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# Evaluation of Specific Metabolic Rates of Major Organs and Tissues: Comparison Between Nonobese and Obese Women

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## Abstract

Elia (1992) identified the specific resting metabolic rates ($K_i$) of major organs and tissues in young adults with normal weight: 200 for liver, 240 for brain, 440 for heart and kidneys, 13 for skeletal muscle, 4.5 for adipose tissue and 12 for residual mass (all units in kcal/kg per day). The aim of the present study was to assess the applicability of Elia's $K_i$ values for obese adults. A sample of young women ($n$ = 80) was divided into two groups, nonobese (BMI <29.9 kg/m$^2$) and obese (BMI 30.0–43.2 kg/m$^2$). This study was based on the mechanistic model: REE = $\Sigma$ ($K_i \times T_i$), where REE is whole-body resting energy expenditure measured by indirect calorimetry and $T_i$ is the mass of individual organs and tissues measured by magnetic resonance imaging. For each organ/tissue, the corresponding Elia's $K_i$ value was analyzed respectively for nonobese and obese groups by using stepwise univariate regression analysis. Elia's $K_i$ values were within the range of 95% confidence intervals (CIs) in the nonobese group. However, Elia's $K_i$ values were outside the right boundaries of 95% CIs in the obese group and a corresponding obesity-adjusted coefficient was calculated as 0.98, indicating that Elia's values overestimate $K_i$ by 2.0% in obese adults. Obesity-adjusted $K_i$ values were 196 for liver, 235 for brain, 431 for heart and kidneys, 12.7 for skeletal muscle, 4.4 for adipose tissue, and 11.8 for residual mass. In conclusion, although Elia's $K_i$ values were validated in nonobese women, obesity-adjustments are appropriate for application in obese women.

## INTRODUCTION

One of the primary aims of human energy metabolism research is to explore the specific resting metabolic rate (i.e., $K_i$ value) for individual organs and tissues. Estimating $K_i$ values forms the basis for understanding daily energy requirements in humans, and for exploring the associations between resting energy expenditure (REE) and body composition (1–3).

Based on reported experimental results in humans and other mammals, Elia (1) presented a review on the $K_i$ values for seven organs and tissues in young adults with normal body

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**DISCLOSURE**

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weight, including 200 for liver, 240 for brain, 440 for heart and kidneys, 13 for skeletal muscle, 4.5 for adipose tissue, and 12 for residual mass (all units are in kcal/kg per day). Residual mass includes skeleton, blood, skin, gastrointestinal tract, lung, spleen, and other organs and tissues present in small amounts. According to Elia, heart and kidneys have the highest $K_i$ values, twice those for liver and brain. In contrast, the $K_i$ value of skeletal muscle is only 1/35 that of heart and kidneys. Adipose tissue has the lowest $K_i$ value among the seven organs and tissues.

Elia's study assumed that the $K_i$ values of major organs and tissues are stable across all adults. However, previous studies suggested that some biological factors influence the $K_i$ values, including growth, development and aging (3–6).

Adiposity is a major source of variations in body composition and physiological function. Adiposity difference between normal-weight and obese subjects influences body composition *per se* (e.g., fat mass and fat-free mass) and related physiological functions (e.g., mass-specific REE). However, it remains unclear whether obesity influences the $K_i$ values of major organs and tissues.

The aim of the present study was to critically compare the applicability of Elia's $K_i$ values between nonobese and obese young women.

## METHODS AND PROCEDURES

### Model development

In this study, we applied an approach that combines a mechanistic REE model with stepwise univariate regression analysis.

**Mechanistic REE model—**The mechanistic model assumes that whole-body REE is equal to the sum of the products of individual organ/tissue mass and their corresponding specific resting metabolic rates (7,8),

$$\mathrm{REE}=\sum (K_i \times T_i) \quad (1)$$

where i (i = 1, 2, …, *n*) indicates individual organ and tissue; $T_i$ is the corresponding mass; and $K_i$ is its specific metabolic rate at rest.

Seven components, including four organs (i.e., liver, brain, heart, and kidneys), two tissues (i.e., skeletal muscle and adipose tissue) and the residuals were considered in equation 1. The rational of this approach is that the four organs have the highest $K_i$ values and the two tissues are the largest components at the organ-tissue level. The following body composition model was thus applied,

$$\mathrm{BM}=T_{\mathrm{liver}}+T_{\mathrm{brain}}+T_{\mathrm{heart}}+T_{\mathrm{kidneys}}+T_{\mathrm{SM}}+T_{\mathrm{AT}}+T_{\mathrm{residual}} \quad (2)$$

where BM is body mass, and $T_{SM}$ and $T_{AT}$ are the mass of skeletal muscle and adipose tissue, respectively. Residual mass was obtained as BM minus the sum of liver, brain, heart, kidneys, skeletal muscle, and adipose tissue masses.

Substituting Elia' $K_i$ values into equation 1, a working REE model was derived,

$$\mathrm{REE}=200T_{\mathrm{liver}}+240T_{\mathrm{brain}}+440T_{\mathrm{heart}}+440T_{\mathrm{kidneys}}+13T_{\mathrm{SM}}+4.5T_{\mathrm{AT}}+12T_{\mathrm{residual}} \quad (3)$$

**Stepwise univariate regression models—**In the present study, we evaluated each Elia's $K_i$ value separately. Specifically, we performed a statistical analysis on $K_i$, when holding the remaining $K_i$ at the values suggested by Elia (1). We constructed marginal 95% confidence intervals (CIs) for each of the seven $K_i$ values via univariate linear regression analysis (9).

Our procedure can be described as follows. For liver we held $K_{\mathrm{brain}}$, $K_{\mathrm{heart}}$, $K_{\mathrm{kidneys}}$, $K_{\mathrm{SM}}$, $K_{\mathrm{AT}}$ and $K_{\mathrm{residual}}$ at 240, 440, 440, 13, 4.5, and 12, respectively. We then evaluated the specific metabolic rate of liver ($K_{\mathrm{liver}}$) with the statistical hypothesis $K_{\mathrm{liver}} = 200$ suggested by Elia (1). With equation 3, we fitted a linear regression model to our data to determine $K_{\mathrm{liver}}$,

$$\mathrm{REE}=K_{\mathrm{liver}}\times T_{\mathrm{liver}}+240T_{\mathrm{brain}}+440T_{\mathrm{heart}}+440T_{\mathrm{kidneys}}+13T_{\mathrm{SM}}+4.5T_{\mathrm{AT}}+12T_{\mathrm{residual}} \quad (4)$$

Standard least squares method yields an estimate with standard error (95% CIs) for $K_{\mathrm{liver}}$ separately for the nonobese and obese groups. The resulting 95% CIs were compared with the hypothesized $K_{\mathrm{liver}}$ value suggested by Elia. Testing the statistical hypothesis $K_{\mathrm{liver}} = 200$ at a significance level of 0.05 was tantamount to checking whether $K_{\mathrm{liver}} = 200$ falls inside the 95% CIs.

The equation 4 can also be rewritten as $\mathrm{REE}_{\mathrm{liver}} = K_{\mathrm{liver}} \times T_{\mathrm{liver}}$, by letting $\mathrm{REE}_{\mathrm{liver}} = \mathrm{REE}-(240T_{\mathrm{brain}} + 440T_{\mathrm{heart}} + 440T_{\mathrm{kidneys}} + 13T_{\mathrm{SM}} + 4.5T_{\mathrm{AT}} + 12T_{\mathrm{residual}})$, the marginal energy of liver. Therefore, we calculated the following marginal $R^2$ and $R^{2\star}$ by using $K_{\mathrm{liver}}$ in equation 4 and Elia's $K$ value (200) respectively,

$$R^2(\mathrm{liver})=1-(\mathrm{REE}_{\mathrm{liver}}-K_{\mathrm{liver}}\times T_{\mathrm{liver}})^2/(\mathrm{REE}_{\mathrm{liver}})^2, \quad (5)$$

$$R^{2\star}(\mathrm{liver})=1-(\mathrm{REE}_{\mathrm{liver}}-200T_{\mathrm{liver}})^2/(\mathrm{REE}_{\mathrm{liver}})^2. \quad (6)$$

The same procedure was repeated for each of the other six $K_i$ values (i.e., $K_{\mathrm{brain}}$, $K_{\mathrm{heart}}$, $K_{\mathrm{kidney}}$, $K_{\mathrm{SM}}$, $K_{\mathrm{AT}}$ and $K_{\mathrm{residual}}$) in the nonobese and obese women.

**Adiposity-stratified $K_i$ value model—**The working REE model (equation 3) is based on an assumption that the $K_i$ values of individual organs and tissues are stable across all healthy adults. In the present study, the subjects were divided into two groups, nonobese and obese, in order to assess the potential influence of adiposity on the $K_i$ values. We consider the following adiposity-stratified REE model,

$$\mathrm{REE}=\sum(O_i\times \text{Elia's } K_i\times T_i) \quad (7)$$

where $O_i$ represents the adiposity-adjusted coefficient for Elia's $K_i$ values. In this study, we made an assumption that the adiposity-adjusted coefficients are the same across all organs and tissues for each group, i.e., $O_i = O$. In other words, we applied a simplified adiposity-stratified REE model,

$$\mathrm{REE}=O\times(200T_{\mathrm{liver}}+240T_{\mathrm{brain}}+440T_{\mathrm{heart}}+440T_{\mathrm{kidneys}}+13T_{\mathrm{SM}}+4.5T_{\mathrm{AT}}+12T_{\mathrm{residual}}) \quad (8)$$

Once the $O$ values in equation 8 were estimated by fitting a univariate linear regression, an adiposity-adjusted $K_i$ values can be calculated for the nonobese and obese groups, respectively,

$$\text{Adiposity}-\text{adjusted } K_i=O\times\text{Elia's } K_i \quad (9)$$

## Subjects

REE-organ/tissue subject data were collected at the Institute of Human Nutrition and Food Science, Christian-Alberchts University, Kiel, Germany. All of the subjects participated in earlier reported studies (10,11). The approvals of institutional review boards were obtained for all of the studies and subjects signed an informed consent. In order to exclude the potential influences of growth, development, aging, gender, race and diseases on the $K_i$ values, only nonelderly (20–49 years) healthy female subjects were included in this study. All subjects were white women ($n$ = 80) who were divided into two groups, nonobese ($n$ = 51, BMI <29.9 kg/m$^2$) and obese ($n$ = 29, BMI ≥30 kg/m$^2$).

## Body composition

Body mass was measured to the nearest 0.1 kg in fasting subjects wearing minimal clothing. Height was measured with a stadiometer to the nearest 0.1 cm.

The volumes of six organs and tissues (i.e., liver, brain, heart, kidneys, skeletal muscle, and adipose tissue) were obtained by summing pixels from images obtained with a 1.5-T Magnetom Vision scanner (Siemens, Erlangen, Germany). The magnetic resonance imaging (MRI) protocol details have been previously described in detail elsewhere (10,12). All MRI images were segmented manually (TomoVision 4.3 Software; Slice-O-Matic, Montreal, Quebec, Canada). Each organ and tissue was analyzed by the same observer who was blinded to the time point and subject identity. The intra-observer coefficients of variation based on comparison of repeated segmentations were 0.07% for liver, 1.8% for brain, 1.7% for heart, and 1.0% for kidneys. The technical errors for measurement of the same scan on two separate days by the same observer of MRI-derived SM and AT volumes are 0.7 ± 0.1% and 1.1 ± 1.2% (mean ± s.d.), respectively.

Organ and tissue mass was calculated as the sum of all cross-sectional areas multiplied by the slice thickness and slice gaps,

$$\text{Oragan/tissue mass}=d\times(t+g)\times\sum((S_i+S_i+1)/2) \quad (10)$$

where S is the organ/tissue cross-sectional area; i is the image number; $t$ is the thickness of each image; $g$ is the gap (distance) between consecutive images, and $d$ is the density of each organ and tissue.

Total body fat mass was measured with a dual-energy X-ray absorptiometry scan (Hologic QDR 4500A; Hologic, Waltham, MA, software version V8.26a:3). Subjects lay supine with arms and legs at their sides during the 10-min scanning. The between-measurement technical error for fat in the same subject is 1.2%. In some subjects skeletal muscle and adipose tissue masses were calculated from dual-energy X-ray absorp-tiometry-estimation, as previously described (10). Skeletal muscle mass was predicted from appendicular lean-

soft tissue (13); and adipose tissue mass was predicted from fat mass, assuming a stable fat content of 80% (14).

### REE

In the present study, indirect calorimetry technique was applied to estimate REE with subjects in a postabsorptive state. The REE protocol details have been previously described in detail elsewhere (10). No food or calorie containing beverages were consumed after 7:00 pm until the REE and all body composition tests were completed the following morning. REE was measured between 7:00 amand 9:00 amwith subjects resting comfortably on a bed with a plastic transparent ventilated hood placed over their heads for 30 min. Continuous gas exchange measurements (Vmax Spectra 29n; SensorMedics, Bilthoven, Netherlands) were made to analyze the rates of $O_2$ consumption and $CO_2$ production.

### Statistical analysis

Group means and their s.d. of body composition and REE were calculated. Two-sided Student's *t* tests at a statistical significance level of 0.05 were used to test the differences in body composition and REE between the nonobese and obese groups. Elia's $K_i$ values for the seven organs and tissues were applied to predict REE and examine the association between measured REE (REEm) and predicted REE (REEp) by means of simple linear regression analysis. The marginal 95% CIs for the seven $K_i$ values were constructed via stepwise univariate linear regression analysis (9). The database was analyzed by programming in *R*, version 2.10.0, a software for statistical computing and graphics initially written by Robert Gentleman and Ross Ihaka, Statistics Department, University of Auckland (Auckland, New Zealand) (15).

## RESULTS

### Subject characteristics and body composition

The characteristics and body composition of the two groups are presented in Table 1. Body mass, BMI, fat mass and %fat were all significantly different between the two groups (non-obese group < obese group, all $P < 0.001$). However, there were no significant differences in age, height and bone mineral contents between the two groups.

The masses of four high metabolic rate organs (i.e., liver, brain, heart, and kidneys) and three low metabolic rate tissues (i.e., skeletal muscle, adipose tissue, and residual mass) are presented in Table 2. There were significant differences in all seven organs and tissues between the two groups (nonobese group < obese group, all $P < 0.001$).

### Measured and predicted REE

The REEm values for the two groups are reported in Table 2. The REEm in the nonobese women was significantly lower than that in the obese women (1,409 ± 139 vs. 1,788 ± 229 kcal/day, $P < 0.001$). According to equation 3, the REEp was 1,402 ± 132 kcal/day for the nonobese women and 1,822 ± 239 kcal/day for the obese women (Table 2). The REEm were correlated with REEp in both groups (Figure 1a,b). Although the (REEm – REEp) was not significantly different from 0 in the nonobese women (7 ± 67 kcal/day, $P = 0.46$), the (REEm – REEp) was significant in the obese women (−34 ± 78 kcal/day, $P = 0.025$). The plots between (REEm – REEp) and adiposity for all subjects pooled show that (REEm – REEp) is negatively correlated with both BMI ($r = -0.31$, $P < 0.01$; Figure 2a) and %fat ($r = -0.276$, $P < 0.05$; Figure 2b).

### Evaluation of $K_i$ values

We thus further evaluated the applicability of Elia's $K_i$ values in the two groups. By using stepwise univariate analysis, the 95% CIs of individual $K_i$ values were calculated (Table 3). For the nonobese women, Elia's $K_i$ values were located within the 95% CIs for each of the seven organs and tissues. For the obese group, however, Elia's $K_i$ values were outside the right boundaries of 95% CIs for all seven organs and tissues (Figure 3). The coefficients of determination, $R^2$ and $R^{2\star}$, were calculated (Table 4) as the proportion of marginal variability reduction due to each marginal model of respective organ/tissues.

Based on equation 8, adiposity-adjusted coefficient of the nonobese group was calculated as $O = 1.004$ ($P = 0.52$) that is not significantly different from 1. On the contrary, adiposity-adjusted coefficients of the obese group was $O = 0.980$ ($P = 0.012$) that is significantly different from 1. A simplified model with a unified parameter $O$ for all women resulted in an estimate $O = 0.992$ ($P = 0.142$). By comparing Akaike information criterion (16) and performing ANOVA test (Table 5), the adiposity-stratified model 8 is preferred and thus, adiposity adjustment is necessary for Elia's $K_i$ values for obese women. According to equation 9, the obesity-adjusted $K_i$ values were 196 for liver, 235 for brain, 431 for heart and kidneys, 12.7 for skeletal muscle, 4.4 for adipose tissue, and 11.8 for residual mass (all in kcal/kg per day, Table 6).

## DISCUSSION

The present study applied two approaches to evaluate the applicability of Elia's $K_i$ values in obese adults. The first approach was to compare REEp with REEm, in which REEp is calculated by equation 3 with Elia's $K_i$ values. If the REEm – REEp difference is not significantly different from zero, we may consider that Elia's $K_i$ values are applicable for this group.

For the nonobese women, the REEp and REEm were in good correlation ($r = 0.88$, $P < 0.001$), and the REEm – REEp difference (7 ± 67 kcal/day) was not significantly different from zero ($P = 0.46$), supporting the applicability of Elia's $K_i$ values. These results were confirmed by previous observations for young adults with normal weight (7,10). Another study also suggested no evidence for the mass dependency of $K_i$ values in subjects with a normal fat mass (11). Our results showed that Elia's $K_i$ values were located within the 95% CIs for the nonobese young women, further validating the applicability of Elia's $K_i$ values in nonobese women.

For the obese women, REEp were significantly higher than REEm by 34 ± 78 kcal/day or 1.9% ($P = 0.025$), revealing that Elia's study overestimated actual $K_i$ values in the obese group. Moreover, we found that there were negative correlations between (REEm – REEp) and adiposity, either in terms of BMI ($r = -0.314$, $P < 0.01$; Figure 2a) or %fat ($r = -0.276$, $P < 0.05$; Figure 2a), suggesting that actual $K_i$ values with greater adiposity should be lower than that suggested by Elia. In order to further evaluate the applicability of Elia's $K_i$ values in obese adults, another approach was applied with stepwise univariate analysis. Elia's $K_i$ values were outside the right boundary of the 95% CIs for the seven organs and tissues (Figure 3). This observation demonstrates that Elia's $K_i$ values overestimate actual $K_i$ values in obese adults. Although the amount of drop in each $K_i$ value is likely to be overly stated because of the marginal approach, our proposed model as specified by equations 8 and 9 distribute the total drop proportionally to all the organs via an obesity-adjusted coefficient ($O = 0.980$, $P = 0.012$). This coefficient $O$ may therefore be interpreted as the average effect of adiposity and should be applied for this group of adults (Tables 5 and 6).

As with the organ-tissue level REE model (i.e., equation 1), REE can be expressed at the cellular level (8),

$$\mathrm{REE}=\sum(J_i \times C_i) \quad (11)$$

where C is the mass of individual cell categories; i is the cell category number (i = 1, 2, …, n); and *J* is the specific resting metabolic rate of individual cell categories. Equation 11 reveals that the magnitude of REE is determined by the mass of individual cell categories ($C_i$) and their corresponding $J_i$ values. Given an individual organ/tissue, the following model can be derived linking the organ-tissue level with the cellular level,

$$K_i \times T_i = J_i \times C_i \text{ or } K_i = J_i \times (C_i/T_i) \quad (12)$$

where ($C_i/T_i$) represents the cellularity of individual organ and tissue. Equation 12 reveals that the magnitude of $K_i$ values is determined by cellularity of individual organs and tissues and their corresponding $J_i$ values.

Our results showed that the $K_i$ values in the obese women were lower by 2.0% (i.e., $O$ = 0.980) compared to Elia's $K_i$ values. According to equation 12, there are two possible explanations for this observation. First, the low $K_i$ values in obese adults may be caused by low $J_i$ values. Although there is a need to measure the $J_i$ values of individual cell categories, *in vivo* quantification of the $J_i$ values requires noninvasive methods that remain technically demanding (17,18). Positron emission tomography with $^{15}O$ or $^{11}C$ markers may allow for *in vivo* quantification of organ/tissue energy consumption (19). Further study is needed to measure the $J_i$ values of major organs and tissues in normal-weight and obese adults.

Second, the cellularity of individual organs and tissues may be lower in the obese adults than in nonobese adults, due to fatty infiltration. In support of this explanation, previous studies reported an increase in the amount of lipid contained with skeletal muscle fibers and liver in obese adults (20–22). In the present study, MRI cross-sectional scans were segmented manually, and small amounts of adipose tissue within skeletal muscle bundles (i.e., intra-muscular adipose tissue, IMAT) were removed. However, small area of IMAT may remain within SM cross-sectional area that cannot be manually removed that causes a relatively low cellularity in obese adults. In nonobese adults, for example, the cellularity of IMAT-free skeletal muscle can be assumed as 0.60 (i.e., $C_{SM}/T_{SM}$ = 0.60). Giving 3% IMAT in skeletal muscle, its cellularity decreases from 0.60 to 0.58, (i.e., $C_{SM}/(1.03 \times T_{SM})$ = 0.58). Assuming the $J_i$ value remains stable, according to equation 12, the corresponding $K_i$ value decreases by about 2% in obesity. As the MRI protocol applied in the present study is not able to determine the concentration of fat within organs and tissues, further study is needed to estimate the fat content of major organs and tissues by using noninvasive techniques such as $^1H$-magnitic resonance spectroscopy (20).

There is another limitation in the present study. In some subjects, adipose tissue mass was calculated from dual-energy X-ray absorptiometry fat estimation, based on an assumption of a constant fat content (80%) in adipose tissue (14). However, a higher fat content of adipose tissue in obese subjects would lead to an overestimation of adipose tissue mass and corresponding underestimation of residual mass.

In conclusion, although applicable in nonelderly nonobese adults, Elia's study overestimates the $K_i$ values by 2% in obese adults, so that obesity-modified $K_i$ values should be applied. This study thus helps to understand the inherent relationship between REE and body

composition in obese adults. A more comprehensive and precise quantification of the association between $K_i$ values and adiposity is certainly an important topic for future studies.

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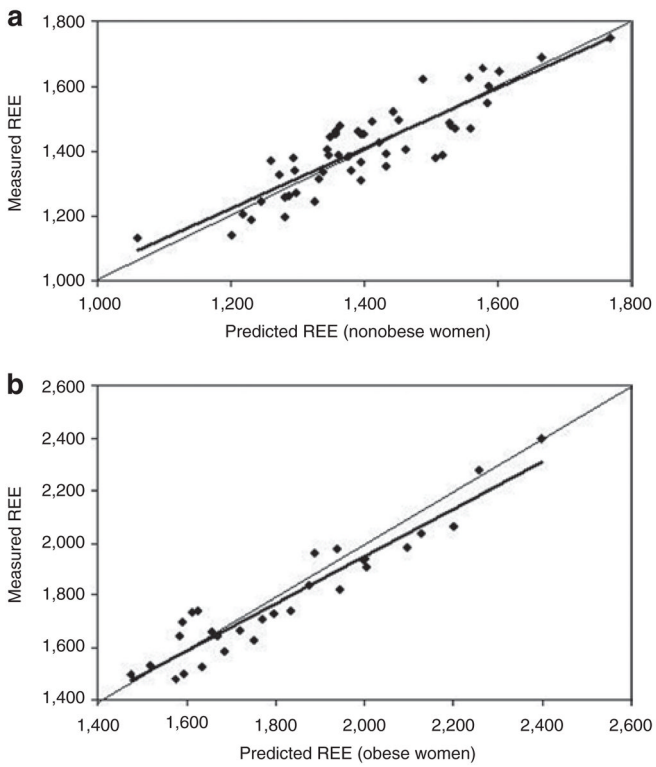


**Figure 1.**

Measured resting energy expenditure (REEm, in kcal/day) vs. predicted REE (REEp) for the (**a**) nonobese women and (**b**) obese women. REEp were calculated by the $K_i$ values suggested by Elia (1), according to equation 3. The lines of identity are shown. (**a**) REEm = 0.925 × REEp + 112, $r = 0.879$, $P < 0.001$, $n = 51$ nonobese women. (**b**) REEm = 0.906 × REEp + 138, $r = 0.946$, $P < 0.001$, $n = 29$ obese women.

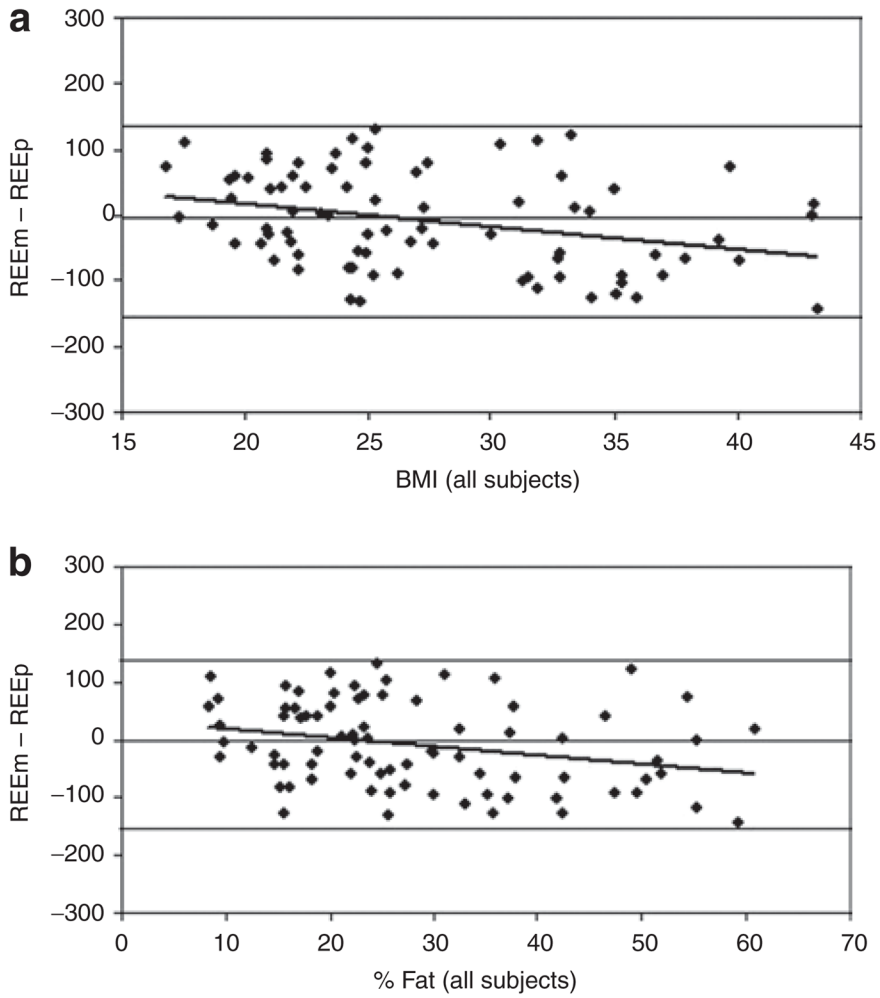


**Figure 2.**

The difference between measured and predicted resting energy expenditure (REEm – REEp, in kcal/day) vs. (**a**) BMI (in kg/m$^2$) and (**b**) %fat for all subjects ($n$ = 80). REEp was calculated using the $K_i$ values suggested by Elia (1), according to equation 3. The zero difference line and the lines representing 2 s.d. for the REE differences (−155 and 139 kcal/day) are shown. (**a**) (REEm – REEp) = 85.7 − 3.43 × BMI; $r$ = −0.314, $P < 0.01$. (**b**) (REEm – REEp) = 34.7 − 1.52 × %fat; $r$ = −0.276, $P < 0.05$.

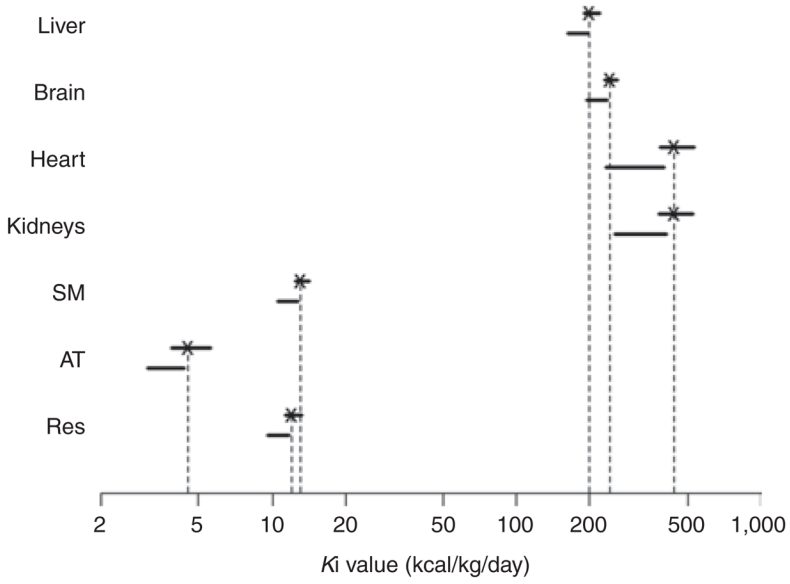


**Figure 3.**

95% Confidence intervals (CIs) for the $K_i$ values of seven organs and tissues, fitted by stepwise univariate analysis are shown on a logarithmic scale, for the nonobese women (upper line) and the obese women (lower line). The Xs represent the $K_i$ values suggested by Elia (1). AT, adipose tissue; Res, residual mass; SM, skeletal muscle.

## Table 1

Baseline subject characteristics

| | Nonobese women | Obese women | *P* |
|---|---|---|---|
| *n* | 51 | 29 | |
| Age (years) | 32.7 ± 8.1 | 33.3 ± 6.9 | 0.74 |
| Body mass (kg) | 65.8 ± 9.0 | 100.2 ± 16.9 | <0.001 |
| Height (m) | 1.69 ± 0.06 | 1.68 ± 0.07 | 0.44 |
| BMI ($kg/m^2$) | 22.9 ± 2.8 | 35.1 ± 3.8 | <0.001 |
| Fat mass (kg) | 19.7 ± 5.8 | 43.0 ± 9.1 | <0.001 |
| %Fat | 30.0 ± 6.3 | 43.2 ± 3.4 | <0.001 |
| BMC (kg) | 2.32 ± 0.31 | 2.40 ± 0.24 | 0.23 |

All values are mean ± s.d. *P* value, *t* test for significant difference between the nonobese and obese women.

%fat, percentage of body mass as fat mass; BMC, bone mineral content.

**Table 2**

Organ/tissue mass and REE results

| | Nonobese women | Obese women | *P* |
|---|---|---|---|
| Liver (kg) | 1.27 ± 0.18 | 1.69 ± 0.30 | <0.001 |
| Brain (kg) | 1.27 ± 0.08 | 1.41 ± 0.13 | <0.001 |
| Heart (kg) | 0.26 ± 0.05 | 0.32 ± 0.06 | <0.001 |
| Kidneys (kg) | 0.25 ± 0.04 | 0.35 ± 0.07 | <0.001 |
| Skeletal muscle (kg) | 21.4 ± 3.2 | 25.5 ± 4.1 | <0.001 |
| Adipose tissue (kg) | 20.9 ± 5.7 | 44.0 ± 9.4 | <0.001 |
| Residual mass (kg) | 20.6 ± 3.0 | 26.8 ± 5.0 | <0.001 |
| REEm (kcal/day) | 1409 ± 139 | 1788 ± 229 | <0.001 |
| REEp (kcal/day) | 1402 ± 132 | 1822 ± 239 | <0.001 |
| REEm – REEp (kcal/day) | 7 ± 67 | −34 ± 78 | 0.34 |

**Table 3**

95% Confidence intervals of $K_i$ of organs and tissues

| Organ/Tissue | Elia's $K_i$ value | 95% Confidence intervals of $K_i$ and $P$ value | |
|---|---|---|---|
| | | Nonobese women | Obese women |
| Liver | 200 | 191, 220 | 163, 196 |
| | | $P = 0.49$ | $P = 0.017$ |
| Brain | 240 | 230, 260 | 194, 234 |
| | | $P = 0.49$ | $P = 0.011$ |
| Heart | 440 | 388, 532 | 232, 402 |
| | | $P = 0.58$ | $P = 0.005$ |
| Kidneys | 440 | 381, 528 | 252, 411 |
| | | $P = 0.70$ | $P = 0.008$ |
| Skeletal muscle | 13 | 12.4, 14.2 | 10.5, 12.7 |
| | | $P = 0.48$ | $P = 0.013$ |
| Adipose tissue | 4.5 | 3.9, 5.6 | 3.1, 4.4 |
| | | $P = 0.56$ | $P = 0.022$ |
| Residual mass | 12 | 11.4, 13.2 | 9.6, 11.7 |
| | | $P = 0.55$ | $P = 0.012$ |

All units of $K_i$ values are in kcal/kg per day. $P$, $P$ value of testing $H_0$: $K_i$ equals to the coefficient suggested by Elia (1).

## Table 4

Coefficients of determination for each marginal model

| Organ/Tissue | Elia's $K_i$ value[a] | Marginal $R^2$ and $R^{2\star}$[b] | | |
|---|---|---|---|---|
| | | All subjects | Nonobese women | Obese women |
| Liver | 200 | $R^2 = 0.94$ | $R^2 = 0.94$ | $R^2 = 0.94$ |
| | | $R^{2\star} = 0.94$ | $R^{2\star} = 0.94$ | $R^{2\star} = 0.93$ |
| Brain | 240 | $R^2 = 0.95$ | $R^2 = 0.96$ | $R^2 = 0.94$ |
| | | $R^{2\star} = 0.95$ | $R^{2\star} = 0.96$ | $R^{2\star} = 0.93$ |
| Heart | 440 | $R^2 = 0.71$ | $R^2 = 0.77$ | $R^2 = 0.67$ |
| | | $R^{2\star} = 0.70$ | $R^{2\star} = 0.76$ | $R^{2\star} = 0.60$ |
| Kidneys | 440 | $R^2 = 0.72$ | $R^2 = 0.75$ | $R^2 = 0.67$ |
| | | $R^{2\star} = 0.71$ | $R^{2\star} = 0.75$ | $R^{2\star} = 0.64$ |
| SM | 13 | $R^2 = 0.94$ | $R^2 = 0.95$ | $R^2 = 0.94$ |
| | | $R^{2\star} = 0.94$ | $R^{2\star} = 0.95$ | $R^{2\star} = 0.93$ |
| AT | 4.5 | $R^2 = 0.77$ | $R^2 = 0.71$ | $R^2 = 0.83$ |
| | | $R^{2\star} = 0.76$ | $R^{2\star} = 0.70$ | $R^{2\star} = 0.80$ |
| Residual mass | 12 | $R^2 = 0.93$ | $R^2 = 0.94$ | $R^2 = 0.94$ |
| | | $R^{2\star} = 0.93$ | $R^{2\star} = 0.94$ | $R^{2\star} = 0.92$ |

AT, adipose tissue; SM, skeletal muscle.

[a] All units of $K_i$ values are in kcal/kg per day.

[b] $R^2$: the proportion of marginal variability reduction by fitting marginal model of respective organ/tissue. To make comparisons, the proportion of marginal variability reduction by directly applying Elia's coefficient was calculated as $R^{2\star}$.

**Table 5**

Adiposity-stratified model and un-stratified model

| Model | Coefficient O | *P* value | AIC[a] | df | ANOVA[b] |
|---|---|---|---|---|---|
| All sample | 0.992 (0.982, 1.003) | 0.142 | 916 | 1 | 0.018 ($P < 0.05$) |
| Adiposity-Stratified | 1.004 (0.990, 1.018)[c] | 0.544 | 912 | 2 | |
| | 0.980 (0.966, 0.994)[d] | 0.006 | | | |

[a] Akaike information criterion (AIC); a model with a smaller AIC is preferred.

[b] A goodness-of-fit test.

[c] %95 confidence interval (CI) for nonobese women ($n = 51$).

[d] %95 CI for obese women ($n = 29$).

## Table 6

Adiposity-adjusted organ and tissue specific metabolic rates ($K_i$) and their 95% confidence intervals (CIs)

| | | Adiposity-adjusted $K_i$ values and (95% CIs) | |
|---|---|---|---|
| **Organ/Tissue** | **Elia's $K_i$ value** | **Nonobese women** | **Obese women** |
| Liver | 200 | 201 (198, 204) | 196 (193, 199) |
| Brain | 240 | 241 (238, 244) | 235 (231, 239) |
| Heart | 440 | 442 (436, 448) | 431 (424, 438) |
| Kidneys | 440 | 442 (436, 448) | 431 (424, 438) |
| Skeletal muscle | 13 | 13.1 (12.9, 13.2) | 12.7 (12.5, 12.9) |
| Adipose tissue | 4.5 | 4.52 (4.46, 4.58) | 4.41 (4.34, 4.48) |
| Residual mass | 12 | 12.1 (11.9, 12.2) | 11.8 (11.6, 12.0) |

All units of $K_i$ values are in kcal/kg per day.