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Resting Energy Expenditure and Its Relationship With Patterns of Obesity and Visceral Fat Area in Chinese Adults[1]

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Objective To investigate the relationship between resting energy expenditure (REE) and patterns of obesity/regional fat parameters in Chinese adults. **Methods** Body mass index (BMI), fat mass (FM), fat-free mass (FFM) were assessed in 109 Chinese adults (52 men and 57 women), and their abdominal visceral adipose tissue area (VA) and subcutaneous fat area (SA) were measured using magnetic resonance imaging (MRI) measurements. REE was measured with indirect calorimetry and compared with normal and obese subjects. Multivariate analysis was used to study the factors related to REE. **Results** The resting energy expenditure per kilogram of body weight (REE/kg) was closely related with the area of abdominal visceral fat measured with MRI. REE/kg was significantly lower in overweight/obesity subjects than in normal-weighted subjects, and significantly lower in subjects with abdominal obesity (VA$\geqslant$100 cm^2) than in subjects with non-abdominal obesity (VA$<$100 cm^2, BMI$\geqslant$25 kg/m^2). In the stepwise regression analysis of REE/kg on regional fat parameters, VA in men and women and SA in women were independent factors reversely related to REE/kg. **Conclusion** REE/kg is associated with the visceral fat area and more prominent in men. REE/kg can be used as an index in the pathophysiology of intra-abdominal obesity.

Key words: Resting energy expenditure (REE); Magnetic resonance imaging; Intra-abdominal obesity

INTRODUCTION

Obesity increases the risk of type 2 diabetes, hypertension, dyslipidemia, atherosclerosis, several types of cancer and many other diseases. These diseases have been shown more closely related to the accumulation of visceral (intra-abdominal) adipose tissue. The rapid increase of overweight and obesity in recent years in China is a great challenge to the public health system of China. The National Nutritional Survey in 1992 showed that overweight (body mass index, BMI$\geqslant$25 kg/m^2) accounted for 14% of the Chinese people aged 20-74 years, while at the end of 1990s, the proportion of overweight increased to 21.51%, and that of obesity to 2.92%[1]. Although obesity is less common in China than in Western countries, the obesity-related metabolic disorders are non-negligible. According to a recent survey in Shanghai, the prevalence of type 2 Diabetes was 9.8%, and that of metabolic syndrome was 10.2%[2]. In the Chinese people, severe obesity was less common, but the proportion of intra-abdominal obesity was surprisingly high. Our recent study revealed that 50%-60% of the people with BMI higher than 25 kg/m^2 could be classified as intra-abdominal obesity[3].

Obesity is presumed to develop when there is an imbalance between energy intake and energy expenditure. Longitudinal surveys showed that the risk of significant weight gain was greater in adults who were sedentary than in those who were active. The resting energy expenditure (REE) measures the energy consumed in basal conditions to keep the consciousness and the normal physiological functions of cells and organs. Accounting for 60%-70% of the total body energy expenditure, a small change can lead to substantial differences in daily energy balance. Among individuals who have undergone weight loss therapy, the decline in REE resulting from such an intervention is associated with weight regain over time[4]. The changes of REE might influence the energy balance in some unrecognized ways. There is a significant, positive linear relationship between palmitate release and REE, showing that REE, instead of body composition, could predict most of the interindividual variation in free fatty acid (FFA) release[5], which could affect some subtle changes in lipid, energy metabolism and insulin sensitivity.

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Some study also showed a close relationship between REE and fat-free mass (FFM)[6].

The aim of this study was to investigate the relationship between REE and the patterns of obesity (accumulation of abdominal visceral fat). We also compared them in groups with different body mass index (BMI), fat mass (FM), FFM, age, and gender. These might provide some clues to a better underst-anding of the pathophysiology of abdominal obesity.

SUBJECTS AND METHODS

Subjects

The subjects consisted of 109 Chinese adults, aged 25-67 years (52 men and 57 women) from local communities. All the volunteers had the oral glucose tolerance test (OGTT) and proved normal. Among the 109 subjects, 39 were normal-weighted (BMI < 5 kg/m^{2}and 70 were over-weighted or obese (BMI $\geqslant$25 kg/m^2, according to WHO 1998 criteria). People with hepatic, renal, thyroid problems or taking drugs affecting energy metabolic balance such as beta-adrenergic blockers were not recruited. The study was approved by the Institutional Review Board of No. 6 Hospital affiliated to the Shanghai Jiaotong University. Written informed consent was obtained from each of the participants.

Measurements of Body Fat

Abdominal adipose tissue was measured using a whole-body imaging system (SMT-100, Shimadzu Co, Japan) with TR-500 and TE-200 of SE. MRI was performed on the subjects in supine position, at the abdominal level between L4 and L5 vertebrae. Abdominal visceral adipose tissue area (VA), abdominal subcutaneous adipose tissue area (SA), and femoral subcutaneous adipose tissue area (FA) were calculated with the software provided by the manufacturer[7-8].

FM and FFM were determined with a bioelectrical impedance analysis system (BIA) (TBF-40, Tanita Co, Japan).

The anthropometric parameters of body fat, height (m) and weight (kg) were measured with subjects standing without shoes and hats, and in light attire. BMI was calculated as weight/height^2 (kg/m^2).

Measurement of REE[9]

REE was determined with an indirect calorimeter (Vmax-29, Sensormedics, USA). After having been fasted for 10-12 h, the volunteers lay in supine position for 30 minutes before the experiment started. Room temperature was at 20℃-25℃. The calorimetry test was terminated if abnormal situations such as fever, insomnia, and strong hungry feelings emerged. Urine samples within 12 hours before the experiment were collected to detect the urea nitrogen (Nu). The expenditure of oxygen (VO_2), production of carbon dioxide (VCO_2) and respiratory quotient (RQ) were measured every minute. The average value during the experiment of 30 minutes was calculated to determine the REE with the Weir Equation:

$$REE=(3.9 \times VO_2 + 1.1 \times VCO_2) \times 1.44 - 2.17 \times Nu$$

Statistical Analysis

VA$\geqslant$100 cm^2 scanned by MRI was accepted to define the abdominal obesity. We used this value as a cut point for distinguishing abdominal obesity from non-abdominal obesity[10,11]. The ratio of REE to body weight (REE/kg), measured in kcal/kg, was introduced to the analyses. Covariance analysis was used to compare the measurement data between groups while adjusted for the effect of FM, FFM, age, and gender. Correlations between REE/kg and the local fat distribution by gender were studied. The stepwise regression analysis was used to study the contribut- ions of the factors affecting REE. All the statistical analyses were performed with the SAS software.

RESULTS

Comparison of REE in Lean and Obese Subjects

Among the 109 subjects, 70 had BMI greater than or equal to 25 kg/m^2 and were diagnosed as overweight/obesity (OW/OB), and 39 were normal weighted (BMI<25 kg/m^2). The mean age of the normal-weight (NW) group was greater than that of the overweight/obesity (OW/OB) group. After adjustments for age and gender, REE/kg in the OW/OB group was significantly lower than that in the NW group (21.17±0.34 kcal/kg vs 23.19±0.44 kcal/kg, P<0.01). BMI, FM, FFM, VA, SA, FA also showed statistical differences between the two groups (Table 1).

Relationship Between REE and Patterns of Obesity

Among the 109 subjects who were examined with MRI, 53 had VA greater than or equal to 100 cm^2 and were diagnosed as intra-abdominal obesity (AO), 28 were non-abdominal obesity (NAO, VA< 100 cm^2, BMI$\geqslant$25 kg/m^2), and 28 were normal weighted (NW, VA<100 cm^2, BMI<25 kg/m^2). After adjustments for age and gender, both the NAO and AO groups had increased BMI, FM, as well as declined REE/kg, compared with the NW group. In the covariance analysis, when BMI was also adjusted for, we found no significant difference in REE/kg between the NAO group and NW group (P=0.62), whereas the REE/kg of the AO group was still significantly lower in comparison with both the NW and the NAO groups (P=0.015 and 0.02, respectively, Table 2).

TABLE 1

Characteristics of Study Subjects With Normal Weight (NW) or Overweight/Obesity (OW/OB) ($\bar{x} \pm s$)

	NW(BMI<25 kg/m^2) (n=39)	OW/OB(BMI⩾25 kg/m^2) (n=70)	P Value
Gender(men/women)	18/21	34/36	-
Age (yr)	51.51±2.26	43.19±2.13	< 0.05
BMI (kg/m^2)	21.58±0.28	29.86±0.45	< 0.001
FM (kg)	14.31±0.78	29.79±1.29	< 0.001
FFM (kg)	43.04±1.00	49.74±1.25	< 0.01
VA	79.03±10.12	119.11±7.99	< 0.01
SA	123.42±10.55	250.09±11.02	< 0.001
FA	68.85±5.17	102.32±4.36	< 0.001
REE/kg (kcal/kg)	23.19±0.44	21.17±0.34	< 0.01

Note. Adjusted for age and gender. BMI: body mass index; FM: fat mass; FFM: fat-free mass; VA: visceral adipose tissue area; SA: subcutaneous adipose tissue area; FA: femoral adipose tissue area; REE: resting energy expenditure; REE/kg: REE per kilogram of body weight.

TABLE 2

Characteristics of Chinese Adults With Normal Weight (NW), Non-abdominal Obesity (NAO) or Abdominal Obesity (AO) ($\bar{x} \pm s$)

	NW(n=28)	NAO (n=28)	AO (n=53)	P values (Adjusted for Age and Gender)		
				P_1	P_2	P_3
BMI(kg/m^2)	21.58±0.71	27.36±0.75	29.01±0.52	< 0.001	< 0.001	0.08
FM(kg)	14.47±1.76	23.69±1.85	29.72±1.27	< 0.001	< 0.001	0.01
FFM(kg)	43.28±1.25	46.99±1.31	49.01±0.90	0.02	< 0.001	0.22
REE/kg(kcal/kg)	24.04±0.49	22.33±0.51	20.52±0.35	0.02(0.62)*	< 0.001(0.015)*	< 0.01(0.02)*

Note. NW: VA<100 cm^2, BMI<25 kg/m^2; NAO: VA<100 cm^2,BMI⩾25 kg/m^2; AO: VA⩾100 cm^2. P_1: NW compared with NAO; P_2: NW compared with AO; P_3: NAO compared with AO.*P value adjusted for BMI, age and gender. BMI: body mass index; FM: fat mass; FFM: fat-free mass; VA: visceral adipose tissue area; SA: subcutaneous adipose tissue area; FA: femoral adipose tissue area; REE: resting energy expenditure; REE/kg: REE per kilogram of body weight.

Correlation Between REE, Body Fat Distribution by Gender

The REE/kg was negatively correlated with BMI, FM, FFM, VA, SA and FA according to the partial correlation analysis after adjustment for age. The highest correlation coefficient in men was found between BMI and VA (R=-0.54, P<0.01), and in women between BMI and FM (R=-0.48, P<0.01). After adjustments for age and FM, only two parameters remained significant in their correlation with REE/kg. They were VA (R=-0.32, P<0.01) and FFM (R=-0.41, P<0.001) of men (Table 3).

Factors Affecting REE

Stepwise regression analyses of REE/kg on age, VA, SA, FA indicated that VA was independently correlated with REE/kg in both genders. The higher the VA, the lower the REE/kg was. SA was also correlated with REE/kg in women (Table 4).

TABLE 3

Correlation Coefficients Between REE/kg and Local Fat Parameters

Variables	REE/kg	
	Men (n=52)	Women (n=57)
BMI	-0.54* (-0.28)	-0.48* (-0.08)
FM	-0.48*	-0.48*
FFM	-0.43* (-0.41*)	-0.37* (-0.19)
VA	-0.54* (-0.32*)	-0.31* (-0.13)
SA	-0.44* (-0.06)	-0.39* (-0.12)
FA	-0.49* (-0.24)	-0.43* (-0.16)

Note. Out Of parentheses: adjusted for age only; In the parentheses: adjusted for age and FM.*: P<0.01. BMI: body mass index; FM: fat mass; FFM: fat-free mass; VA: visceral adiposetissue area; SA: subcutaneous adipose tissue area; FA: femoral adipose tissue area; REE: resting energy expenditure; REE/kg: REE per kilogram of body weight.

TABLE 4

Stepwise Regression Analysis of REE/kg on the Regional Fat Parameters

Dependent Variable	Independent Variable	Regression Coefficient	Partial $r^2 \times 100$	Model $r^2 \times 100$	*P* Value
REE/kg, Men (*n*=52)	VA	-0.03	30	30	< 0.001
REE/kg, Women (*n*=57)	VA	-0.02	13	13	< 0.01
	SA	-0.01	20	33	< 0.001

Note. Independent variables: Age, VA, SA, FA.VA: visceral adipose tissue area; SA: subcutaneous adipose tissue area; FA: femoral adipose tissue area; REE: resting energy expenditure; REE/kg: REE per kilogram of body weight.

DISCUSSION

Abdominal obesity has been associated with a cluster of metabolic disorders. Excess fat in the upper part of the body (central or abdominal) more often correlates with an increased mortality and risk for disorders such as diabetes, hyperlipidemia, hypertension, and atherosclerosis of coronary, cerebral, and peripheral vessels than the lower body or gluteo-femoral or peripheral depot type of fat distribution.

Researches have shown that REE is related to body fat distribution, but the actual relationship between patterns of obesity and REE remains unclear. In addition, REE varies in races[12]. For example, REE of African Americans is lower than the white. A research in Tanzania showed that the mean REE was higher in subjects from the rural and pastoralist populations than in urban dwellers[13].

The total body energy expenditure (TEE) can be divided into three parts: REE, the adaptive thermogenesis, and the activity-related energy expenditure (AEE). Every person is regulated in the precise balance of energy intake and consumption, which keeps the homeostasis of body weight. The maladjustment of energy balance could influence the body weight. REE could be affected by age, gender, energy regulation related hormones, sympathetic nerves, and could be different among different races and individuals[4]. Previous studies have found the differences of REE in obese and lean subjects. The waist to hip ratio (WHR), FM, FFM, and age were referred to as factors affecting REE[13,14]. Before weight control treatment, REE, adjusted for body composition, was significantly lower in black subjects than in white subjects. And black subjects lost significantly less weight during the treatment than white subjects. Analyses controlling for initial REE and changes in FM and FFM showed that the black had significantly greater decreases in REE after treatment than the white[5]. This may explain the common phenomenon that some people could not get expected weight reduction solely by hypocaloric diet, and only had more significant weight control when they combined the low caloric food with active lifestyle at the same time, which apparently increased their AEE and TEE. The low REE may limit the weight control effect of hypocaloric diet. The combination of improving dietary habits and increasing physical activity at the same time may be necessary.

Our findings showed that, in the Chinese adults, REE/kg was significantly lower in subjects of abdominal obesity than in those of non-abdominal obesity, indicating that REE/kg is a useful index in the description of abdominal obesity. This indicated that the imbalance of energy and body-weight control in obesity was even more evident in the abdominal obesity. It is well-known that the heavier the person weighs, the higher the REE. But when we put the weight into calculation, just like in REE/kg, we saw the opposite tendency. The body fat mass was closely related with the REE/kg, while by analyzing the fat mass in detail, we could see some clues of different functions of adipose tissue in different depots. The multivariate analysis showed that the increase of abdominal visceral fat was independently related to the decease of the REE/kg, with the contribution of 30% in men and 13% in women. VA was more correlated with REE/kg in men than in women. This study indicates that low REE/kg is closely related to the pathogenesis of abdominal obesity. And the gender differences in pathophysiological changes of obesity may be partly related to energy expenditure. The specific mechanisms warrant further investigation.

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