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Resting and sleeping energy expenditure in the elderly

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An estimate of a patient's energy needs is usually derived from equations, which predict energy expenditure (EE) by considering sex, age and body weight. Due to the increasing number of elderly people in a hospital population, more data on energy requirements in this age-group are needed. In this study resting energy expenditure (REE) of 40 healthy men and women, aged 51–82 years, was measured using a ventilated hood system. The results showed that some commonly used prediction equations underestimated REE by approximately 6 per cent. REE was highly correlated with fat free mass (FFM) ($r = 0.88$; $P < 0.001$) and body weight ($r = 0.85$; $P < 0.001$). A stepwise multiple regression analysis showed that the combination of body weight, sex and age resulted in the best prediction for REE; REE (kcal) = 1641 + 10.7 weight (kg) − 9.0 age (years) − 203 sex (1 = male, 2 = female) ($r = 0.92$). However, REE of an individual may be over- or underestimated by ± 225 kcal (10–20 per cent) due to large between-subject variations. We suggest therefore that the energy requirements of elderly people should be measured rather than predicted. Due to small within-subject variations (including measurement error) a single REE measurement would suffice. Sleeping energy expenditure (SEE) was 7 per cent lower than REE.

There is growing clinical interest in predicting accurately energy requirements of individual patients. One reason for this interest is to fulfil energy needs of critically ill hospitalized patients, avoiding at the same time the adverse clinical consequences of overfeeding (Sheldon, Peterson & Sanders, 1978; Lowry & Brennan, 1979; Askanazi *et al.*, 1980). Artificial nutrition is often planned for hospital patients on the basis of estimated daily energy expenditure (EE) which is seldom measured. The most common approach is to apply an equation such as that of Harris Benedict (HB) (Harris & Benedict, 1919), to estimate the normal resting energy expenditure (REE) for an individual of the patient's age, size and sex, and then add an arbitrary factor such as 10 per cent for the thermic effect of a mixed diet and perhaps 20–40 per cent for the presumed energy needs of physical activity and disease.

There are indications that the HB equation is not the best reference as standard in an elderly population of patients. Roza & Shizgal (1984) suggested that this formula underestimates REE in patients with weight loss. In contrast, Daly *et al.* (1985) found that the HB equation overestimates REE in healthy men and women. Feurer, Crosby & Mullen (1984) found that the HB prediction over-or underestimates REE by 10 per cent or more in 20 per cent of healthy control subjects. Owen *et al.* (1986, 1987) have recently published data concerning REE in healthy men and women. They concluded

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that the classic prediction equations including the HB formula overestimate REE in men and women under the age of 64. REE is slightly underestimated in men over 64 years of age. Women over 64 years of age were not included in their study.

The original HB equation is based on REE measurements in volunteers in the age-group 18–65 years. However, the number of studies in young and middle-aged people has exceeded those in the elderly. An extensive analysis of all available data in the literature by Schofield (1985) resulted in two linear equations for the elderly relating REE to body weight, based on 50 measurements in men and 38 measurements in women. Now that a larger proportion of the total population and especially the hospital population is composed of people aged over 60 years and older, it is even more desirable to quantitate accurately their energy requirements.

In the current study the energy requirements of 40 apparently healthy men and women (50 years and older) were measured at rest. Measured REE values were compared with three predicted values. Furthermore, the relationship between sleeping energy expenditure (SEE) and REE was examined.

Subjects and methods

Forty healthy men and women between the age of 51 and 82 years living in Maastricht and surroundings participated in the study (Table 1). All volunteers had normal dietary habits, had stable weight for at least 6 months before the study and had no evidence of physical or mental disease. Their physical activities were approximately comparable from day to day. All subjects had normal blood pressures, pulse rates and body temperatures. They underwent a medical examination to exclude disorders that might have affected their metabolic rate, such as high blood pressure, thyroid dysfunction, heart failure, infectious disease, chronic obstructive pulmonary disease and anaemia.

REE was measured once or several times. The first time all subjects came to the hospital in the morning after a 10-h overnight fast. They were asked to travel by car, bus or train in order to reduce physical activity. REE was measured after a period of at least 30-min bed rest. Measurements were performed with a ventilated hood system during a half hour. Gas analyses were performed using a paramagnetic oxygen analyser (Mijnhardt Servomex module, Bunnik) and an infrared carbon dioxide analyser (modified Mijnhardt UG51, Bunnik). Dry gases were measured and the results converted to standard temperature and pressure. Flow through the canopy was kept constant during measurements and was adjusted to the body weight of the patient (25–50 l/min). System control and calculations were performed on a microcomputer. The equipment was calibrated at the start and at the end of every experiment. Zero settings were performed by passing 100 per cent nitrogen through the analysers. The span of the O_2 and CO_2 analysers was set by passing a special gas mixture (0.8 ± 0.01 per cent CO_2 and 19.0 ± 0.01 per cent O_2 in N_2 through

Table 1. Subject characteristics (mean ± s.d.).

	Males (n = 18)	*Females (n = 22)*	*Total (n = 40)*
Age (years)	63 ± 8	66 ± 7	65 ± 8 (range 51–82)
Weight (kg)	81.1 ± 11.0	64.8 ± 7.1	72.1 ± 12.1 (range 54–112)
BMI (kg m^{-2})	26.4 ± 2.4	25.5 ± 2.6	25.9 ± 2.5 (range 21–31)
FFM (kg)	60.1 ± 6.8	44.1 ± 4.0	51.3 ± 9.7 (range 39–77)

BMI = body mass index; FFM = fat free mass.

the analyser. The hood consisted of clear plexiglas and had a volume of 30 litres. REE was calculated using the abbreviated Weir formula (Weir, 1949). The measured REE was extrapolated to 24 h and was then compared to the corresponding values predicted by the HB, the Schofield and the Owen equations (Table 3).

Body composition was determined by measurement of the bioelectrical impedance (BI) with the person in the supine position. Fat-free mass (FFM) was calculated using the sex and fatness specific formulae of Segal *et al.* (1988) which further include body weight, body height, age and resistance.

To assess reproducibility of the results a second REE measurement was performed after an interval of about 5 months under the same conditions in subjects with the highest REE (n = 11) and in subjects with the lowest REE (n = 11), expressed as a percentage of the HB value. SEE and subsequently REE were measured in 30 subjects (out of 40). For the measurement of SEE each subject stayed for 12 h (2000–0800 h) in a computerized open-circuit indirect calorimeter (14 m^3), equipped with a bed, toilet, television and chair. The volume of air drawn through the chambers was measured by a dry gas meter (Dort, The Netherlands) and continuously analysed by a paramagnetic O_2-analyser (Servomex Taylor, England) and an infrared CO_2-

Table 2. Resting energy expenditure (REE) in the elderly (mean ± s.d.).

	Males (n = 18)	*Females (n = 22)*	*Total (n = 40)*
REE (kcal)	1733 ± 205	1330 ± 155	1512 ± 269 (range 1106–2145)
REE (kcal/kg BW)	21.4 ±1.5	20.6 ± 2.0	21.0 ± 2.0 (range 17.5–26.0)
REE (kcal/kg FFM)	28.9 ± 2.0	30.2 ± 3.3	29.6 ± 2.9 (range 25.1–36.5)

BW = body weight; FFM = fat free mass.

Table 3. Measured and predicted resting energy expenditure (REE) (mean ± s.d.).

	Measured	*Predicted HB*	*Predicted SCHO*	*Predicted OWEN*
REE (kcal)	1512 ± 269	1420 ± 244***	1427 ± 244***	1461 ± 240*

HB = Harris and Benedict; SCHO = Schofield; OWEN = Owen.
* $P < 0.05$ OWEN vs. measured; *** $P < 0.001$ HB, SCHO vs. measured.

OWEN:	
Males	REE (kcal) = 879 + 10.2 W
Females	REE (kcal) = 795 + 7.2 W
HB:	
Males	REE (kcal) = 66 + 5H + 13.7 W − 6.8A
Females	REE (kcal) = 655 + 1.9H + 9.6W − 4.7A
SCHO:	
Males, 30–60 years	REE (kcal) = (0.048W + 3.653)/0.0042
Males, > 60 years	REE (kcal) = (0.049W + 2.459)/0.0042
Females, 30–60 years	REE (kcal) = (0.034W + 3.538)/0.0042
Females, > 60 years	REE (kcal) = (0.038W + 2.755)/0.0042

W = weight; H = height; A = age.

analyser (Hartmann and Braun, West Germany). From the air flow rate and the O_2 and CO_2 concentration of the in- and outflowing air, O_2 consumption and CO_2 production were computed on line through an automatic acquisition system interfaced with a computer (Schoffelen *et al.* 1985). SEE was calculated during the period of sleeping from 0300–0600 h. The next morning the subjects left the room after waking up and REE was measured under the usual conditions using the ventilated hood system.

REE was expressed in absolute terms (REE), per kg body weight (REE/BW), per kg FFM (REE/FFM) or as a percentage of the HB, Schofield and Owen equations, respectively (REE/HB, REE/SCHO, REE/OWEN). The relationship between REE and several independent variables was assessed using Pearson's coefficient of correlation. Stepwise multiple regression was used to determine the best predictors of REE of these subjects. Further statistical procedures included Student's paired *t*-test. Results are presented as mean ± s.d. and *P*-values < 0.05 were regarded as statistically significant.

Results

Mean REE of the 40 healthy volunteers was 1512 ± 269 kcal (Table 2). REE/BW and REE/FFM were in the same range for men and women. Measured REE was higher than predicted REE no matter what prediction equation was used (Table 3). The HB, Schofield and Owen equations underpredicted the measured value by 7 per cent, 6 per cent and 4 per cent, respectively.

Significant correlations existed between REE and FFM ($r = 0.88$), body weight ($r = 0.85$), sex ($r = 0.75$) and age ($r = 0.54$). A stepwise multiple regression analysis revealed that the combination of body weight, sex and age gave the best prediction for REE [$r = 0.92$ and s.e. of estimate = 111; REE (kcal) = 1641 + 10.7 weight (kg) − 9.0 age (years) − 203 sex (1 = male, 2 = female)]. When BW and age were used as the variables to predict REE of men and women, the slopes of the regression lines were statistically indistinguishable. Therefore, no separate regression lines were developed for men and women. By taking weight, sex and age into account, 84 per cent of the variance in REE could be explained. The 95 per cent prediction limits calculated as two times the s.e. of estimate were wide (± 225 kcal), reflecting the heterogeneous nature of the REE for healthy people over 50 years of age. This was also demonstrated by the wide range for REE/BW (17.5–26.0 kcal/kg) and for REE/FFM (25.1–36.5 kcal/kg).

The 22 subjects (mean age 64 ± 8 years) who were measured twice showed no significant differences in REE between the two measurements (Table 4). There were also no significant differences in body weight and body composition. The test-retest correlation coefficient was high ($r = 0.96$). The standard error of measurement of a single determination of 24-h REE was 53 kcal resulting in a within-subject coefficient of variation (CVw) of 3.5 per cent. The same results were found when the data of the subjects with either a high or a low REE were analysed separately. No difference in REE was found between the two measurements, with a highly significant correlation coefficient ($P < 0.001$) and a CVw of 3.6 per cent and 3.4 per cent, respectively.

In a subgroup of 30 subjects (mean age 69 ± 7 years) SEE as well as REE was determined. Most of these subjects had SEE that

Table 4. Reproducibility of resting energy expenditure (REE) in subjects with either high ($n = 11$) or low ($n = 11$) REE during the first measurement.

	1st Measurement	*2nd Measurement*	*r*	*CVw(%)*
Low REE	1392 ± 309	1376 ± 270	0.98	3.4
High REE	1598 ± 207	1599 ± 228	0.93	3.6
Total	1495 ± 277	1488 ± 269	0.96	3.5

r = Correlation coefficient; CVw = within-subject coefficient of variation.

was lower than REE (Fig. 1). The mean ratio of SEE : REE was 0.93 ± 0.08. Furthermore, the difference between REE and SEE seems to be independent of REE.

Discussion

An accurate prediction of REE is particularly important when calculating energy requirements. The energy costs for physical activity, for the thermic effect of food and for disease or injury are usually determined by multiplying the REE by an empirical factor. Thus, the estimation of energy needs is usually based on the predicted REE. Few data on REE in the elderly are published.

This study showed that measured REE for healthy elderly people is higher than the predicted REE based on results from the most commonly used prediction equation of HB. This seems to be in agreement with the observation of Owen *et al.* (1987) that the HB equation slightly underestimates REE in men over 64 years of age. It is therefore necessary to study many more elderly people to evaluate properly the influence of age on REE. Although the original HB equations developed in 1919 are based on REE measurements in healthy people in the age-group 18–65 years, two further studies published by Benedict (1928, 1935) included subjects with a wider age range. A re-evaluation of these data by Roza & Shizgal (1984) showed that the regression equations

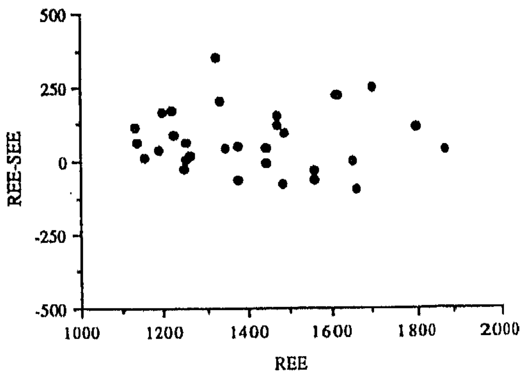

Fig. 1. The difference between resting energy expenditure (REE) and sleeping energy expenditure (SEE) in healthy individuals as a function of REE.

derived using the original 1919 data are virtually identical to the equations obtained with the data from the larger number of subjects. The HB equation seems therefore equally valid for both younger and older individuals.

Measured REE in the current study was also higher than predicted by the new equations published by Owen. This can be explained by the fact that REE in the study of Owen was measured mainly in younger people (males: 38 ± 16 years; females: 35 ± 12 years). The finding that the Schofield equations underpredicted measured REE by 6 per cent was quite unexpected, because these equations were based on all data on REE in the elderly that are available in the literature. Our results indicate that the currently available equations underestimate the REE of older healthy men and women. The impact of underestimation of on average 6 per cent may not be neglected. Energy requirements are based on the predicted REE which in itself accounts for about 65–70 per cent of total EE. Further, for individuals the predicted REE may over- or underestimate actual REE by 10–20 per cent. Therefore, it seems important to employ the most appropriate prediction equation when calculating daily energy requirements.

The differences between our results and results of other studies may be ascribed to both technical and biological differences. The possibility cannot be excluded that today's adults (over 50 years of age) have a different REE compared to their ancestors, as a result of climatic factors, level of physical activity, dietary habits and general level of health. If and to what extent these factors may contribute to the observed differences is unknown.

We developed a new prediction equation for the REE of healthy men and women of 50 years and older. It should be emphasized that, due to the large variations in measured REE, predicted REE may over- or underestimate the actual REE by 10–20 per cent, which makes the usefulness of a prediction equation questionable. The metabolic requirements of elderly people should therefore preferably be measured rather than predicted. In critically ill patients there is even greater necessity to measure EE, because daily energy requirement estimates are much less accurate.

The best predictor for REE was FFM. A multiple regression analysis resulted, however, in a prediction equation without FFM, but with body weight, sex and age ($r = 0.92$; SEE = 111). The prediction equation including the same variables, but FFM instead of body weight resulted in a correlation coefficient of 0.90 and a SEE of 121. This possibly casual finding can be explained by the fact that FFM was highly interrelated with weight and sex ($r > 0.83$). Body weight has the advantage of being a variable that is more easily determined than FFM. Only 16 per cent of the total variance in REE in the healthy elderly cannot be explained by these three variables.

The results of this study are in agreement with earlier reports that REE measurements are highly reproducible (Garby & Lammert, 1984; Soares & Shetty, 1986; Murgatroyd, Davies & Prentice, 1987; Soares *et al.*, 1989). A CVw of 3.5 per cent indicates both reasonable methodological precision and small within-subject variability. This small within-subject variation for both subjects with a high or low REE confirms the observation that there is a wide range of REE for healthy men and women over 50 years of age.

The terms basal, resting and sleeping EE (BEE, REE and SEE, respectively) all refer to energy exchange, measured under conditions that differ only slightly. Although the term BEE is still commonly used, the measurement conditions usually equal those of REE. The differences measured between SEE, BEE and REE are small; however, these differences may be of importance. The FAO/WHO/UNU (1985) recommendations for daily energy requirements are based on the assumption that SEE is equal to REE. Two recent studies have demonstrated SEE to be 5 per cent lower than REE (Garby *et al.*, 1987; Goldberg *et al.*, 1988). In those studies SEE was measured during a period of at least 7 h of sleeping, while in our study SEE was measured from 0300–0600 h. SEE as measured in the current study was 7 per cent lower than REE. Therefore, overnight EE will be overestimated with 5–7 per cent by the use of the REE-value.

We conclude that commonly used prediction equations underestimate the REE of healthy men and women over 50 years of age. Furthermore, due to large between-subject variation in REE it is difficult to predict accurately individual energy requirements. Therefore, we suggest that energy requirements of elderly people should preferably be measured rather than predicted. Due to small within-subject variation and methodological error in REE, only a single measurement is needed, which can be performed under strictly defined conditions on an outpatient basis.

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