.99
Height (cm)	0.04	0.46
BMI (kg/m²)	-0.01	0.79
RMR (kcal/day)	0.08	0.14
RMR/Kg (kcal/day/kg)	0.10	0.08
$V.O_2$ (ml/min)	0.06	0.24
$V.CO_2$ (ml/min)	0.11	0.05
RQ	0.14	0.01
Fat mass (kg)	0.00	0.95
Fat free mass (kg)	0.00	0.87
Waist to hip ratio	0.03	0.57
Waist circumference (cm)	0.01	0.86

*n: 301. BMI body mass index, RMR resting metabolic rate, Vco_2 Carbon dioxide consumption, Vo_2 Oxygen consumption, RQ respiratory quotient. * P-value <0.05 is significant.*

Discussion

The results of this study revealed that people who consumed higher-energy density foods had higher RMR. According to previous studies, people who consume higher-energy density foods, tend to have high-

Table 4. Correlation between RMR/Kg and dietary energy density

	Dietary energy density		
Correlation between RMR/Kg and DED	**β±SE**	**T-value (95% CI)**	**P-value***
Crude model[(a)]	1.04±0.36	2.85(0.32-1.76)	<0.0001
Model1 [(b)]	0.96±0.32	2.58 (0.23-1.70)	0.01
Model2[(c)]	1.00±0.37	2.68 (0.26-1.74)	<0.0001
Model3 [(d)]	0.891±0.409	2.118 (0.86-1.69)	0.03

*n= 301. DED: dietary energy density. [(a)]: relationship between the energy density and RMR/Kg, [(b)]: energy density adjusted for age, [(c)]: energy density adjusted for age and fat free mass, [(d)]: energy density adjusted for age, fat free mass and physical activity. * P-value <0.05 is significant.*

Table 5. Correlation between food groups with low and high energy density

Food groups	Dietary energy density Low (n=145) Mean ± Std. Deviation	High (n=146) Mean ± Std. Deviation	P-value*
Refined grain (g/day)**	388.18 ± 199.39	476.20 ± 231.39	<0.0001
Whole grain (g/day)	10.54 ± 11.32	9.724 ± 11.42	0.53
Low fat dairy (g/day)	297.29 ± 217.39	261.93 ± 223.69	0.17
High fat dairy (g/day)	112.50 ± 151.27	107.63 ± 128.14	0.76
Red meat (g/day)	22.04 ± 18.38	20.91 ± 1.8.69	0.60
White meat (g/day)	46.48 ± 39.52	47.21 ± 50.89	0.89
Organ meat (g/day)	2.41 ± 4.017	2.83 ± 4.71	0.41
Process meat (g/day)	4.49 ± 10.69	5.54 ± 7.98	0.34
Fruits (g/day)	641.02 ± 375.17	478.89 ± 314.15	<0.0001
Vegetables (g/day)	520.42 ± 279.01	312.91 ± 177.08	<0.0001
Starch vegetables (g/day)	28.96 ± 26.12	27.25 ± 27.75	0.58
Legumes (g/day)	46.69 ± 38.23	46.19 ± 40.49	0.91
Nuts (g/day)	11.54 ± 10.51	11.62 ± 13.49	0.95
Animal fat (g/day)	20.66 ± 25.11	27.62 ± 25.98	0.02
Vegetable oil (g/day)	20.08 ± 159.14	4.73 ± 11.99	0.24
Olive (g/day)	5.79 ± 11.46	8.42 ± 2.0.70	0.19
Sweets (g/day)	91.88 ± 106.16	87.60 ± 122.53	0.75
High energy beverage (g/day)	6.72 ± 7.34	5.13 ± 7.00	0.06
Tea and coffee (g/day)	5.30 ± 4.11	7.11 ± 5.89	<0.0001

** p-value <0.05 is significant. ** g/day is the amount of daily intake in grams per day and all intakes are adjusted for the residual model.*

er levels of weight gain, abdominal obesity and waist circumference (1, 10). Diets with lower ED include whole grains, vegetables, fruits, low-fat dairies and lean meats and diets with higher ED include refined grain, animal fat and process meat (9).

Probably, increasing RMR with consumption of high DED may be due to, that the body do this (increasing RMR) to maintain normal performance and maintain its sustainability in order to cope with a high-energy density diet.

For example, leptin, which reduces appetite, is higher in obese people and lower in underweight people (20). Also, ghrelin, which increases appetite, is lower in obese people and high in underweight people (21).

On the other hand, obese subjects have higher vaspin levels (22). Vaspin has a positive relationship with RMR (13). Probably increasing RMR may be due to increased secreted vaspin from adipose tissue in people who consume higher-energy density foods.

In this study the correlation between RMR/Kg body weight and DED was investigated. According to the results, there is a significant relationship between DED and RMR/Kg body weight. Our study showed that for one-unit increase in DED, the RMR/Kg body weight is increased 0.89 percent. According to previous studies, there is a significant and positive relationship between RMR and EI and RMR is a strong determinant of EI (23, 24). Also, other studies showed RMR is a marker of EI and could represent a signal for hunger (24) and DED has an important effect in the regulation of EI (6). Therefore, it can be said that DED has an effect on the RMR and RMR/Kg body weight.

Although some studies have shown a relationship between DED and obesity, (25-27) we did not see any significant relationship in this study between DED and weight, BMI, FM, FFM, WHR and waist circumference another important finding of the present study is high DED increases the RQ. Also according to this study, a high DED contains foods such as animal fats, refined grains and processed meat that increase RQ. The higher RQ represents pure fat synthesis and high intake of carbohydrates and energy, while the lower RQ indicates inadequate reception (28, 29). Also lipogenesis increases the RQ (28).

Our study also showed that high DED increases Vo_2 and Vco_2. The increase in Vo_2 and Vco_2 will increase the RMR. (30) Maybe, this is due to that, high DED include fats, and fats have higher Vo_2 and Vco_2 (28).

This study demonstrated an excessive consumption of tea and coffee within high energy density diet. Tea and coffee stimulate metabolism (31). This may increase RMR in this way.

The findings of this study suggest that energy density of diet had an effect in RMR. There is a positive relationship between energy density of diet and RMR. The study revealed that obese people consumed higher energy density, which increases the RMR.

Conclusion

The findings of this study suggest that there is a positive relationship between RMR, RQ and DED.

Limitation and strength of study

The limitation of the present study was the type of study (cross-sectional) and the cause and effect relationship is not well known. We suggest conducting experimental clinical trials studies. Another limitation is the relatively small number of subjects in the sample (301 females). Moreover, the assessment focused only on obese women.

As far as our knowledge, the strength of this study is the first study that evaluates the relationship between energy density of diet and RMR in obese women.

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