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ORIGINAL CONTRIBUTION

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A new equation especially developed for predicting resting metabolic rate in the elderly for easy use in practice

Summary *Background* Equations published in the literature for predicting resting metabolic rate (RMR) in older individuals were exclusively derived from studies with small samples of this age group. *Aim* of the present investigation was therefore to compare the measured RMR of a relatively large group of older females and males with values for RMR calculated from the most commonly used WHO [1] equations. Furthermore, on the basis of the data collected by our study group a new equation for calculating RMR in the elderly was to be developed. Variables used in this equation should be easily and exactly determinable in practice. *Subjects and methods* RMR was measured by indirect calorimetry after an overnight fast in a sample of 179 female (age 67.8 ± 5.7 y, BMI 26.4 ± 3.7 kg/m^2) and 107 male (age 66.9 ± 5.1 y, BMI 26.3 ± 3.1 kg/m^2) participants in the longitudinal study on nutrition and health status in an aging population of Giessen, Germany. The subjects were at least 60 years old, did not suffer from thyroid dysfunction, and were not taking thyroid hormones. Stepwise multiple linear regression analysis was used to estimate the best predictors of RMR. *Results* In females there was no significant difference between our measured RMR (5504 ± 653 kJ/d) and RMR predicted with the WHO [1] equation (5458 ± 440 kJ/d), whereas in males measured RMR (6831 ± 779 kJ/d) was significantly higher than calculated RMR (6490 ± 550 kJ/d). Results of regression analysis, considering body weight, body height, age, and sex, showed that RMR is best calculated by the following equation: RMR [kJ/d] = 3169 + 50.0 · body weight [kg] – 15.3 · age [y] + 746 · sex [female = 0, male = 1]. The variables of this equation accounted for 74 % (R^2) of the variance in RMR and predicted RMR within ± 486 kJ/d (SEE). *Conclusion* On the basis of the data determined in a large group of older individuals, we offer a new equation for calculating RMR in the elderly that is both easy and accurate for use in practice.

Key words Resting metabolic rate – predictive equation – elderly

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Introduction

The principle of relying on estimates of energy expenditure, rather than energy intake from dietary surveys, has been adopted to estimate the energy requirement of adults [1–3]. Because resting metabolic rate (RMR) constitutes between 60 and 75 % of total energy expenditure, it forms the basis of this factorial approach. Energy expenditure of different age and sex groups is currently estimated as a multiple of RMR, and RMR is calculated from predictive equations using reference standards for body weight and body height. Equations published in the literature for predicting RMR in older individuals were exclusively derived from studies with small samples of this age group [1, 4–8]. The national and most of the international recommendations for energy intake [1–3] are based on data for RMR calculated with the age and sex specific equations from the WHO [1]. The WHO [1] equations (Table 1) were developed by Schofield et al.

Table 1 WHO equations for estimating RMR in the elderly (≥60 years) [1, 9]

	WHO equations	R	R^2	SEE	n
Females	RMR = 2491 + 43.9 · BW	0.74	0.54	451	38
Males	RMR = 2037 + 56.5 · BW	0.79	0.62	619	50

RMR resting metabolic rate (kJ/d); *BW* body weight (kg)

[9] on the basis of 114 published studies of RMR, representing data of about altogether 7,000 subjects from 23 countries. However, the WHO [1] equations for subjects who are older than 60 years of age rely solely on RMR data of a small sample of this age group, consisting of only 38 elderly women and 50 elderly men. The main purpose of our investigation was therefore to develop a new equation for calculating RMR in the elderly on basis of the data determined in a group of older subjects which constitutes the largest group up to now. All the variables included in this equation should be easily and exactly determinable in practice. Furthermore, the age specific WHO [1] equations should be cross-validated by comparing measured RMR in our study with values for RMR calculated with the WHO equations.

Subjects and methods

Study design

The present investigation 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 have been investigated at yearly intervals since 1994. Within the scope of the GISELA study, many points are considered including anthropometrical data, body composition, and RMR of the study participants. Measurements take place at the Institute of Nutritional Science in Giessen, Germany from June to November between 6:00 and 11:00 a. m. after an overnight fast. Subjects were familiarized with the experimental procedure and a 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 had to be at least 60 years of age, physically mobile, and available around Giessen on a long-term basis. Subjects were recruited by physicians, notices, senior citizens' meetings, advertisements in local newspapers, and by recruitment through subjects who had already been participants. During the first five years of the GISELA study (1994–1998), a total of 345 female and 144 male Germans took part in the investigations. The present report includes cross-sectional data from the baseline examination of those 424 participants with complete data on anthropometrical measurements, body composition, and RMR. Data of 138 subjects who suffered from hypothyroidism, hyperthyroidism, edema, took thyroid hormones, or diuretics were excluded because these diseases or medications may influence RMR or body composition measurement. The results from 179 females and 107 males were used for further analysis.

Resting metabolic rate

RMR was determined by an open-circuit indirect calorimeter (Deltatrac™ MBM-100, Hoyer, Bremen, Germany). Oxygen uptake and carbon dioxide production were measured for 25–35 min at one-minute intervals by respiratory gas analysis using a ventilated-hood system with the subjects in a supine position and completely at rest in a thermoneutral environment. Calibrations of the gas analyzer were performed immediately before each measurement. Participants were allowed to acclimatize appropriately before measurements were started. Data collected during the initial 10 min of the measurements were discarded. RMR was calculated by using the equation derived by Weir [10]. The Deltatrac metabolic monitor was shown to be accurate within 3% for RMR [11]. The mean coefficient of variation for measured RMR in our laboratory was 1.05%.

Anthropometrical data and body composition

Body weight was determined 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 measured weight 0.5 to 1.0 kg was subtracted for remaining clothes. Body height was obtained by a height measurement device integrated in the scale to the nearest 0.5 cm with the subjects in standing position without shoes. The 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 an upright position. The waist circumference was assessed at 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 a single frequency (50 kHz) bioelectrical impedance analyzer (Akern-RJL BIA 101/S, Data Input, Frankfurt, Germany) with the subjects in a supine position according to the manufacturers' instruction. Coefficient of variation for measured body impedance in our laboratory was 1.15%. Fat-free mass and fat mass were calculated by applying the equation derived from the cross-validation study (Akern-RJL BIA 101 vs. underwater weighing) from Deurenberg et al. [12].

Subjects' characteristics

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

Statistical analysis

Statistical analyses were carried out with the SPSS/PC Statistical Package version 6.1.3 (SPSS Inc, Chicago, USA). Data were checked concerning normal distribution by the Kolmogorow-Smirnow test. Differences between measured RMR and RMR predicted with the WHO equations were examined by Wilcoxon signed-ranks test for paired samples. To determine the associations between measured and predicted RMR Spearman's rank correlations as well as Bland-Altman plots [13] were used. Stepwise multiple linear regression analysis was used to estimate the best predictors of RMR. At first, in a physiological model potential physiological predictors of RMR were considered. After that, the influence of variables which are easily and exactly measurable in practice was investigated in a practical model. Regression equations are presented together with probability (P), coefficient of multiple correlation (R), R^2 and standard error of the estimate (SEE). Results are given as mean and standard deviation (SD). Results were considered statistically significant if P values were less than 0.05.

Results

The study group comprised 179 women and 107 men and is characterized in Table 2. The subjects' age ranged from 60 to 85 years but most of the females (68.7 %) and males (78.5 %) were between 60 and 70 years old. The mean measured RMR was 5504 kJ/d in females and 6831 kJ/d in males (Table 3). There was a significant positive correlation between measured RMR and RMR predicted with the WHO equations in women (R = 0.75, P < 0.001) and men (R = 0.61, P < 0.001). Fig. 1 shows that, in both

Table 2 Characteristics of the subjects (mean ± SD)

	Females (n = 179)	Males (n = 107)
Age (y)	67.8 ± 5.7	66.9 ± 5.1
Body height (cm)	159.9 ± 5.5	173.0 ± 6.5
Body weight (kg)	67.5 ± 10.0	78.8 ± 9.7
BMI (kg/m²)	26.4 ± 3.7	26.3 ± 3.1
WHR	0.84 ± 0.06	0.95 ± 0.06
Fat-free mass (kg)	37.2 ± 4.8	53.3 ± 5.3
Fat mass (kg)	30.3 ± 6.1	25.5 ± 5.8
Fat mass (%)	44.6 ± 3.6	32.1 ± 4.2
Smokers (%)	11.2	4.2

Table 3 Measured RMR compared to RMR predicted with the WHO [1] equations (mean ± SD)

	Females (n = 179)	Males (n = 107)
$RMR_{measured}$ (kJ/d)	5504 ± 653	6831 ± 779
$RMR_{predicted}$ (kJ/d)	5458 ± 440	6490 ± 550
Difference (%)	0.8 ± 7.8	5.3 ± 8.8[a]

[a] Significant difference between measured and predicted RMR: P < 0.05

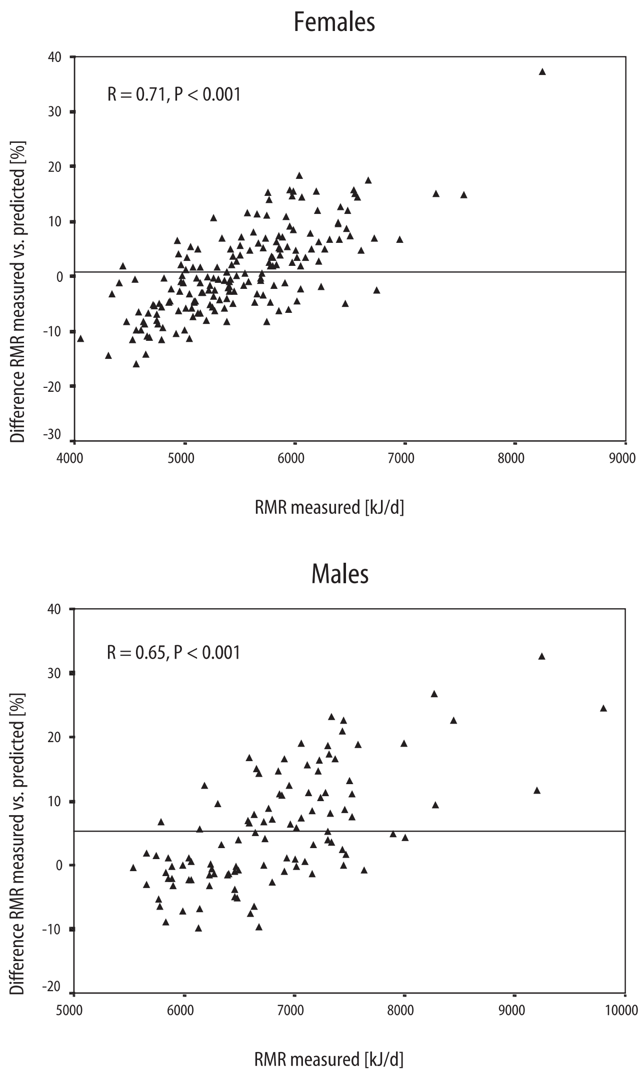

Fig. 1 Bland-Altman plots for comparison measured RMR with RMR predicted with the WHO equations [1, 13].

men and women, the difference between measured and predicted RMR depends on the absolute values for measured RMR. On average, there was no significant difference in females between measured RMR and RMR predicted with the WHO equation, whereas in males measured RMR was slightly but significantly higher than calculated RMR (Table 3). When we compared measured to predicted RMR in different age and BMI groups separately (Tables 4 and 5), we did not observe any significant differences between measured and predicted RMR in women either. In men, measured and predicted RMR differed significantly by 3.8 % to 8.0 % depending on the respective age groups and by 3.8 % to 6.2 % in the different BMI groups.

The results of regression analysis for calculation of RMR are shown in Table 6. First, the potential physiological predictors of RMR (fat-free mass, fat mass, WHR, age, and sex) were considered in multiple regression analysis. Fat-free mass was the strongest predictor of RMR explaining 72 % of the total variance in RMR. In addition, fat mass, WHR, and age proved to be significant predictors of RMR, whereas sex had no influence on RMR in this regression model. All together the parameters of this physiological equation explained 76 % of the variability in RMR. Afterwards the influence of variables which can be easily and exactly measured in practice (body weight, body height, age, and sex) on RMR was comprehensively investigated in multiple regression analysis. Results showed that RMR is best calculated with an equation including body weight, sex, and age. These variables accounted for 74 % of the variance in RMR.

Table 4 Measured RMR compared to RMR predicted with the WHO [1] equations for separate age groups (mean ± SD)

	Age (y)			
	< 65	65–69	70–74	≥75
Females	(n = 65)	(n = 50)	(n = 41)	(n = 23)
$RMR_{measured}$ (kJ/d)	5624 ± 670	5548 ± 649	5337 ± 563	5369 ± 720
$RMR_{predicted}$ (kJ/d)	5529 ± 422	5476 ± 475	5350 ± 398	5412 ± 463
Difference (%)	1.7 ± 8.9	1.2 ± 6.1	−0.3 ± 7.2	−0.9 ± 9.1
Males	(n = 40)	(n = 38)	(n = 22)	(n = 7)
$RMR_{measured}$ (kJ/d)	6978 ± 746	6762 ± 881	6876 ± 645	6218 ± 492
$RMR_{predicted}$ (kJ/d)	6477 ± 561	6507 ± 601	6537 ± 491	6314 ± 427
Difference (%)	8.0 ± 9.7[c]	3.8 ± 7.9[a]	5.3 ± 8.2[b]	−1.5 ± 5.3

[a, b, c] Significant difference between measured and predicted RMR: [a] = $P < 0.05$, [b] = $P < 0.01$, [c] = $P < 0.001$

Table 5 Measured RMR compared to RMR predicted with the WHO [1] equations for separate BMI groups (mean ± SD)

	BMI (kg/m^2)			
	< 24.0	24.0–25.9	26.0–27.9	≥28.0
Females	(n = 51)	(n = 32)	(n = 44)	(n = 52)
$RMR_{measured}$ (kJ/d)	5167 ± 501	5305 ± 486	5399 ± 536	6047 ± 641
$RMR_{predicted}$ (kJ/d)	5044 ± 272	5303 ± 187	5486 ± 226	5936 ± 342
Difference (%)	2.4 ± 7.5	0.0 ± 7.3	−1.7 ± 7.2	1.8 ± 8.6
Males	(n = 25)	(n = 29)	(n = 27)	(n = 26)
$RMR_{measured}$ (kJ/d)	6349 ± 570	6579 ± 507	6883 ± 677	7519 ± 835
$RMR_{predicted}$ (kJ/d)	5984 ± 313	6259 ± 274	6635 ± 397	7082 ± 486
Difference (%)	6.2 ± 9.1[b]	5.2 ± 8.2[b]	3.8 ± 8.5[a]	6.2 ± 9.8[b]

[a, b] Significant difference between measured and predicted RMR: [a] = $P < 0.05$, [b] = $P < 0.01$

Discussion

In the present investigation we determined RMR in 286 free-living elderly German subjects. To the best of our knowledge this is the largest group of older subjects investigated concerning RMR. Within this study, the widely used WHO [1] equations for calculating RMR in the elderly were cross-validated first. Results show that significant differences between our measured and predicted RMR occur in men but not in women. Whereas the difference in the total male group was only moderate on average (5.3 %), the differences were in some cases more pronounced when the various age or BMI groups

Table 6 Results of stepwise multiple linear regression analysis for prediction of RMR

Physiological model: Considering fat-free mass, fat mass, WHR, age, and sex	P	R	R^2	SEE
RMR = 2227 + 87.2 · FFM	0.000	0.85	0.72	508
RMR = 1556 + 86.9 · FFM + 24.0 · FM	0.000	0.86	0.74	485
RMR = 311 + 75.5 · FFM + 21.7 · FM + 2053 · WHR	0.000	0.87	0.76	469
RMR = 985 + 73.3 · FFM + 22.1 · FM + 2236 · WHR – 11.1 · A	0.000	0.87	0.76	466
Practical model: Considering body weight, body height, age, and sex	**P**	**R**	**R^2**	**SEE**
RMR = 1238 + 66.4 · BW	0.000	0.79	0.62	585
RMR = 2078 + 50.8 · BW + 751 · S	0.000	0.86	0.73	492
RMR = 3169 + 50.0 · BW + 746 · S – 15.3 · A	0.000	0.86	0.74	486

RMR resting metabolic rate (kJ/d); *FFM* fat-free mass (kg); *FM* fat mass (kg); *A* age (y); *S* sex (female = 0, male = 1); *BW* body weight (kg) were considered separately. This is in accordance with the findings of two earlier studies by Arciero et al. [14, 15] who cross-validated the WHO equations in a group of 75 female and 89 male Americans aged between 50 and 81. While the authors found no significant difference between measured and predicted RMR in females, measured RMR in males was about 4% higher than RMR predicted with the WHO equation.

In the literature various other equations for calculating RMR are available [4–8]. However, as in the WHO equations, the predictive equations for the elderly were also exclusively derived from studies with small samples of this age group. For example, the Harris-Benedict [4] equation, the most common equation used in the clinical setting, was based on RMR data of a wide age range, but included only six women and three men who were over 60. Therefore, on the basis of our large study group we wanted to develop a new equation for calculating RMR in the elderly. For this the predictive potential of several physiological determinants of RMR was examined first. As expected and in agreement with earlier studies [14–18], most of the variance (72%) in RMR could be attributed to fat-free mass in our investigation. Besides fat-free mass, fat mass as well as body fat distribution were also significant determinants of RMR explaining 2% of the variability in RMR in each case. These results demonstrate that fat mass has an influence on RMR, and that there are regional variations in the RMR of fat mass. RMR increased with increasing abdominal fat mass independent of body composition, indicating that abdominal fat mass has a higher RMR compared with fat mass located in the gluteal-femoral region. The higher RMR may be due to the special metabolic characteristics of the abdominal, especially the visceral adipose tissue and has already been discussed elsewhere [19–22]. In the physiological regression model, age proved to be an additional significant predictor of RMR. This means that there is a decrease in RMR with aging that is not explained by changes in body composition, implying that the metabolic rate of various tissues declines in the course of aging. However, at present it is not clear whether this decrease is caused by structural changes of organs or whether there is a reduction in the oxidative capacity of individual organs and tissues [23, 24]. All together the physiological regression model, including body composition, fat distribution, and age, accounts for 76% of the variance in RMR and predicts RMR within ± 466 kJ/d.

In practice it is not always possible to determine body composition of the subjects. Furthermore values for fat-free mass and fat mass depend considerably on the assessment method as well as the predictive equation used [25–27]. Therefore the major purpose of our investigation was to develop an equation exclusively including variables which were easily and exactly determinable in practice. In this practical model body weight, body height, age, and sex were considered. Results of the regression analysis show that in this case most of the variance in RMR might be due to body weight (62%). This observation may be explained by the fact that body weight is strongly correlated with the metabolic active fat-free mass (females: $R = 0.88$, $P < 0.001$; males: $R = 0.85$, $P < 0.001$). Apart from body weight, sex was an additional significant determinant on RMR. Women show a lower relative proportion of fat-free mass and a corresponding higher proportion of fat mass to body weight than men. Probably the sex variable takes these differences in body composition between women and men into account. The observation that in the physiological model sex was not a significant determinant of RMR when considering fat-free mass and fat mass supports this speculation. As in the physiological model, age proved to be a significant predictor of RMR as it was in the practical model. As a total, variables of the practical equation account for 74% of the variance in RMR and predict RMR within ± 486 kJ/d. Thus, the explained proportion of variance in RMR calculated by the practical equation is relatively high and only negligibly lower (2%) compared to the physiological equation indicating that this model is well suited for predicting RMR in the elderly.

Apart from this, our proposed practical equation is more suitable for calculating RMR in the elderly than the WHO [1] equations for different reasons. On the one hand, in our equation the explained proportion of variance in RMR is higher for both men and women and in men the error of estimate is lower compared to the WHO equations. On the other hand, our practical equation was based on RMR data collected from a considerably larger and a more homogeneous sample of elderly subjects. While none of our study participants suffered from diseases or took medications that may influence RMR, Schofield et al. [9] did not consider diseases or medications in their analysis. In our investigation RMR was measured under constant standardized experimental conditions. By contrast, the 114 studies evaluated by Schofield et al. [9] were conducted under different experimental conditions with different types of devices and different procedures and covered a very large period of time (1914–1983). Furthermore, our results clearly show that, even within the elderly age group, age still has an influence on RMR. Therefore age has to be considered when calculating RMR in the elderly. In contrast, the WHO equations for subjects who were older than 60 years of age did not allow for age.

However, it is important to note some limitations associated with the predictive equation developed in the present investigation. Our study sample did not include volunteers who were older than 85 years of age. Therefore we have no information about development of RMR in very old age. Furthermore our equation was specific to German subjects, because ethnic differences in RMR exist. Subjects from North Europe and North America show higher values of RMR than Asiatic subjects [9, 28]. Therefore our equation should not be generalized to subjects of older age groups or other ethnic backgrounds.

In summary, relying on RMR data determined in a study considering the largest group of older individuals thus far, we offer a new equation for calculating RMR in the elderly, which is both easy and accurate for use in practice.

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