Effects of Fat Mass and Body Fat Distribution on Resting Metabolic Rate in the Elderly

Petra M. Lührmann, Birgit M. Herbert, and Monika Neuhäuser-Berthold

The aim of the present study was to investigate the relationship between resting metabolic rate (RMR) and fat-free mass, fat mass, and body fat distribution in 164 women (age 60 to 85 years; body mass index [BMI], 18.5 to 35.6 kg/m^2) and 98 men (age 60 to 85 years; BMI, 18.3 to 36.5 kg/m^2). After an overnight fast, RMR was assessed by indirect calorimetry and body composition by bioelectrical impedance analysis. Waist-to-hip ratio (WHR) was used to determine fat distribution. Results from linear regression analysis showed that most of the variance in RMR could be attributed to fat-free mass in women (R^2 = 0.54) and men (R^2 = 0.44), respectively. Fat mass explained an additional 3% and 2% of the variability in RMR in women and men, respectively. In stepwise multiple regression analysis, considering body composition and fat distribution, only fat-free mass and WHR were significant predictors of RMR in both sexes. In addition to fat-free mass, in women 6% and in men 8% of the variability in RMR was attributable to WHR. Grouping subjects according to their WHR, RMR, and RMR adjusted for fat-free mass and fat mass showed a significant increase with increasing WHR in both sexes. Results indicate that RMR not only depends on fat-free mass but also is influenced by fat mass, especially by fat distribution. These findings support our hypothesis of an elevated RMR with increasing abdominal body fat as a direct consequence of its greater metabolic activity.

IT IS WELL KNOWN that resting metabolic rate (RMR) is determined largely by fat-free mass, especially by the metabolic active organ mass (eg, brain, heart, liver, kidney).[1,2] As several investigations with young and middle aged people have shown, not only fat-free mass, but also fat mass has an influence on RMR.[3-5]

In vitro and in vivo studies have demonstrated regional variations in the metabolic activity of human adipose tissue. Metabolic activity of fat mass located in the abdominal, especially in the visceral region, has been found to be higher than in the gluteal-femoral region.[6-10] Whether these differences are associated in vivo with higher rates of energy expenditure in abdominal fat than in gluteal-femoral fat is unclear. Some investigations[11,12] have shown a relationship between fat distribution and RMR, whereas other studies[13-16] could not confirm these findings. At present, only a few investigations with small groups of young and middle-aged overweight subjects, especially females, have been carried out concerning this question. Studies with elderly subjects examining the association between RMR and body fat distribution are rare, although this age group is of particular interest because of the increase and shift in body fat mass resulting in a centralization of fat mass with increasing age.[17-20]

The aim of the present study was therefore to investigate the relationships between RMR, body composition, and fat distribution in a relatively large group of older women and men. We hypothesize the existence of increased RMR with increasing abdominal body fat as a direct consequence of its greater metabolic activity.

From the Institute of Nutritional Science, University of Giessen, Giessen, Germany.

Submitted October 11, 2000; accepted January 29, 2001.

Address reprint requests to Monika Neuhäuser-Berthold, PhD, Institute of Nutritional Science, University of Giessen, Goethestr 55, D-35390 Giessen, Germany.

0026-0495/01/5008-0005$35.00/0
doi:10.1053/meta.2001.24871

SUBJECTS AND METHODS

Study Design

The present examination is part of the longitudinal study on an aging population of Giessen, Germany (GISELA), in which the nutritional and health status of free-living elderly people has been investigated annually since 1994. Within the scope of the GISELA study anthropometrical data, body composition, RMR, and various biochemical parameters in blood as well as energy and nutrient intake of the study participants are examined. Measurements take place in the Institute of Nutritional Science in Giessen, Germany from June to November between 6 and 11 AM after an overnight fast. Subjects were familiarized with the experimental procedure, and written informed consent was obtained from each study participant. The study protocol was approved by the ethical committee of the faculty of medicine at the Justus-Liebig University, Giessen, Germany.

Subjects

Study participants were recruited by physicians, notices, senior citizens' meetings, and advertisements in local newspapers as well as by recruitment through subjects who had already been participants. Subjects had to be at least 60 years old, physically mobile, and available around Giessen on a long-term basis. During the first 4 years of the GISELA study (1994 through 1997), 320 women and 133 men participated in the investigations. The present report includes cross-sectional data from the baseline examinations of those participants with complete data on anthropometric measurements, body composition, and RMR. Data on subjects with hypothyroidism, hyperthyroidism, or edema, and subjects who took thyroid hormones or diuretics were excluded. Results from 164 women and 98 men remained for further analysis.

RMR

RMR was measured for 25 to 35 minutes at 1-minute intervals by respiratory gas analysis using a ventilated-hood system (Deltatrac MBM-100; Hoyer, Bremen, Germany) with the subjects in a supine position and completely at rest in a thermoneutral environment. Participants were allowed to acclimatize appropriately before the ventilated hood was placed over their head and measurements were started. Data collected during the initial 10 minutes of the measurements were discarded. RMR was calculated using the equation of Weir.[21]

Anthropometric Data and Body Composition

Body weight was measured with a calibrated digital scale (Seca, Vogel & Halke, Frankfurt, Germany) to the nearest 0.1 kg after shoes,

coats, and sweaters had been removed. From determined weight, 0.5 to 1.0 kg was subtracted for remaining clothes. Body height was obtained using a height measurement device integrated in the scale to the nearest 0.5 cm with the subjects in standing position without shoes. Waist-to-hip ratio (WHR) was used as a marker for body fat distribution. Waist and hip circumferences were measured with a tape to the nearest 1 cm in the upright position. The waist circumference was assessed as the smallest point between the lower rib and the iliac crest. The hip circumference was measured at the widest point in the greater trochanter and buttocks area. Body composition was investigated by using bioelectrical impedance analysis (Akern-RJL BIA 101/S; Data Input, Frankfurt, Germany) with the subjects in a supine position according to the manufacturers' instruction. Fat-free mass and fat mass were calculated by applying the equation of Deurenberg et al.[22]

Subjects' Characteristics

Further data, such as age, diseases, and medication, were obtained from the study participants by a questionnaire.

Statistical Analysis

Data were checked for normal distribution by the Kolmogorow-Smirnow test and for homogeneity of variance by the Levene test. Differences between women and men were analysed using the Student unpaired *t* test. Differences between WHR groups were examined by applying 1-way analysis of variance. To determine the associations between RMR and several measurements, Pearson product-moment correlations were calculated. Simple or multiple linear regression analyses were used to assess the effect of body composition and WHR on RMR. Regression equations are presented with probability (*P*), coefficient of multiple correlation (*R*), R^2, and standard error of the estimate (SEE). To control for variations in RMR attributable to differences in body composition, RMR was adjusted as delineated by Ravussin and Bogardus[23]: $RMR_{adjusted} = RMR_{group\ mean} + RMR_{measured} - RMR_{predicted}$. Intercepts and slopes of the regression line regarding RMR, fat-free mass, and fat mass did not differ between women and men. Therefore, predicted RMR was calculated for the whole study group using the following equation: RMR [kJ] = 1,636 + 85.6 fat-free mass [kg] + 22.7 fat mass [kg]. Statistical analyses were carried out with the SPSS/PC Statistical Package version 6.1.3 (SPSS Inc, Chicago, IL). Results are given as means and standard deviation (SD). Results were considered statistically significant if *P* values were $<.05$.

RESULTS

Age, anthropometric data, body composition, and RMR of the subjects are listed in Table 1.

Table 1. Age, Anthropometric Data, Body Composition, and RMR of the Subjects

	Women (n = 164)	Men (n = 98)
Age (yr)	67.7 ± 5.6	67.1 ± 5.2
Body height (cm)	159.5 ± 5.5	173.2 ± 6.5*
Body weight (kg)	67.5 ± 9.7	78.6 ± 9.3*
BMI (kg/m^2)	26.4 ± 3.7	26.2 ± 2.9
WHR	0.83 ± 0.06	0.95 ± 0.06*
Fat-free mass (kg)	37.2 ± 4.7	53.2 ± 5.3*
Fat mass (kg)	30.3 ± 6.0	25.4 ± 5.3*
Fat mass (%)	44.6 ± 3.7	32.1 ± 4.0*
RMR (kJ/d)	5502 ± 651	6785 ± 747*
$RMR_{adj\ FFM,FM}$† (kJ/d)	5973 ± 426	5996 ± 549

NOTE. Results are presented as means ± SD.
* Significant difference between women and men; $P < .001$.
† RMR adjusted for fat-free mass and fat mass.

Table 2. Pearson Correlation Coefficients Between RMR and Age, Anthropometric Data, and Body Composition

	Women (n = 164)		Men (n = 98)	
	RMR (kJ/d)	$RMR_{adj\ FFM,FM}$ (kJ/d)	RMR (kJ/d)	$RMR_{adj\ FFM,FM}$ (kJ/d)
Age (yr)	−0.16*	0.00	−0.23*	−0.19
BMI (kg/m^2)	0.59‡	0.01	0.53‡	0.13
WHR	0.36‡	0.26†	0.31†	0.26†
Fat-free mass (kg)	0.73‡	−0.03	0.66‡	−0.05
Fat mass (kg)	0.63‡	0.02	0.47‡	0.00
Fat mass (%)	0.21†	0.03	0.16	0.00

* $P < .05$.
† $P < .01$.
‡ $P < .001$.

RMR correlated significantly negatively with age and significantly positively with body mass index (BMI), WHR, fat-free mass, and fat mass in both sexes (Table 2). However, RMR adjusted for body composition showed a significantly positive correlation only with WHR in both women and men.

In linear regression analysis, most of the variance in RMR was accounted for by fat-free mass in women ($R^2 = 0.54$) and men ($R^2 = 0.44$), respectively (Table 3). Fat mass could explain an additional 3% and 2% of the variability in RMR in women and in men. In stepwise multiple regression analysis, considering body composition and fat distribution, fat-free mass and WHR proved to be significant predictors of RMR in both sexes. However, fat mass was not a significant determinant of RMR when fat-free mass and WHR were included in the regression model. In addition to fat-free mass, in women 6% and in men 8% of the variability in RMR could be attributed to WHR.

In Table 4, subjects were classified in tertiles according to WHR. In both sexes, BMI and fat mass increased significantly with increasing classes of WHR, whereas fat-free mass did not differ between WHR groups. RMR as well as RMR adjusted for fat-free mass and fat mass increased significantly with increasing WHR in both women and men.

DISCUSSION

The aim of the present investigation was to examine the relationship between RMR, body composition, and fat distribution in a relatively large sample of older women and men. WHR, an extremely suitable method for epidemiologic studies, was used for assessment of body fat distribution . This parameter correlates significantly positively with abdominal adipose tissue as well as with visceral fat mass and therefore is supposed to distinguish between abdominal and gluteal-femoral fat distribution.[24-26]

As expected, in our investigation most of the variance in RMR could be attributed to fat-free mass in both sexes. Besides fat-free mass, fat mass is also a significant determinant of RMR, explaining 2% to 3% of the variability in RMR. These results confirm the observations of studies with young and middle-aged people that fat mass accounts for 1% to 10% of the variance in RMR.[3-5] Elia[2] stated that RMR of adipose tissue is approximately 19 kJ/kg fat mass on average. This is approximately in accordance with the findings from our regression

Table 3. Results of Linear Regression Analysis for Prediction of RMR Considering Fat-Free Mass, Fat Mass, and WHR

	Linear Regression Equations	*P*	*R*	R^2	SEE
Women (n = 164)	RMR = 1,688 + 102 FFM	.000	.73	.54	444
	RMR = 1,737 + 78.6 FFM + 27.7 FM	.000	.76	.57	428
	RMR = −492 + 96.6 FFM + 2,876 WHR*	.000	.77	.60	415
Men (n = 98)	RMR = 1,862 + 92.5 FFM	.000	.66	.44	564
	RMR = 1,913 + 79.3 FFM + 25.7 FM	.000	.68	.46	554
	RMR = −1,485 + 91.2 FFM + 3,601 WHR*	.000	.72	.52	526

NOTE. RMR measured in kJ/d, fat-free mass (FFM) in kg, and fat mass (FM) in kg.

* Stepwise multiple regression analysis considering FFM, FM, and WHR.

equations (Table 2), which indicate an RMR of approximately 25 to 28 kJ/kg fat mass. In addition, our results clearly show that there are regional variations in the RMR of fat mass and that fat distribution has a more important influence on RMR than fat mass itself. RMR increased with increasing abdominal fat mass independent of body composition. These results confirm our hypothesis that abdominal fat mass has a higher RMR than fat mass located in the gluteal-femoral region. The higher RMR may be attributable to the special metabolic characteristics of the abdominal, especially the visceral adipose tissue. Visceral fat mass is marked by increased blood flow, greater responsiveness to norepinephrine, and lower sensitivity to the antilipolytic effect of insulin as well as increased sympathetic nervous system activity and a higher rate of lipolysis compared with subcutaneous adipose tissue.[6-10] These characteristics not only lead to a higher RMR, but they play also a role in the development of several metabolic complications (eg, hyperlipidemia, hypertension, glucose intolerance, insulin resistance) in individuals with abdominal obesity.[24,27,28]

Several in vivo studies concerning the relationship between RMR and fat distribution have been carried out. However, results are not consistent, regardless of whether fat distribution was determined indirectly by WHR or directly using computed tomography or magnetic resonance imaging. Findings from our investigation mostly confirm those of Weststrate et al[11] and Armellini et al.[12] Weststrate et al[11] studied 32 premenopausal obese women and subdivided them into 3 groups (gluteal-femoral, intermediate, and abdominal) according to WHR. RMR adjusted for fat-free mass, fat mass, and age was significantly higher in the abdominal group than in the gluteal-femoral and intermediate groups. Armellini et al[12] proved in a recent investigation of 55 premenopausal and 19 postmenopausal obese women and 21 obese men, aged 18 to 70 years, that visceral adipose tissue determined by computed tomography is a significant predictor of RMR in all study groups. In contrast, in an earlier study by Armellini et al[14] focusing on a smaller group of premenopausal obese women (n = 27), neither WHR nor visceral fat, as determined by computed tomography, was related to RMR, adjusted for fat-free mass, fat mass, and age. In other investigations with a limited number (15 to 34 subjects) of premenopausal obese women, RMR, adjusted for body composition, also did not differ between abdominal and gluteal-femoral obese subjects.[13,15,16] Nicklas et al[29] also showed that RMR adjusted for fat-free mass did not correlate with WHR or with visceral fat mass, as assessed by computed tomography in 29 obese women aged 52 to 72 years. However, they found a significantly positive correlation between waist circumference and RMR, adjusted for fat-free mass. Leenen et al[30] could not prove a relationship between WHR and RMR, adjusted for fat-free mass, in 40 obese women and 38 obese men aged 25 to 51 years. However, visceral body fat as evaluated by magnetic resonance imaging correlated significantly positively with RMR adjusted for fat-free mass in women but not in men.

Table 4. Age, Anthropometric Data, Body Composition, and RMR of the Subjects Categorized According to WHR

	WHR, Women			WHR, Men		
	<0.810 (n = 54)	0.810-0.850 (n = 55)	>0.850 (n = 54)	<0.928 (n = 32)	0.928-0.971 (n = 33)	>0.971 (n = 32)
Age (yr)	66.9 ± 4.6	67.3 ± 5.9	68.9 ± 6.1	66.5 ± 4.7	67.1 ± 4.3	67.8 ± 6.5
BMI (kg/m^2)	25.3 ± 3.6‖	26.4 ± 3.6	27.5 ± 3.6	24.5 ± 2.1*,¶	25.8 ± 2.2¶	28.5 ± 2.9
Fat-free mass (kg)	36.6 ± 4.6	37.3 ± 4.9	37.6 ± 4.5	53.3 ± 5.8	52.1 ± 4.3	54.4 ± 5.7
Fat mass (kg)	28.1 ± 5.7*,¶	30.3 ± 5.8	32.4 ± 5.8	22.3 ± 4.9*,¶	24.4 ± 3.4¶	29.6 ± 4.8
Fat mass (%)	43.1 ± 4.1*,¶	44.6 ± 3.3§	46.1 ± 3.1	29.3 ± 4.0†,¶	31.9 ± 3.0¶	35.1 ± 2.8
RMR (kJ/d)	5,298 ± 558‖	5,460 ± 614§	5,731 ± 704	6,586 ± 643‖	6,596 ± 545‖	7,178 ± 887
$RMR_{adj\ FFM,FM}$ (kJ/d)	5,873 ± 327‖	5,921 ± 432§	6,119 ± 473	5,862 ± 540§	5,925 ± 441§	6,190 ± 617

NOTE. Results are presented as means ± SD.

* Significantly different from WHR group 2, $P < .05$.

† Significantly different from WHR group 2, $P < .01$.

‡ Significantly different from WHR group 2, $P < .001$.

§ Significantly different from WHR group 3, $P < .05$.

‖ Significantly different from WHR group 3, $P < .01$.

¶ Significantly different from WHR group 3, $P < .001$.

The controversial results of these investigations may be attributable to the small size of the study sample as well as to the homogeneous nature of the study groups (especially premenopausal obese women). The influence of fat mass and fat distribution, respectively, on RMR is relatively small compared with the effect of fat-free mass. Therefore, a relatively large sample size with a wide range of WHR is necessary to prove that RMR is affected by fat distribution. At present, our investigation is the largest one examining the relationship between body fat distribution and RMR. Our data clearly indicate that RMR is influenced by fat mass, especially by fat distribution. We could prove this influence, probably because we investigated an appropriately large group of subjects with a wide range of body fat distribution (WHR 0.7 to 1.1). Furthermore, it is possible that the effects of body fat distribution are more pronounced in older people because of the increase in body fat as well as the shift of fat mass to the abdominal region with increasing age.[17-20] In summary, our results support the hypothesis of an increased RMR with increasing abdominal body fat as a direct consequence of its greater metabolic activity.

REFERENCES

1. Holliday MA: Metabolic rate and organ size during growth from infancy to maturity and during late gestation and early infancy. Pediatrics 47:169-179, 1971
2. Elia M: Organ and tissue contribution to metabolic rate, in Kinney JM, Tucker HN (eds): Energy Metabolism. Tissue Determinants and Cellular Corollaries. New York, NY, Raven, 1992, pp 61-79
3. Nelson KM, Weinsier RL, Long CL, et al: Prediction of resting energy expenditure from fat-free mass and fat mass. Am J Clin Nutr 56:848-856, 1992
4. Tataranni PA, Ravussin E: Variability in metabolic rate: biological sites of regulation. Int J Obes 19:S102-S106, 1995 (suppl)
5. Sparti A, DeLany JP, Bretonne JA de la, et al: Relationship between resting metabolic rate and the composition of the fat-free mass. Metabolism 46:1225-1230, 1997
6. Arner P, Engfeldt P, Lithell H: Site differences in the basal metabolism of subcutaneous fat in obese women. J Clin Endocrinol Metab 53:948-952, 1981
7. Arner P: Differences in lipolysis between human subcutaneous and omental adipose tissues. Ann Med 27:435-438, 1995
8. Jones PP, Snitker S, Skinner JS, et al: Gender differences in muscle sympathetic nerve activity: Effect of body fat distribution. Am J Physiol 270:E363-E366, 1996
9. Hoffstedt J, Arner P, Hellers G, et al: Variation in adrenergic regulation of lipolysis between omental and subcutaneous adipocytes from obese and non-obese men. J Lipid Res 38:795-804, 1997
10. Millet L, Barbe P, Lafontan M, et al: Catecholamine effects on lipolysis and blood flow in human abdominal and femoral adipose tissue. J Appl Physiol 85:181-188, 1998
11. Weststrate JA, Dekker J, Stoel M, et al: Resting energy expenditure in women: impact of obesity and body-fat distribution. Metabolism 39:11-17, 1990
12. Armellini F, Zamboni M, Mino A, et al: Postabsorptive resting metabolic rate and thermic effect of food in relation to body composition and adipose tissue distribution. Metabolism 49:6-10, 2000
13. Besten C den, Vansant G, Weststrate JA, et al: Resting metabolic rate and diet-induced thermogenesis in abdominal and glutealfemoral obese women before and after weight reduction. Am J Clin Nutr 47:840-847, 1988
14. Armellini F, Robbi R, Zamboni M, et al: Resting metabolic rate, body-fat distribution, and visceral fat in obese women. Am J Clin Nutr 56:981-987, 1992
15. Buemann B, Astrup A, Quaade F, et al: 24-hour energy expenditure and substrate oxidation rates are unaffected by body fat distribution in obese women. Metabolism 43:109-113, 1994
16. Van Gaal LF, Vanuytsel JL, Vansant GA, et al: Sex hormones, body fat distribution, resting metabolic rate and glucose-induced thermogenesis in premenopausal obese women. Int J Obes 18:333-338, 1994
17. Forbes GB, Reina JC: Adult lean body mass declines with age: some longitudinal observations. Metabolism 19:653-663, 1970
18. Borkan GA, Norris AH: Fat redistribution and the changing body dimensions of the adult male. Hum Biol 49:495-514, 1977
19. Enzi G, Gasparo M, Biondetti PR, et al: Subcutaneous and visceral fat distribution according to sex, age, and overweight, evaluated by computed tomography. Am J Clin Nutr 44:739-746, 1986
20. Stevens J, Knapp RG, Keil JE, et al: Changes in body weight and girths in black and white adults studied over a 25 year interval. Int J Obes 15:803-808, 1991
21. Weir JB de V: New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 109:1-9, 1949
22. Deurenberg P, van der Kooy K, Leenen R, et al: Sex and age specific prediction formulas for estimating body composition from bioelectrical impedance: A cross-validation study. Int J Obes 15:17-25, 1991
23. Ravussin E, Bogardus C: Relationship of genetics, age, and physical fitness to daily energy expenditure and fuel utilization. Am J Clin Nutr 49:968-975, 1989
24. Bouchard C, Bray GA, Hubbard VS: Basic and clinical aspects of regional fat distribution. Am J Clin Nutr 52:946-950, 1990
25. Pouliot MC, Després JP, Lemieux S, et al: Waist circumference and abdominal sagittal diameter: best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women Am J Cardiol 73:460-468, 1994
26. Cefalu WT, Wang ZQ, Werbel S, et al: Contribution of visceral fat mass to the insulin resistance of aging. Metabolism 44:954-959, 1995
27. Björntorp P: Regional patterns of fat distribution. Ann Intern Med 103:994-995, 1985
28. Björntorp P: Classification of obese patients and complications related to the distribution of surplus fat. Am J Clin Nutr 45:1120-1126, 1987
29. Nicklas BJ, Goldberg AP, Bunyard LB, et al: Visceral adiposity is associated with increased lipid oxidation in obese, postmenopausal women. Am J Clin Nutr 62:918-922, 1995
30. Leenen R, Van der Kooy K, Deurenberg P, et al: Visceral fat accumulation in obese subjects: Relation to energy expenditure and response to weight loss. Am J Physiol 263:E913-E919, 1992