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BODY CIRCUMFERENCES ARE PREDICTORS OF WEIGHT ADJUSTED RESTING ENERGY EXPENDITURE IN OLDER PEOPLE

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Abstract: *Objective:* To evaluate predictors of resting energy expenditure (REE) in older people which are more comfortable for them than indirect calorimetry and which are suitable for field studies. *Design:* Cross-sectional study. *Setting:* Department of Human Biology, Kiel University. *Participants:* 100 (51 males, 49 females) healthy independently-living normal-weight (BMI, males 26.0±2.67 kg/m², females 25.0±3.29 kg/m²) Germans, aged 60-83 years. *Measurements:* REE, body composition, anthropometry, peak expiratory flow rate (PEF), and physical activity level were determined using indirect calorimetry, bioimpedance analysis, anthropometrics, peak-flow-meter, and standardized questionnaire, respectively. Stepwise linear multiple regression analysis was performed with REE or weight adjusted REE as dependent variables. Independent variables were body height, weight, body mass index (BMI), waist circumference, abdomen circumference, hip circumference, waist-to-hip ratio (WHR), lean body mass (LBM), PEF, and physical activity level. *Results:* The only significant predictor of REE was LBM in males and BMI in females. Trunk circumferences emerged as strong predictors of weight adjusted REE. Abdomen circumference and hip circumference explained in males and females 69% and 70% of variation in adjusted REE, respectively. Weaker predictors were LBM in males (R^2 increased from 0.69 to 0.80) as well as body height and BMI in females (R^2 increased from 0.70 to 0.91). Waist circumference, WHR, physical activity level, and PEF were no significant determinants of adjusted REE. *Conclusion:* These findings demonstrate that trunk circumferences, but not WHR, are very strong predictors of weight adjusted REE in non-geriatric older people. This implies that the sex-specific use of abdomen or hip circumference in combination with LBM or body height and BMI seems to be well sufficient to predict weight adjusted REE in the aged. These measures might also be of clinical relevance, because they are more comfortable for older sick people than indirect calorimetry. Further studies are needed to test the applicability of the prediction equations to frail older populations.

Key words: Resting energy expenditure, hip circumference, abdomen circumference, waist circumference.

Introduction

Resting energy expenditure (REE) is the main component of total energy expenditure in sedentary persons (1). The measurement of REE in older people is crucial for determining their energy needs with the objective to ensure an adequate nutrition. The REE is measured with indirect calorimetry, but this is cumbersome and expensive. Also, several strict pretest and measurement conditions have to be met. Pretest conditions include overnight fasting and absence of physical activity (2) which are uncomfortable to the subjects, in particular to sick persons, and sometimes difficult to maintain. In addition, elderly people have difficulties with breathing at the various indirect calorimetric devices (3, 4). Besides indirect calorimetry, REE can also be predicted from lean body mass using bioelectrical impedance analysis (BIA). This is often practised in field studies and easier to handle, although population specific algorithms have to be used and hydration status should be carefully controlled (5). Also, there exist several equations to estimate REE in elderly people, based on anthropometric measurements of the subjects including weight and body height (e.g., 6-8). Other anthropometric measurements such as body circumferences might also be informative to predict REE. However, there is few literature assessing trunk circumferences as determinants of REE (9, 10). In particular, data on the significance of circumferences for predicting REE in older people are very scarce (11).

In addition, there are further non-anthropometric parameters which might be useful for predicting REE. In this context, previous studies dealt with the influence of the physical activity level or functional status on REE and body composition in older subjects (12-15). Another parameter easily to obtain is the peak expiratory flow rate, which can be regarded as a measurement of thoracic volume (16). The combination of anthropometric measurements, body composition, peak expiratory flow rate, and physical activity level possibly permits a more practical approach to predict the REE in elderly people. Therefore, the purpose of this study was to evaluate such parameters for predicting REE, because they are more comfortable for healthy and sick older subjects and are suitable in field studies.

Subjects and Methods

Subjects

Subjects were 100 healthy elderly volunteers (51 males and 49 females) of German origin, aged 60 to 83 years. They resided in the environments of Kiel, northern Germany.

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Inclusion criteria were age ≥ 60 years and living independently in own households. Exclusion criteria were wearing a pacemaker, amputations of limbs, presence of thyroid and renal diseases, insulin-dependent diabetes mellitus, having oedema, taking diuretics or other medicaments that might impact the metabolic rate or body composition. The study protocol was approved by the local ethics committee at the faculty of medicine at the University of Kiel. All subjects gave their written informed consent before participating in the study.

Resting energy expenditure

The REE was determined by indirect calorimetry using the BIOPAC MP35 unit (BIOPAC Systems Inc., Goleta, CA, USA; software, BSL PRO, Santa Barbara, California, USA). This indirect calorimeter contains a pneumotachygraph that is connected via tubing and a non-rebreathing T-valve to a gas analysis system (GASSYS2-EA) which measures O_2 and CO_2 concentrations in expired air. Pretest conditions for the subjects were an overnight fast, abstaining from alcohol consumption for 24 hours and from physical activity for 12 hours. After calibration of the device with room air (20-27°C), the REE was measured between 8:00 and 10:00 a.m. After resting for ten minutes, the subjects were lying awake and wearing a nose clip while breathing through a mouthpiece and a bacterial filter into the device. The following parameters were recorded: fractions of O_2 (%) and CO_2 (%) in the expired air, airflow through the pneumotachygraph (L/sec), VO_2 (L/min), VCO_2 (L/min), and RQ. Measurements were recorded for ten minutes. The first five minutes were discarded. The following five minutes were analyzed, assuming a constant RQ of 0.85. The REE was computed from the following equation (17): REE (kcal/24h) = 1027.327 + 309.524 x sex + 863.761 x VO_2, where VO_2 is given in L/min and sex is coded as 1 for males or 0 for females. The REE was adjusted to body weight as kcal/kg/24h.

Anthropometry and body composition

With an anthropometer the body height was measured to the nearest 0.1 cm without shoes. Weight was determined on a digital scale (TBF-538, Tanita Corp., Tokyo, Japan) to the nearest 0.1 kg while the subject wore light clothes and without shoes. Weight (kg) / height² (m²) was calculated as body mass index (BMI). Waist circumference (no. 62 of Martin), abdomen circumference (no. 62.1), and hip circumference (no. 64.1) were measured in the standing position to the nearest 0.1 cm, as described in Knussmann (18), using a tape measure. The waist-to-hip ratio (WHR) was calculated as waist circumference (cm) divided by hip circumference (cm). Lean body mass was estimated using a tetrapolar whole-body bioelectrical impedance analyzer (Nutriguard-M, Data Input Company, Darmstadt, Germany) and Nutri-Plus 5.1 software (19).

Peak expiratory flow rate

The Vitalograph peak-flow-meter (Vitalograph Inc., Hamburg, Germany) was used to determine peak expiratory flow rate (PEF) in the participants. Subjects were instructed after a maximal inspiration to extend their maximal and fastest exhalation into the peak-flow-meter through a disposable mouthpiece. A scale reading permits to obtain the maximum value. The maximum value of three trials was used.

Questionnaires

Demographic and lifestyle data of the older subjects were assessed by a self-designed questionnaire. Their degree of physical activity was determined by a standardized questionnaire (20). It consists of items referring to household, sports, and leisure time activities over a period of one year. Intensity codes for type of activities and factors for weekly and monthly duration of each activity were assigned. Altogether these scores add up to an overall activity score.

Statistics

For all statistical analyses, the SPSS/PC software package for MS Windows, release 15 (SPSS Inc., Chicago, IL) was applied. Data are shown as means ± standard deviation. The Kolmogorov-Smirnov test was used to test the distribution of metric data for normality. Depending on data were normally distributed or not, the correlation coefficient of Pearson (r) or Spearman (rs), respectively, was used in order to analyze relationships between variables. The test-retest reliability of REE was evaluated with the t test for paired samples. Multiple linear stepwise regression analysis was applied to determine predictors of REE or REEadjusted, separately for older males and females. A P value less than 0.05 (two-tailed) was considered as statistically significant.

Results

General characteristics of the study population

Demographic, lifestyle, anthropometric, and metabolic characteristics of the study population are shown in Table 1. The mean age was 68.4 ± 4.48 years in males and 68.1 ± 5.15 years in females. Most males (84.3%) and half of females (49%) were living together with a partner. The majority of males (96.1%) and females (79.6%) were retirees. Only three subjects were smokers. The degree of physical activity was very similar in males and females. Their BMI indicates that the study population is not underweight or very obese as well, since 72.5% and 79.6% of males and females, respectively, were normal weight, following the criteria of Müller et al. (21) who considered a BMI of 18.5-27.5 kg/m² as normal weight for persons older than 60 years. Lowest BMI in males and females was 20.8 kg/m² and 20.1 kg/m², respectively.

Reproducibility of indirect calorimetric measurements

Reproducibility of indirect calorimetry was determined in ten participants. Measurements were repeated after a mean period of 7.2 days (range: 7-9 days) at the same time of day. Table 2 displays the results of first and second measurements. There were no statistically significant differences with respect to VO_2 (L/min), VCO_2 (L/min), RQ, and REE ($P > 0.05$)

indicating good reproducibility.

Table 1
Demographic, lifestyle, anthropometric and metabolic characteristics of the older study population

Characteristic	Males (n = 51)	Females (n = 49)
Marital status		
Single (%)	0	2
Married/living together (%)	84.3	49.0
Widowed/divorced/separated (%)	15.7	49.0
Profession		
Retiree (%)	96.1	79.6
Houseman/wife (%)	0	16.3
Employee (%)	0	2.0
Self-employee (%)	2.0	2.0
Civil servant (%)	2.0	0
Smokers (%)	3.9	2.0
Physical activity level (scores, mean ± SD)	16.0 ± 7.69	15.3 ± 7.67
Anthropometry		
Age (years, mean ± SD)	68.4 ± 4.48	68.1 ± 5.15
Height (m, mean ± SD)	1.77 ± 0.06	1.63 ± 0.05
Weight (kg, mean ± SD)	80.8 ± 9.05	66.8 ± 11.08
BMI (kg/m², mean ± SD)	26.0 ± 2.67	25.0 ± 3.29
Waist circumference (cm, mean ± SD)	94.7 ± 7.16	83.1 ± 9.60
Abdomen circumference (cm, mean ± SD)	97.5 ± 7.49	90.9 ± 9.01
Hip circumference (cm, mean ± SD)	103.7 ±5.18	101.4 ± 7.71
WHR (mean ± SD)	0.91 ± 0.05	0.82 ± 0.05
REE (kcal/24h, mean ± SD)	1561.8 ±51.3	1201.0 ± 45.4
REEadjusted (kcal/kg/24h, mean ± SD)	19.5 ± 2.04	18.4 ±2.54
Peak expiratory flow rate (L/min, mean ± SD)	487.7 ± 92.6	330.4 ±54.3
LBM (kg, mean ± SD)	62.7 ± 5.54	44.9 ± 4.11

Abbreviations: BMI, body mass index; SD, standard deviation; WHR, waist-to-hip ratio.

Table 2
Reproducibility of indirect calorimetric measurements in ten older subjects

Variable	First Measurement Mean	SD	Second Measurement Mean	SD	t[a]	P
VO_2 (L/min)	0.276	0.039	0.278	0.037	-0.19	0.852
VCO_2 (L/min)	0.204	0.050	0.203	0.036	0.07	0.943
RQ	0.738	0.130	0.721	0.061	0.51	0.624
REE (kcal/24h)	1451.4	181.3	1453.2	187.2	-0.19	0.852

Abbreviations: REE, resting energy expenditure; RQ, respiratory quotient; SD, standard deviation; [a] t test for paired samples

Factors predicting REE and weight adjusted REE

Correlation analyses showed that REE was positively related with LBM in both sexes (males, r = 0.34, P = 0.014; females, r = 0.41, P = 0.003), but not with body height (P>0.05). There was a positive relationship with BMI in females (r = 0.36, P = 0.012), but not in males (r = 0.13, P = 0.358). The REE correlated also highly with waist circumference (r = 0.44, P = 0.002), abdomen circumference (r = 0.37, P = 0.011), and hip circumference (r = 0.30, P = 0.036) in females. The weight adjusted REE (REEadjusted, kcal/kg/24h) correlated negatively and significantly in both sexes with BMI, body height, LBM, waist circumference, abdomen circumference, and hip circumference (Fig. 1). The REEadjusted correlated also negatively with PEF in females (r = -0.47, P = 0.001), but not in males (r = -0.07, P = 0.604). The degree of physical activity was positively related with REEadjusted in females (r = 0.29, P = 0.47), but not in males (r = 0.03, P = 0.842).

Subsequently, regression analysis was performed for both sexes separately in order to determine the main factors for predicting REE and REEadjusted. Independent variables were body height, body weight (only for REE), BMI, waist circumference, abdomen circumference, hip circumference, WHR, LBM, PEF, and physical activity level. Results are given in Table 3. Out of these independent variables, LBM was the only significant predictor of REE in males and BMI was the only significant predictor in females. The other variables were excluded by the regression analysis. By contrast, the main significant predictors of REEadjusted were sex-specific trunk circumferences, i.e. abdomen circumference in males and hip circumference in females, explaining each about 70% of variation in REEadjusted. By contrast, waist circumference was no significant predictor of REEadjusted, neither in males nor in females. A secondary, but weaker, predictor of REEadjusted was LBM in males which increased R^2 by 11% from 0.691 to 0.798. In females, secondary predictors were body height (increasing R^2 by 13% from 0.704 to 0.830) and BMI (increasing R^2 by additional 8% from 0.830 to 0.910). Based on these results, we developed five predictive equations for calculating weight adjusted REE in older people:

Males, model 1: $REE_{adjusted} = 41.567 – 0.226 \times \text{abdomen circ.}$ (1)
Males, model 2: $REE_{adjusted} = 44.189 – 0.153 \times \text{abdomen circ.} – 0.156 \times LBM$ (2)
Females, model 1: $REE_{adjusted} = 46.155 – 0.273 \times \text{hip circ.}$ (3)
Females, model 2: $REE_{adjusted} = 69.865 – 0.229 \times \text{hip circ.} – 0.173 \times ht$ (4)
Females, model 3: $REE_{adjusted} = 68.143 – 0.025 \times \text{hip circ.} – 0.210 \times ht – 0.519 \times BMI$ (5)

where REEadjusted is given in kcal//kg/24h, abdomen and hip circumferences (circ.) in cm, LBM in kg, height (ht) in cm, and BMI in kg/m². Equation (1), (2), (3), (4), and (5) are explaining 69%, 80%, 70%, 83%, and 91% of the variance of REEadjusted, respectively. Since the equations (1), (3) to (5) are independent of determining LBM, they can be applied to older people with altered hydration state.

Discussion

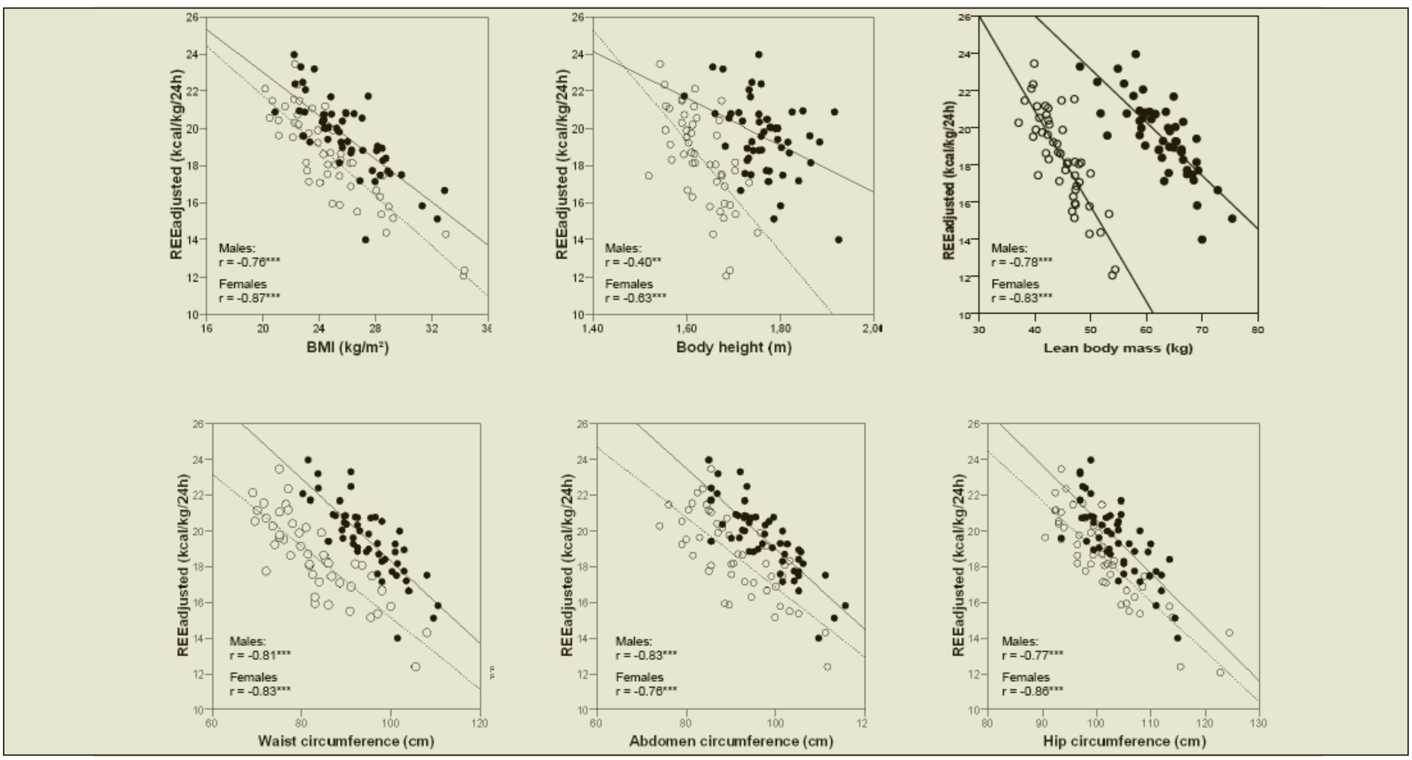
This study evaluated different anthropometric characters, LBM, PEF, and physical activity level for predicting REE in healthy older subjects. We observed a mean REEadjusted of 19.5 kcal/kg/24h for older males and of 18.4 kcal/kg/24h for older females. These values agree well with the weight adjusted REE of 19.4 kcal/kg/24h, reported by Gaillard et al. (22) for healthy elderly of both sexes, based on a large data base. The most relevant finding of the present study is that trunk circumferences are strong predictors of weight adjusted REE in healthy older people. Based on this observation, we presented for the first time equations for determining REE from body circumferences.

Table 3
Significant predictors of resting energy expenditure (REE) in older males and females, as assessed by multiple linear stepwise regression analyses

Dependent variable	Sex	Model	R^2	SEE	F^a	P	Predictors
REE (kcal/24h)	Males	Model	0.117	48.73	6.5	0.014	LBM
	Females	Model	0.201	40.80	11.0	0.002	BMI
$REE_{adjusted}$ (kcal/kg/24h)	Males	Model 1	0.691	1.14	109.5	< 0.001	Abdomen circumference
		Model 2	0.798	0.93	94.9	< 0.001	Abdomen circumference, LBM
	Females	Model 1	0.704	1.28	104.5	< 0.001	Hip circumference
		Model 2	0.830	0.98	104.7	< 0.001	Hip circumference, height
		Model 3	0.910	0.72	142.0	< 0.001	Hip circumference, height, BMI

Abbreviations: BMI, body mass index; LBM, lean body mass; REE, resting energy expenditure; $REE_{adjusted}$, weight adjusted REE; R^2, coefficient of determination; SEE, standard error of the estimate; [a] Analysis of variance

Figure 1
REEadjusted (kcal/kg/24h) correlated negatively and significantly with body mass index (BMI), body height, lean body mass (LBM), waist circumference, abdomen circumference, and hip circumference in both sexes. Males, closed circles and solid lines; females, open circles and broken lines. Significance levels: ** P<0.01, *** P<0.001



Significance of body circumferences as predictors of REE

REEadjusted (kcal/kg/24h) correlated negatively and significantly with trunk circumferences in both sexes, i.e. with waist circumference, abdomen circumference, and hip circumference. The most important finding of our study was that the main predictor of REEadjusted was abdomen circumference in males and hip circumference in females, whereas waist circumference and WHR did not predict REEadjusted, neither in males nor in females. This agrees well with other studies reporting that hip circumference is a significant predictor of REE in patients with type 2 diabetes (23) and a significant predictor of REE, adjusted for fat mass and LBM, in Japanese older males, but not in older females (11). The latter authors also found no significant relationship between waist circumference and adjusted REE in older males and females, as we did in the present study. We noted that abdomen and hip circumference are strong sex-specific predictors, explaining each about 70% of variation in REEadjusted. The relationship of these trunk circumferences with REEadjusted can be explained with respect to the fat mass distribution. In general, higher trunk circumferences refer to increased fat mass or overweight. There are findings of a lower metabolic rate in overweight subjects being associated with a lower REE (24). More obese subjects with higher trunk circumferences have lower metabolic rates, i.e. REE per kg body weight, and this might explain the negative correlation of the weight adjusted REE with body circumferences observed in our study. The finding that abdomen circumference is the main predictor in males, but hip circumference in females, can be attributed to the sex-specific regional body fat distribution. In males, abdominal fat is more prominent being related to abdomen circumference, as shown in the present study. By contrast, in females, gluteal-femoral fat is predominant being connected with hip circumference. In addition, these regional variations of fat mass influence REE (25). The REE increases with increasing abdominal fat, because it has a higher REE compared with fat located in the gluteal-femoral region, due to a higher rate of lipolysis (26, 27). Prediction equations for determining REEadjusted are proposed with the use of sex-specific body circumferences.

Significance of BMI, body height, and LBM as predictors of REE

As has been outlined, the main predictors of REEadjusted were trunk circumferences. Additional but weaker predictors were LBM in older males as well as body height and BMI in older females. They explained lower percentages of variation in REEadjusted than the trunk circumferences did. Therefore, they might be used additionally in prediction equations for populations were bioelectrical impedance measurements are applicable. The observed inverse relationship between REEadjusted and BMI agrees well with findings of Gaillard et al. (22). Also, the negative relationship between REEadjusted and body height is supported by a recent study reporting that weight adjusted REE is lower in tall subjects due to the effect of high-metabolic-rate brain mass (28). Likewise, the observed negative relationship between REEadjusted and LBM is in coherence with former studies (i.e., 29) which demonstrated a decrease of REE per kg LBM with increasing body weight. This can be explained by the fact that the LBM is a metabolically heterogeneous compartment (29), consisting of skeletal muscle mass and visceral organ mass. With increasing LBM occurs a disproportional higher increase of skeletal muscle mass than of visceral organ mass. Since skeletal muscle mass has a lower metabolic rate than visceral organ mass (30, 31), this results in a lower REE per kg LBM in subjects with higher LBM. Thus, the proportion of lesser metabolically active components of the LBM decreases with increasing LBM in the body, as it is the case with increasing weight and BMI (32). Given the former argument that a proportionally higher skeletal muscle mass in the LBM results in a decreasing REEadjusted due to the decreasing rate of metabolically active components such as internal organs, the observed inverse relationship between the adjusted REE and BMI, LBM, and height in our study may result, first, from a greater absolute magnitude of LBM with increasing weight and, second, from an increasing proportion of lesser active components of the LBM with increasing LBM, and possibly height, in the body.

Significance of peak expiratory flow rate and physical activity level as predictors of REE

Neither in older males nor in females the PEF was a significant predictor of REEadjusted. However, the PEF correlated negatively with REEadjusted in females ($r = -0.47$, $P = 0.001$), but not in males ($r = -0.07$, $P = 0.604$). It is known that the PEF is directly related to height as it increases with height at any given age. The observed inverse relationship between REEadjusted and PEF in females might reflect the negative association of adjusted REE with body height and the possibility that smaller subjects have a higher REE/kg and a lower PEF due to lower thoracic or lung volume. In persons having normal airways, the magnitude of PEF depends on the force of expiration resulting from the power of the expiratory muscles. PEF is also influenced by body build and, in particular, by the volume of the thorax (16). However, in the present older sample, the PEF did not significantly predict REE or adjusted REE in the older study population. This indicates that it is not suited for determining REE or weight adjusted REE.

Likewise, the degree of physical activity did not predict REEadjusted in our male and female older subjects. Literature data on the effect of physical activity level on REE are inconsistent. While many studies have found that long term training increases REE, others did not observe such effects (overview in 33). In general, a lower level of physical activity and changes in the hormonal status might account for a lower REE in older subjects. However, several authors found no clear relationship between physical activity level and REE in the aged (12, 34). Kyle et al. (14) noted significant associations between physical activity level and body cell mass in older males and females, but stated, that the determination of causal effects of physical activity level on LBM or fat mass is difficult to elucidate. Furthermore, the cause or effect of relationship between body composition, which influences REE, and physical activity level is difficult to determine. In our older study group, PEF and physical activity level were not eligible to predict of REE.

Application of the results

We here propose equations to calculate weight adjusted REE for elderly people. Since our study population comprises healthy mobile elderly persons, these equations have further to be tested in a more representative older population, including sick, frail, and very old persons. In a more geriatric population, differences in hydration status might often be present, which might interfere with the BIA measurement to determine LBM. Alternative methods, e.g. dual-energy X-ray absorptiometry, are more expensive and less suitable for field studies. For this reason, we also presented equations where LBM is not essentially needed to predict REEadjusted. It is possible though to take LBM into account for adequate populations to enhance the precision of the prediction equation. Since in a review by Gaillard et al. 2007 (22), the authors found no significant difference in weight adjusted REE for healthy elderly and sick elderly patients, as well as no significant differences in fat-free mass respectively, such a cross-validation of the here proposed prediction equation in a more representative older population seems feasible. If tested successfully, it offers great possibilities for further usage in determination of REE. This might be useful for the mobile majority of the elderly population to determine their energy needs in case of preventing over- or underweight, respectively, e.g., at the level of general practitioners. On the other hand, it may be helpful to determine REE of frail and sick older people in clinical or institutionalised settings to prevent malnutrition, without the need to use uncomfortable and cumbersome indirect calorimetry. Circumference measurements can easily be obtained by caregivers and nurses.

In conclusion, the findings of the present study demonstrate that body circumferences are very strong predictors of weight adjusted REE in healthy older people. Abdomen circumference and hip circumference explained in males and females 69% and 70% of variation of weight adjusted REE, respectively. Weaker predictors were LBM in males as well as body height and BMI in females. By contrast, peak expiratory flow rate and physical activity level were no significant predictors. This implies that the sex-specific use of abdomen and hip circumference in combination with LBM or body height and BMI seems to be well sufficient to predict weight adjusted REE in older subjects according to the prediction equations we propose. Such anthropometric measures are of relevance for non-geriatric older populations in general to easily determine their REE. These measures might offer great advantage for the clinical practicioners, too, because they are more comfortable for older sick people than the indirect calorimetric measurements. Since the present study was performed in healthy older people, further studies are needed to test the applicability of the prediction equations to frail older populations. The use of relatively easy obtainable measurements for determining REE offers great possibilities for many settings, especially, because the indirect calorimetry is very impractical in use for older people.

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