Basal energy expenditure in southern Chinese healthy adults: measurement and development of a new equation

Xiaojiao Yang1, Ming Li1, Deqian Mao2, Guo Zeng1, Qin Zhuo2, Wen Hu3, Jianhua Piao2*, Xiaoguang Yang2 and Chengyu Huang1*

1Department of Nutrition and Food Safety, West China School of Public Health, Sichuan University, Chengdu 610041, People’s Republic of China
2National Institute for Nutrition and Food Safety, Chinese Center for Disease Control and Prevention, Beijing 100050, People’s Republic of China
3Department of Clinical Nutrition, West China Hospital, Sichuan University, Chengdu, People’s Republic of China

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The objective of the present study is to measure basal energy expenditure (BEE) using the Cosmed K4b2 portable metabolic system (Rome, Italy) and to develop a new predictive equation for BEE in southern Chinese adults. A total of 165 healthy Chinese adults aged 18–45 years with normal body weight were involved in the present study. BEE was measured by Cosmed K4b2. Body composition was determined by body composition analysers (ImpediMed DF50, QLD, Australia). Multiple linear regression analysis and correlation analysis were applied to develop a new optimal equation for predicting BEE of southern healthy Chinese adults. Measured BEE (mBEE) of southern Chinese healthy adults was 5513 (SEM 96) kJ/d, which was similar to the results predicted by the equation developed by of Liu 5579 (SEM 57) kJ/d (P=0.37) and significantly lower than those from equations developed by Henry (5763 (SEM 54) kJ/d), Schofield (5898 (SEM 58) kJ/d) and Harris–Benedict (HB; 5863 (SEM 51) kJ/d) (all P<0.001). The optimal equation developed by our data was BEE (kJ/d) = 277 + 89 weight (kg) + 600 sex (male = 1 and female = 0) (r² = 0.48, n 165). For males, BEE (kJ/d) = 105 weight (kg) – 58 (r² = 0.27, n 79); for females, BEE (kJ/d) = 69 weight (kg) + 1335 (r² = 0.24, n 86). In conclusion, the mBEE of southern Chinese healthy adults was 5513 (SEM 96) kJ/d. The BMR of Chinese adults of normal weight is overestimated by widely used prediction equations developed by Henry, Schofield and HB. The equation developed in the present study (equation 7) can be used in predicting BEE for Chinese adults aged 18–45 years with normal body weight.

Basal energy expenditure: Chinese adults: Indirect calorimetry: Predictive equations

China is currently facing challenges of both overweight and underweight. Obesity and overweight are major risk factors for developing non-communicable chronic diseases, including type 2 diabetes, CVD, hypertension and stroke, and certain forms of cancer1,2. This burgeoning public health concern has prompted numerous interventions to facilitate healthy weight management. However, to design an appropriate weight loss intervention for this population, it is essential to accurately assess their energy requirement. This assessment is best accomplished by measuring the basal energy expenditure (BEE) of each subject. BEE can be measured using devices such as direct and indirect calorimeters and respiratory chambers, but the operation of these devices requires trained personnel and it is expensive and time consuming. For these reasons, calculation of BEE by mathematical equations has been adopted as a major method of assessing the energy requirement of individuals3.

However, there exist several published empirical equations for estimating BEE from anthropometrical variables, including body weight, height, age and sex of healthy adult subjects. In practice, these equations are routinely used to estimate energy requirements. For instance, Chinese recommended nutrient intakes of energy are derived from the FAO/WHO/UNU equations to predict BEE. However, FAO/WHO/UNU equations were developed using the Schofield database that contained a disproportionate number – 3388 out of 7173 (47 %) – of Italian subjects. The Schofield database contained relatively few subjects from the tropical regions4,5. BEE studies conducted more recently have shown that the predicted values using the FAO/WHO/UNU equations overestimated BEE in Asian and Chinese subjects4,6,7.

With the emergence of new advanced technology in recent years, measurements of BEE have become easier and more reproducible, providing a good opportunity to re-examine BEE and estimating total energy requirements. Although there is now a considerable body of BEE data from individuals living in Western countries, there are still relatively few data on individuals living in other parts of the world. Moreover, there is a glaring lack of BEE data from mainland China4. Hence, the purpose of the present study was to measure...
BEE of southern Chinese healthy adults and to develop a new equation for predicting BEE in southern Chinese healthy adults.

Materials and methods

Subjects

A total of 165 recruited healthy Chinese adults aged 18–45 years with normal body weight (BMI, 18.5–24.0 kg/m²) were involved in the present study. All the subjects were from the southern areas of the Yangtze River (China) and had been living in Chengdu for at least 2 years. They were recruited through notice-board postings and at university lectures for students. Subjects with thyroid diseases, insulin-dependent diabetes mellitus, renal diseases, chronic obstructive pulmonary disease, under medication, history of recent weight loss, unusual dietary practices and women with irregular menstrual cycles, or who were pregnant or lactating were excluded. The data of eight subjects were obtained for students. Subjects with thyroid diseases, recruited through notice-board postings and at university were involved in the present study. All the subjects were from the southern areas of the Yangtze River (China) and were involved in the present study. All the subjects were financially compensated for participating in the present study.

The determination of basal energy expenditure

BEE was measured from pulmonary gas exchange using a breath-by-breath portable gas analyser (Cosmed K₄b², Rome, Italy). Subjects were instructed to refrain from eating for at least 12–14 h after a meal low in fat and dietary fibre and to avoid smoking, drinking and doing vigorous exercises during the measurement period. Moreover, female subjects were instructed to schedule their appointments to avoid the menstrual period because of the requirement for 24 h urinary nitrogen analysis, which was involved in BEE calculation.

Subjects had been asked to stay in a hotel and become accustomed to the apparatus, face mask and the surrounding environment on the day before the experiment day. All calorimetric measurements were performed by one investigator according to standardised protocols. BEE measurements were performed in the morning for at least 6 min at a thermoneutral room with a temperature of 24–27°C and a relative humidity of 64–79 ± 8.96%. The subjects were awakened from sleep, kept fully awake and laid down quietly and completely relaxed during the measurements. BEE was repeatedly measured in the same individual on consecutive 2 d, and steady-state data in the 2 d were averaged and were used for the analysis of BEE. Steady-state data here meant a total of 12 min of data in the 2 d with a breath-by-breath record on O₂ consumption and CO₂ production in which values were within mean and 2 SD.

The Cosmed K₄b² contains a portable unit (a part of the Cosmed K₄b² that contains O₂ and CO₂ analysers) and three face masks with different sizes. The flexible face mask, covering a subject’s mouth and nose, was attached to a flow meter. The flow meter is a bidirectional digital turbine. The face mask was secured to the subjects with a nylon mesh hairnet and Velcro straps. A disposable gel seal was placed between the face mask and the subject’s face to provide an airtight seal. Before each test, the Cosmed K₄b² system was warmed up for at least 45 min, with O₂ and CO₂ analysers calibrated using ambient air and reference gas with 16% O₂ and 5% CO₂. The flow meter was calibrated by a 3 litre syringe (Quinton Instruments, Seattle, WA, USA).

On the day that BEE was measured, urine was collected over a 24 h period to measure daily urinary nitrogen (g/d). Total urinary nitrogen was determined by a standard Kjeldahl method. BEE was calculated using O₂ consumption, CO₂ production and urinary nitrogen production with the Weir equation:

\[
\text{BEE (kcal/d)} = 3.941 \times V_{O2} + 1.106V_{CO2} - 2.17 \times UN
\]

Here, \(V_{O2}\) represents O₂ consumption in l/d; \(V_{CO2}\) represents CO₂ production in l/d; UN represents 24 h urinary nitrogen production in g/d.

Comparison between the measured basal energy expenditure and the predicted values using predictive equations in the literature

The predictive equations of Harris–Benedict (HB)\(^{11}\), Schofield \(\text{et al.}\lbrack^{12}\rbrack\), Liu \(\text{et al.}\lbrack^{13}\rbrack\) and Henry\(^{5}\) were used for calculating BEE. These equations were chosen because they had been widely used in healthy Chinese population studies (equations of HB and Schofield), derived based on a Chinese database (Liu equation), or reported to be better suitable for a Chinese population (Henry equation)\(^{14}\).

Measurement of body composition and body surface area

Standing height (± 1 mm) and weight (± 0.01 kg, A&D, HW100KGL, Japan) were measured after the measurement of BEE. Fat-free mass (FFM) was assessed by means of bioelectrical impedance analysis; resistance and reactance were measured while the subjects were in the supine position using an ImpediMed body composition analyser according to the manufacturer’s instructions (ImpediMed IMP DF50, QLD, Australia; 50 kHz). The value for FFM was calculated using the following equations\(^{15}\):

\[
Z = (r^2 + c^2)^{0.5}
\]

\[
\text{FFM} = 0.340H^2/Z + 0.153H + 0.273W - 0.127A + 4.56S - 12.44
\]

where \(Z\) is the bioelectrical impedance in \(\Omega\); \(r\) is the resistance in \(\Omega\); \(c\) is the reactance in \(\Omega\); FFM is measured in kg; \(H\) is the height in cm; \(W\) is the weight in kg; \(A\) is the age in year; \(S\) is the sex (male = 1 and female = 0).
Body surface area (BSA) was calculated using the following formula proposed by Zhao et al.\(^\text{(16)}\). For men, BSA (\(m^2\)) = 0.00607 height (cm) + 0.0127 weight (kg) − 0.06981. For women, BSA (\(m^2\)) = 0.00586 height (cm) + 0.0126 weight (kg) − 0.0461\(^\text{(17)}\).

**Data analysis**

Statistical analysis was performed using the SPSS software package for MS Windows (release 15.0; SPSS, Inc., Chicago, IL, USA) and Microsoft Excel 2003. Statistical significance was set at \(P<0.05\) (two-sided test). The relationship between measured BEE and the predictive variables was assessed using Pearson’s correlation. Independent variables were FFM, BSA, body weight, height, sex and age. Multiple regressions were used to derive a new prediction equation to estimate BEE. The coefficient of determination (\(r^2\)), the coefficient of determination (\(r^2\), SEM and the residual standard deviation (RD) were generated in the linear regression analyses as measures of goodness of fit of the newly developed equations. The relationship between BEE measured by Cosmed K\(_4\)b\(^2\) and the corresponding BEE calculated from predictive equations was assessed using Student’s paired \(t\) test (statistical difference between means).

**Results**

**Anthropometric characteristics and measured basal energy expenditure of subjects**

Males were taller and heavier, and had greater FFM and greater BSA than females (\(P<0.001\)). However, no significantly statistical differences were detected for age (\(P=0.78\)) and BMI (\(P=0.37\)) between the male and the female subjects. Results revealed that the males had a higher BEE, consumed more \(O_2\) and produced more \(CO_2\) than females (\(P=0.001\)) (Tables 1 and 2).

**Correlation between the measured basal energy expenditure and predictive variables**

According to Pearson correlation analysis, the measured BEE (mBEE) correlated best with BSA (\(r=0.70\)) and FFM (\(r=0.69\)). Both BSA and FFM correlated well with weight, height and sex (\(r=0.97, 0.92\) and 0.84; \(r=0.91, 0.69\) and 0.87, respectively, \(P<0.001\)) (Table 3). When BEE was adjusted for weight, BSA and FFM, the males had a higher BEE adjusted for weight and BSA (104 kJ/kg weight, 3626 kJ/m\(^2\) BSA) than the females (95 kJ/kg weight, 3197 kJ/m\(^2\) BSA, \(P=0.001\)). Whereas females had a higher BEE adjusted for FFM (132 kJ/kg FFM) than males (120 kJ/kg FFM, \(P=0.001\)).

**Development of a new equation with Cosmed \(K_4b^2\) for predicting basal energy expenditure in southern Chinese healthy adults**

The correlation between mBEE and predictive variables is presented in Table 3. Strong relationships were found between BEE and BSA, FFM, weight, height and sex. These parameters were therefore used for deriving the equation for estimation of BEE in southern Chinese healthy adults.

Multiple regression analysis was used for deriving formulae predicting BEE (Table 4). When only one variable was considered, BSA yielded the highest \(r^2\) and the lowest

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**Table 1. Anthropometric characteristics of subjects**

(Mean values with their standard errors and ranges)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total (n 165)</th>
<th>Male (n 79)</th>
<th>Female (n 86)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Range</td>
</tr>
<tr>
<td>Age (years)</td>
<td>30.84</td>
<td>0.64</td>
<td>18–45</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>162.41</td>
<td>0.63</td>
<td>139.5–186.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>55.32</td>
<td>0.55</td>
<td>40.92–75.62</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>20.92</td>
<td>0.12</td>
<td>18.40–24.10</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>43.97</td>
<td>0.66</td>
<td>26.63–63.39</td>
</tr>
<tr>
<td>BSA (m(^2))</td>
<td>1.61</td>
<td>0.01</td>
<td>1.31–2.00</td>
</tr>
</tbody>
</table>

FFM, fat-free mass by bioelectrical impedance analysis; BSA, body surface area.

Mean values were significantly different from those for the males: **\(P<0.001\) (two-sided).

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**Table 2. Measured basal energy expenditure data of subjects**

(Mean values with their standard errors)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total (n 165)</th>
<th>Male (n 79)</th>
<th>Female (n 86)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Range</td>
</tr>
<tr>
<td>BEE (kJ/d)</td>
<td>5513</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>EE (kJ/kg per h)</td>
<td>4.14</td>
<td>0</td>
<td>4.34</td>
</tr>
<tr>
<td>V(_{\text{O2}}) (l/d)</td>
<td>275.45</td>
<td>5.00</td>
<td>310.81</td>
</tr>
<tr>
<td>V(_{\text{CO2}}) (l/d)</td>
<td>230.81</td>
<td>4.26</td>
<td>263.72</td>
</tr>
<tr>
<td>RQ</td>
<td>0.84</td>
<td>0.01</td>
<td>0.86–0.96</td>
</tr>
</tbody>
</table>

BEE, basal energy expenditure; EE, energy expenditure; V\(_{\text{CO2}}, \text{CO2 production per day.}

Mean values were significantly different from those for the males: *\(P<0.05\), **\(P<0.001\) (two-sided).
Comparison between measured basal energy expenditure and predicted values using predictive equations

Paired t tests were used to compare the differences between mBEE in the present study and predicted BEE (pBEE) using predictive equations developed by Liu (eq-Liu), Henry, Schofield and HB (Table 5). The mBEE in the present study significantly correlated with the BEE values obtained with the eq-Liu (r 0.71). No significant differences were observed between the mBEE 5513 (SEM 96) kJ/d and the predicted values estimated using the eq-Liu 5579 (SEM 57) kJ/d (P=0.34, Table 6). In contrast, the BEE estimated by the equations developed by Henry 5763 (SEM 54) kJ/d, equations developed by Schofield 5898 (SEM 58) kJ/d and equations developed by HB 5863 (SEM 51) kJ/d was significantly higher than the mBEE (P=0.001 for all).

The results of the paired t test between mBEE in the present study and pBEE indicated that the best pBEE was

Table 3. Pearson correlation coefficient for basal energy expenditure (BEE, kJ/d) and other predictive variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>BEE</th>
<th>VO₂</th>
<th>VCO₂</th>
<th>Ht</th>
<th>Wt</th>
<th>BSA</th>
<th>BMI</th>
<th>FFM</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCO₂ (l/d)</td>
<td>0.97**</td>
<td>0.97**</td>
<td>0.67**</td>
<td>0.66**</td>
<td>0.66**</td>
<td>0.68**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO₂ (l/d)</td>
<td>0.97**</td>
<td>0.86**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ht (cm)</td>
<td></td>
<td>0.67**</td>
<td>0.66**</td>
<td>0.67**</td>
<td>0.61**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wt (kg)</td>
<td></td>
<td>0.66**</td>
<td>0.65</td>
<td>0.67**</td>
<td>0.81**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>0.71**</td>
<td>0.69**</td>
<td>0.68**</td>
<td>0.61**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>0.24**</td>
<td>0.23</td>
<td>0.24**</td>
<td>0.06</td>
<td>0.63**</td>
<td>0.44**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>0.69**</td>
<td>0.67**</td>
<td>0.72**</td>
<td>0.34**</td>
<td>0.34**</td>
<td>0.34**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (0,1)†</td>
<td>0.55**</td>
<td>0.53**</td>
<td>0.58**</td>
<td>0.70**</td>
<td>0.59**</td>
<td>0.69**</td>
<td>0.07</td>
<td>0.87**</td>
<td></td>
</tr>
</tbody>
</table>

VCO₂, CO₂ production per day; BSA, body surface area; FFM, fat-free mass by bioelectrical impedance analysis.
* Correlation is significant at the 0.05 level (two-sided).
** Correlation is significant at the 0.01 level (two-sided).
† Female = 0 and male = 1.

Discussion

So far, most studies for a practical and valid method to assess BEE have been focused on Western countries. To the best of
Table 5. Predictive equations for estimation of basal energy expenditure based on the equation derived by other authors

<table>
<thead>
<tr>
<th>Author (age)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Henry (18–30) (kJ/d)</td>
<td>51W + 3500</td>
<td>47W + 2880</td>
</tr>
<tr>
<td>Henry (30–60) (kJ/d)</td>
<td>53W + 3070</td>
<td>39W + 3070</td>
</tr>
<tr>
<td>Schofield (18–30) (kJ/d)</td>
<td>63W + 2896</td>
<td>62W + 2036</td>
</tr>
<tr>
<td>Schofield (30–60) (kJ/d)</td>
<td>48W + 3653</td>
<td>34W + 3538</td>
</tr>
<tr>
<td>HB (≥18) (x 4.184 kJ/d)</td>
<td>66.473 + 5.003H + 13.752W − 6.775A</td>
<td>655.096 + 1.850H + 9.563W − 4.676A</td>
</tr>
<tr>
<td>Liu (≥18) (x 4.184 kJ/d)</td>
<td>13.88W + 4.16H − 3.43A − 112.40S + 54.34 (male = 0 and female = 1)</td>
<td></td>
</tr>
</tbody>
</table>

W, weight (kg); H, height (cm); A, age (years); S, sex; HB, Harris–Benedict.

Table 6. Mean difference and correlation coefficient between measured basal energy expenditure (mBEE, kJ/d) in the present study and predicted BEE using predicted equations (pBEE, kJ/d) for subjects aged 18–45 years

<table>
<thead>
<tr>
<th>Equations</th>
<th>Mean difference (kJ/d)</th>
<th>SEM</th>
<th>P values in paired t test</th>
<th>Correlation coefficient (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HB</td>
<td>-350</td>
<td>70</td>
<td>0.000</td>
<td>0.70**</td>
</tr>
<tr>
<td>Schofield</td>
<td>-385</td>
<td>70</td>
<td>0.000</td>
<td>0.68**</td>
</tr>
<tr>
<td>Henry</td>
<td>-250</td>
<td>70</td>
<td>0.001</td>
<td>0.69**</td>
</tr>
<tr>
<td>Liu</td>
<td>-66</td>
<td>69</td>
<td>0.339</td>
<td>0.71**</td>
</tr>
<tr>
<td>equation 7 in the present study</td>
<td>25</td>
<td>69</td>
<td>0.717</td>
<td>0.69**</td>
</tr>
</tbody>
</table>

HB, Harris–Benedict.
Mean difference (kJ/d) = mBEE (kJ/d) − pBEE (kJ/d).
** Correlation is significant at the 0.01 level (two-sided).

![Fig. 1. Linear regression between mBEE (measured basal energy expenditure with Cosmed K4b2) and pBEE-eqLiu (basal energy expenditure calculated with the predictive equation developed by Liu; r 0.71, P<0.001).](https://doi.org/10.1017/S0007114510002795)
was collected daily, the subjects continuously ate a ‘standard diet’ for 16 d during the trial (the results will be reported in another paper). Both studies included subjects from various occupations; therefore, good compliance could hardly be achieved simultaneously. Most urban subjects in the present study were college students who were younger (24–4 years) and had a relatively lower BMI (20.60 kg/m^2, in the normal body weight range) than other studies. However, previous practice in assessing energy requirements had indicated that body weight varied in composition, and hence in energy requirement. In addition, adjustment procedures using ratio scaling, i.e. per kg body weight, often overestimated the energy transduction of individuals with small body weight and underestimated that of individuals with large body weight. And still some studies reported that the coefficient of inter-individual variability depended upon the variations in body size; the larger the variation in body weight among subjects, the larger the CV of total energy expenditure. Further studies in the measurement of Chinese BEE may be necessary to involve more various occupations.

Conclusions

mBEE of southern Chinese healthy adults was 5513 (SEM 70) kJ/d. The BMR of Chinese adults of normal weight is overestimated by widely used prediction equations developed by Henry, Schofield and HB. The equation developed in the present study (equation 7) can be used in predicting BEE for Chinese adults aged 18–45 years with normal body weight.

Acknowledgements

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References