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ORIGINAL CONTRIBUTION

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Regional lean body mass and resting energy expenditure in non-obese adults

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Summary *Objective* To study the effect of regional lean body mass (LBM) on resting energy expenditure (REE). *Design* Cross-sectional study in a homogenous group of 26 young healthy non-obese subjects. *Methods* Regional body composition was assessed by dual-energy X-ray absorptiometry (DEXA). REE was measured by indirect calorimetry. *Results* REE showed positive relationships with whole body LBM (LBM_b; r=0.89) as well as with regional LBM (LBM_{trunk} = LBM_t, r = 0.88, and $LBM_{arms+legs}$ = LBM_e for $LBM_{extremities}$, r = 0.89) with non-zero intercepts (between 1.86 and 2.83 MJ/d). REE per kg LBM_b falls as LBM_b increases (r = 0.77). By contrast, REE adjusted for regional distribution of LBM (i. e. the ratio of LBM_t to LBM_e) increases as LBM_b increases (r = 0.91) showing a near-zero intercept (i. e. 0.048 MJ/d). Adjusting REE for LBM_b as well as for the ratio of LBM_t to LBM_e can be used for comparison between subjects. *Conclusions* Our data suggest that regional distribution of LBM is a determinant of REE. Assessment of LBM_t and LBM_e by DEXA provides a possibility to adjust for the non-linearity of REE on LBM_b.

Key words Body composition analysis – DEXA – Resting energy expenditure – Lean body mass (LBM) – Regional LBM distribution

Introduction

Studying the association between resting energy expenditure (REE) and lean body mass (LBM) provides insight into human energy requirements as well as the regulation of body weight. LBM is the major determinant of REE. However, the ratio of REE to LBM is not constant and varies with body weight (1, 2). Subjects with higher body weights have a lower REE per kg LBM when compared with subjects with lower body weights (1, 2). It has been speculated that the composition of LBM (i. e. skeletal muscle and visceral organs) may explain this phenomenon (1, 2). This is because visceral organs contribute more to REE than do muscles. Thus, from a metabolic point of view, LBM is a heterogeneous compartment which varies in its composition with varying body mass.

This idea is difficult to prove in humans. Using imaging technologies (i. e. computer tomography, CT or magnetic resonance imaging, MRI) for in vivo body composition studies four different groups of authors (3–6) have recently shown that the composition of LBM contributes to the variance in REE. The ratio of REE to LBM decreased with an increasing ratio of muscle mass to the MRI-derived sum of internal organ masses (5, 6). These data support the idea that the relative proportion of metabolically very active tissues (i. e. the mass of visceral organs) determines *specific* REE (i. e. REE on LBM) and contributes to the interindividual variance of REE (1, 2).

CT- and MRI-technologies are cumbersome and their use is now limited to a small number of scientific studies. Dual-energy X-ray absorptiometry (DEXA) has become an important area of body composition research (7). DEXA allows valid and reproducible analysis

EJN 332

European Journal of Nutrition, Vol. 40, Number 3 (2001)

of total as well as regional body composition (8). However, the association between whole body, trunk and peripheral (i. e. arms plus legs = extremities) LBM with REE has not been widely studied. In a first study on 121 overweight postmenopausal women REE was correlated with regional LBM (9). Trunk LBM was superior to whole body and peripheral LBM with respect to the explanation of the interindividual variance in REE. When compared with peripheral LBM trunk LBM has a higher visceral component. The authors concluded that visceral organs account for most of the metabolically active tissues and, thus, contribute more to REE than peripheral LBM (9). In a more recent study trunk LBM was also shown to be superior as a predictor of REE when compared with peripheral LBM (10). However, in the latter study the predictive value of trunk LBM did not exceed that of whole body LBM (10). Both studies did not systematically investigate the effect of the ratio of trunk to peripheral LBM on REE. The present study addresses this problem. We wanted to see whether the results of our previous study using MRI technologies (6) could be confirmed by the simpler assessment of regional body composition by DEXA.

Methods

Twenty-six healthy subjects (13 females, 13 males) participated in the study (see Table 1). The study protocol has been approved by the ethical committee of the Christian-Albrechts-Universität zu Kiel. Before participation each subject provided written consent. All subjects were healthy and weight stable. None had a history of recent illness or of obesity, diabetes, hyperlipidemia, hypertension or endocrinopathy. Each had a normal physical examination. Energy intake (11.35 ± 3.42 and 7.68 ± 1.47 MJ/d in males and females, respectively) was assessed by 7 day records. Physical exhaustion was avoided during 7 days before examination. In females, measurements of REE and body composition were performed in the follicular phase of the menstrual cycle (i. e. < 10 days since last menstruation).

Table 1 Characterisation of the study population

	females n=13	males n=13	p <
age (years)	24.8±2.4	26.2±2.1	–
body weight (kg)	62.8±9.5	77.3±10.2	0.01
height (cm)	169.6±6.2	185.2±7.7	0.01
BMI[1] (kg/m^2)	22.14±2.47	22.53±1.82	–
LBM_b[2] (kg)	43.6±5.5	64.4±7.8	0.01
$LBMI_b$[3] (kg/m^2)	15.2±2.0	18.7±1.2	0.01
FM_b[4] (kg)	19.2±6.0	12.9±4.4	0.01
FMI_b[5] (kg/m^2)	6.6±1.8	3.7±1.2	0.01

[1] BMI, body mass index, [2] LBM_b, lean body mass (whole body), [3] $LBMI_b$, lean body mass index (whole body), [4] FM_b, fat mass (whole body), [5] FMI_b, fat mass index (whole body)

Weight was measured using an electronic scale without shoes and with light clothing and after voiding (SECA, Modell 709, Vogel&Halke, Hamburg, Germany) at an accuracy of 0.1 kg. Height was assessed to the nearest 0.5 cm using a stadiometer. Resting energy expenditure was measured as described elsewhere (6, 11) using an open circuit indirect calorimeter (Deltatrac Metabolic Monitor, Datex Instruments, Helsinki, Finland). Measurements were performed between 7.00 and 8.00 a. m. in our metabolic ward at constant humidity (55 %) and room temperature (22 °C). On the day before the subjects had their last evening meal between 6.00 and 7.00 p. m. Gas exchange measurements were done continuously for at least 1 h. The first 20 min were omitted and data were integrated for 5-min intervals. The means of at least 40 measurements were presented as individual value. Calibrations of the gas analysers were performed immediately before and after the measurements. Variation caused by the technique was calculated based on five repeated measurements of propan combustion and was found to be < 4 %. The within-day coefficent of variation of the 5-min oxygen consumption values was below 7.5 %. Daily variances between individuals based on test-retest measurements in a subgroup of ten weight-stable subjects performed on three different days within a 14-day period were below 6 %. Urinary nitrogen excretion was assessed overnight (i. e. between 10 p. m. and the morning). REE was then calculated as described by Weir (12).

Bone mineral content, total and regional LBM and fat mass (FM) were measured by DEXA with a total body scanner (Hologic QDR 4500A, Hologic Inc. Waltham, MA, USA) (6, 8). DEXA-scans were analysed with the manufacturer's whole body version 5.54 (Hologic). LBM and FM data are presented as LBM_b and FM_b (for whole body), LBM_t and FM_t (for trunk) and LBM_e and FM_e (for extremities = arms+legs).

All data were recorded in database system using a personal computer, statistical analyses were performed by SPSS for Windows 5.0.2. Data are presented as means ± SD. The Mann-Whitney *U* test was used for comparison of sex differences. Pearson's correlation coefficient was calculated for testing the relationship between different quantities in a bivariate regression model. To eliminate the effect of LBM REE was adjusted according to (1): $REE_{adj.}\ 1 = REE_{measured} + [(LBM_b$group mean – LBM_bmeasured)x a] where a is the slope derived from the regression analysis between LBM_b and REE in the whole group of subjects. This value was further adjusted by regional LBM distribution according to $REE_{adj.}\ 2 = REE_{adj.}\ 1 + [(LBM_t/LBM_e$group mean – LBM_t/LBM_e measured) x b] where b is the slope from the regression analysis between LBM_t/LBM_e measured and REE in the whole group.

Results

Subject details are given in Table 1 and Table 2. At similar BMI we observed sex differences in body weight, lean body mass (LBM), fat mass (FM) and bone mineral content. Men had higher LBM and bone mass, whereas women had a higher FM. DEXA-derived body mass and body composition are presented in Table 2. Measuring regional tissue masses and tissue composition showed that trunk weight explains 46.9 % and 47.6 % of body weight in females and males, respectively (Table 2). LBM accounts for 74 and 83 % of trunk weight. Males had more limb LBM than females. Of peripheral weight 59–79 % (arms) or 58–78 % (legs) is explained by LBM. The ratio of LBM_t to LBM_e was 1.12 ± 0.06 and 0.96 ± 0.05 for females and males, respectively ($p < 0.05$). FM contributes more to peripheral than to trunk weight. FM_t was similar in both sexes, whereas FM_e was higher in females. Regional proportions of bone mineral content were similar between sexes (Table 2).

Whole body LBM showed a close correlation with REE with a non-zero intercept (Fig. 1). REE (MJ/d) could be predicted from 0.0897 x LBM (kg) + 2.0237. Similar associations were observed between REE and LBM_t and LBM_e, respectively (Fig.1). The average slope of REE on LBM_b was 89.7 kJ/kg x d. When compared to this value the average slopes of REE on LBM_t or LBM_e were higher and exceeded 100 kJ/kg x d (Fig. 1). Expressing REE per kg LBM_b showed that this value falls as LBM_b increases (Fig. 2). By contrast, expressing REE per regional LBM distribution (i. e. the ratio of LBM_t to LBM_e) showed that this parameter increases as LBM_b increases (Fig. 2).

REE was lower in females than in males (Table 3). Dividing REE by LBM_b showed that women had higher values than men (Table 3). To eliminate the effect of whole body LBM REE was adjusted for LBM by a covariate analysis. Using this method ($REE_{adj.}$ 1) men again had higher values (Tab.3). This idea was confirmed by further adjustment for the effect of regional LBM ($REE_{adj.}$ 2) (Table 3).

Table 2 The percentage contribution of fat, lean body mass (LBM) and bone mineral content determined by DEXA (dual-energy x-ray absorptiometry) to the mass of whole body and major body segments in healthy young adults

	females n=13	males n=13
Whole body		
Mass (kg)	58.14 (± 9.63)**	70.22 (± 8.22)
FM_b[1] (%)	30.35 (± 5.13)**	16.28 (± 4.33)
LBM_b[2] (%)	65.91 (± 5.07)**	79.71 (± 4.16)
BMC[3] (%)	3.72 (± 0.35)**	4.02 (± 0.36)
Trunk		
Mass (kg)	27.26 (± 4.17)**	33.45 (± 4.63)
FM_t[1] (%)	23.74 (± 6.70)**	14.95 (± 5.23)
LBM_t[2] (%)	74.03 (± 6.60)**	82.84 (± 5.01)
BMC[3] (%)	2.22 (± 0.34)	2.21 (± 0.31)
Legs		
Mass (kg)	24.14 (± 3.96)*	26.87 (± 2.66)
FM[1] (%)	38.07 (± 4.45)**	17.56 (± 4.67)
LBM[2] (%)	58.14 (± 4.43)**	77.64 (± 4.50)
BMC[3] (%)	3.79 (± 0.27)**	4.79 (± 0.31)
Arms		
Mass (kg)	6.74 (± 1.25)**	9.90 (± 1.42)
FM[1] (%)	36.13 (± 7.33)**	15.73 (± 4.01)
LBM[2] (%)	59.14 (± 7.14)**	79.34 (± 3.89)
BMC[3] (%)	4.70 (± 0.37)*	4.92 (± 0.45)

* $p < 0.05$; ** $p < 0.01$; [1] FM, fat mass; [2] LBM, lean body mass; LBM_b (whole body), LBM_t (trunk); [3] BMC, bone mineral content

Discussion

The present data confirm previous results on the assessment of major body regions by DEXA (Table 2; 8). We also found a strong and positive relationship between whole body as well as regional LBM and REE (Fig. 1). Contrary to other authors (9, 10) in our study LBM_t was

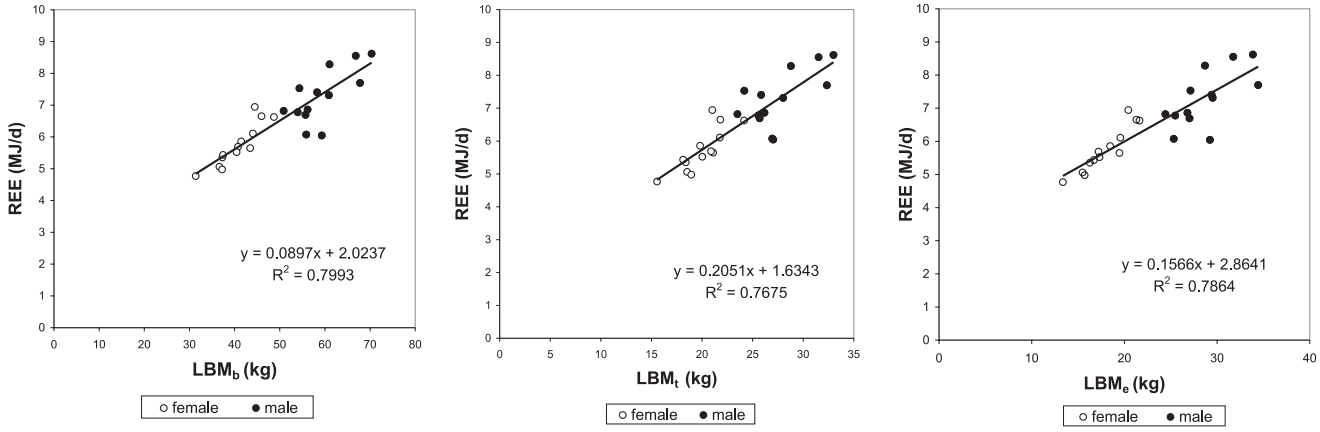

Fig. 1 Relationship between resting energy expenditure (REE) and whole body (=LBM_b), trunk (=LBM_t) and peripheral LBM (i. e. LBM of arms plus legs = $LBM_{extremities}$ = LBM_e). LBM was measured by DEXA in a group of 26 young, non-obese subjects.

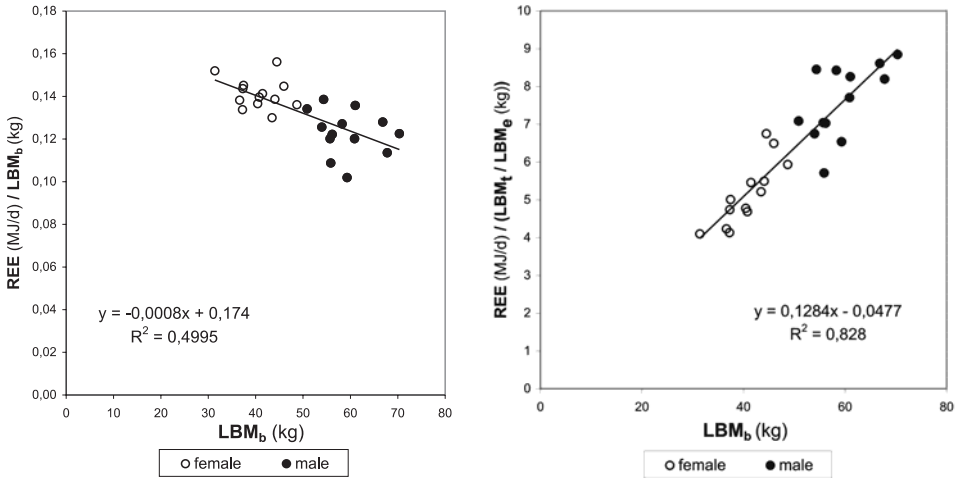

Fig. 2 Relationship between resting energy expenditure (REE) on LBM_b and LBM_b (left panel) and REE on LBM_t/LBM_e and LBM_b in 26 healthy non-obese young subjects. LBM was measured by DEXA.

Table 3 Resting energy expenditure (REE) and respiratory quotient (RQ) in 26 healthy non-obese subjects

	females (f) n=13	males (m) n=13	differences (m–f) absolute values (%)	p <
REE, MJ/d	5.74±0.68	7.28±0.85	1.54 (23.7)	0.01
MJ/kg body weight	0.095±0.009	0.092±0.006	–0.003 (3.2)	–
MJ/kg body weight^{0,75}	0.28±0.02	0.26±0.01	–0.02 (7.4)	0.05
MJ/kg LBM_b[1]	0.13±0.00	0.12±0.01	–0.01 (8.0)	0.01
adj 1[2], MJ/d	5.74±0.70	7.28±1.02	1.54 (23.7)	0.01
adj 2[3], MJ/d	5.78±0.86	7.29±1.06	1.51 (23.1)	0.01
RQ	0.84±0.05	0.85±0.06	0.01 (1.2)	–

[1] LBM_b, lean body mass (whole body); [2] REE adjusted for LBM_b according to ref. 1 (see Methods); [3] REE adjusted for LBM_b and regional lean body mass distribution LBM_t/LBM_e; LBM_t, LBM_{trunk}; LBM_e, $LBM_{extremities} = LBM_{arms+legs}$ (see Methods)

not superior to whole body or LBMe with respect to its association with REE. Regarding the correlation coefficients our data were between the results of Svendsen et al. (9) and Kistorp et al. (10). The latter authors observed stronger associations between REE and DEXA-derived whole body or regional LBM (i. e. r-values exceeding 0.9).

The new finding of our study is that the ratio of REE to LBM_t/LBM_e increases with increasing LBM_b (Fig. 2). When compared with LBM_b LBM_t has a higher visceral component. Visceral organs contribute more to REE because of their higher metabolic activity (i. e. about 1.5 MJ/kg organ weight x d; 2). The proportion of metabolically active non-muscle organ mass is, thus, a further determinant of REE. The contribution of regional LBM to LBM_b also explains the association of REE with LBM_b (see Fig. 2). The relationship between REE and LBM_b has a non-zero intercept (i. e. 2.0237 MJ/d, Fig. 1). This finding implies that a component of REE remains when there is no LBM by extrapolation. However, adjusting for LBM distribution (i. e. the LBM_t/LBM_e-ratio) results in a near-zero intercept (i. e. 0.0477 MJ/d; Fig. 2). This finding suggests that humans have a decreased proportion of highly metabolically active LBM with greater LBM. Our present data support our earlier findings based on MRI-derived estimates of organ masses (6).

Using the LBM_t/LBM_e-ratio in addition to LBM_b may be helpful to compare REE in individuals or groups differing with respect to LBM_b. Regional DEXA measurements provide a possibility to adjust raw data of REE on LBM_b for their non-zero intercept. This idea provides insight into human energy expenditure as well as into the regulation of body weight. To give two examples:

- First, absolute values of REE were higher in males than in females (Table 3). This is mainly explained by sex differences in LBM (13, 14). However, dividing REE by body weight, body weight$^{0.75}$ or by LBM_b showed that women had a higher REE than men (Table 3). This is in accordance with previous data (15, 16). However, the ratio method is misleading because of the non-zero intercept between body weight or LBM_b and REE. To overcome this problem the use of the slope of REE on LBM from the regression equation has been recommended to examine the relationship between REE and LBM (1, 15). Using that method the mean adjusted REE ($REE_{adj.}$ 1, Table 3) was again lower in women than in men (15, 16). This is also confirmed by taking into account sex diffe-

rences in regional LBM (i. e. $REE_{adj.}$ 2, Table 3, Results).

- Secondly, comparing two of our subjects markedly differing with respect to LBM_b (58.3 kg in subject 1 and 31.4 kg in subject 2) as well as with respect to LBM distribution, i. e. the LBM_t to LBM_e-ratio (i. e. 0.88 in subject 1 and 1.16 in subject 2) results in different REE values: unadjusted REE, 6.0 vs. 5.4 MJ/d, $REE_{adj.}$ for differences in LBM_b 6.1 vs. 5.9 MJ/d, $REE_{adj.}$ for LBM distribution, 5.6 vs. 6.2 MJ/d. It is evident that when compared with subject 1 subject 2 has a higher visceral component of LBM and, thus, a higher REE on LBM.

We recommend that for comparing REEs in different individuals a modified regression model should be used including an intercept of REE on LBM_b as well as of REE on regional LBM-distribution.

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