Original Article

Basal Energy Expenditure of Chinese Healthy Adults: Comparison of Measured and Predicted Values*

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Abstract

Objective This study aimed to measure the basal energy expenditure (BEE) of Chinese healthy adults and establish an accurate predictive equation for this population.

Methods In total, 470 Chinese healthy adults had their BEE measured using the Cosmed K4b^2 portable metabolic system. Multiple linear regression analysis was applied to develop new optimal equations for predicting BEE. The bias, accuracy rate, concordance correlation coefficient (CCC), and root mean square error (RMSE) were used to evaluate the accuracy of the predictive equations.

Results There was a significant difference in BEE between males and females, with 5,954 kJ/d and 5,089 kJ/d, respectively. People living in rural areas expended significantly higher BEE (5,885 kJ/d) than those in urban areas (5,279 kJ/d). Previous equations developed by Henry, Schofield, Harris-Benedict (H-B), and Liu overestimated the BEE of Chinese healthy adults. The new equations derived from the present study displayed the smallest average bias and RMSE from the measured basal energy expenditure (mBEE). The CCC of the new equations was higher than other predictive equations, but it was lower than 0.8. There was no significant difference in the accuracy rate among all predictive equations.

Conclusions Sex and regional differences in BEE were observed in Chinese healthy adults. Neither the widely used previous predictive equations nor the one derived in the present study were accurate enough for estimating the BEE of Chinese healthy adults. Further study is required to develop more accurate equations for predicting the BEE of Chinese healthy adults aged between 20–45 years.

Key words: Basal energy expenditure; Chinese healthy adults; Indirect calorimetry; Predictive equations

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INTRODUCTION

The total energy expenditure of healthy adults is defined by the sum of the basal energy expenditure (BEE), thermal effect of food, and physical activity[1]. The BEE is the most important determinant of a person's total energy expenditure, accounting for 52% to 70%[2]. It is a strict measurement and obtained under total inactivity and controlled research conditions[2]. The Nutrition and Health Survey of Chinese Residents in 2012 showed that the energy intake of Chinese residents has decreased in the past 20 years[3]. The average energy intake per capita per day for Chinese residents was 10,424 kJ/d in 1982, 9,742 kJ/d in 1992, 9,416 kJ/d in 2002, and 9,088 kJ/d in 2012[3,4]. The energy intake in 2012 was 93% of the Chinese dietary reference intakes (DRIs)[3], but the prevalence of overweight and obese Chinese residents has grown rapidly in the recent years. The prevalence of overweight and obese Chinese residents aged 18 years and above in 2012 witnessed an absolute increase of 7.3% and 4.8%, respectively since 2002[3]. Although this may be due to a decrease in exercise, the energy DRIs of Chinese residents may also be too high.

BEE can be measured directly and indirectly using calorimeters or respiratory chambers, but these devices are often expensive and time consuming. Thus, calculation of BEE by predictive equations has been adopted as a major method of assessing the energy requirement of individuals[5]. Studies on BEE from individuals living in western countries have shown that there are distinct differences in BEE between men and women, obese and non-obese adults, old and young adults, different races/ethnicities, and possibly between individuals with different physiological states[6-10]. With regards to Chinese adults, there is still limited information on BEE.

Until now, several predictive equations have been widely used such as the Schofield formula, the FAO/WHO/UNU equation, Harris-Benedict (H-B) equation, and the Liu equation[11-14]. However, BEE studies have shown that the predicted values using the FAO/WHO/UNU equation overestimated the BEE in Asian and Chinese subjects[15,16]. Although a few studies have attempted to investigate the BEE or total energy expenditure of Chinese adults[17-20], they were primarily based on relatively small sample sizes or were not intended to be population or regional based. Therefore, the present study aimed to measure the BEE of Chinese healthy adults from different regions using a large sample size, as well as to establish an accurate predictive equation for this population.

METHODS

Study Design and Participants

The study was conducted in five provinces of China, including the northern regions of China, such as Mudanjiang in the Heilongjiang province, Shijiazhuang in the Hebei province, and Beijing, and the southern regions of China, such as Chengdu in the Sichuan province and Shenzhen. Rural regions were selected in Mudanjiang, Shijiazhuang, and Chengdu, and urban regions were chosen in Beijing, Shenzhen and Chengdu.

We first used the statistical formula [$n = (U_\alpha \times \sigma/\delta)^2$] to calculate the lowest sample size required for this study. In the formula, α was significant level and the value was 0.05, and U value was 1.96; σ represented the standard deviation of basal metabolism values for adult males and females, for which we referred to values reported by previous studies[20,21]; δ was acceptable error. By the calculation, the lowest number was 166 for males and 133 for females. Each region was assigned the same number of participants. To ensure an adequate sample size, double the minimum subjects were enrolled. The subjects were enrolled in different regions and underwent medical examination. Individuals with thyroid diseases, hepatic diseases, renal diseases, insulin-dependent diabetes mellitus, or any other metabolic disorder were excluded. For female subjects, their menstruation was required to be regular with no menstruation during the experiment. Pregnant and lactating women were not selected during the experiment. In total, 470 healthy adults of normal body weight (BMI between 18.5 and 23.9 kg/m^2) aged from 20 to 45 years old were selected finally.

All procedures involving human subjects were approved by the National Institute for Nutrition and Health Chinese Center for Disease Control and Prevention Ethical Review Committee (Ethical approval no.: 2009−0212). Written informed consent was obtained from all subjects.

Physical Examination

The height of subjects was determined with the Fix Feet Tall (Lameris, Utrecht, Netherlands) with an accuracy of 0.01 meter. Participants stood straight and barefoot on the baseboard of the Fix Feet Tall to measure their height, and their weight was determined with the Digital Weight Scale (HW100KGL, Japan) with an accuracy of 0.01 kg. After a night of fasting, participants in their underwear stood on the baseboard of the Digital Weight Scale to measure their body weight (Body weight = measured weight − weight of their underwear). The body surface area (BSA) was calculated using the following formula proposed by Zhao et al.[22,23]; for men, BSA (m^2) = 0.00607 height (cm) + 0.0127 weight (kg) − 0.0698; for women, BSA (m^2) = 0.00586 height (cm) + 0.0126 weight (kg) − 0.0461.

Determination of BEE

The BEE was measured with a portable indirect device called the cardiopulmonary function tester (Cosmed, K4B^2, Italy). On the day before the experiment, each subject stayed in a single room with a stable temperature of 20–25 °C and humidity of 40%–60%. The subjects were asked to get accustomed to the apparatus, face mask, and the surrounding environment. BEE was measured in the morning when subjects with 12 h fasting were awakened gently from sleeping and asked to lie down quietly. During the procedure, the subjects could not move or speak. Once the consumption of oxygen and production of carbon dioxide were stable, the measurement lasted for 4 minutes. At the same time, the temperature, heart rate, and respiratory rate of subjects, and the temperature and humidity of the room were measured and recorded. Values for energy expenditure (EE) were calculated from V_{O_2} and V_{CO_2} using Weir's equation[24].

The K4b^2 is a portable piece of equipment that can monitor the real-time exhaled gas of a subject with remote sensing technology. It determinates the amount of gas exhaled by a subject and then calculates the amount of oxygen and carbon dioxide expenditure, from which the respiratory quotient is acquired. Before each test, the Cosmed K4b^2 system was warmed up for at least 45 minutes, and the O_2 and CO_2 analyzers were calibrated using ambient air and reference gas with 16% O_2 and 5% CO_2. The flow meter was calibrated using a 3 liter syringe (Quinton Instruments, Seattle, WA, USA).

Comparison between the Measured Basal Energy Expenditure (mBEE) and the Predicted Values Using Predictive Equations

The predictive equations of Henry et al.[25], Schofield et al.[11], H-B et al.[13], and Liu et al.[14] were used to calculate the BEE. These equations were chosen either because they had previously been widely used in healthy Chinese population studies (Schofield equation, H-B equation)[11,13], derived based on a Chinese database (Liu equation)[14], or reported to be better suitable for a Chinese population (Henry equation)[25]. The predictive equations chosen for the estimation of BEE are presented in Table 1.

Statistical Analyses

The data were analyzed with the SPSS software (version 19.0; SPSS, Inc., Chicago, IL, USA). Descriptive data are presented as mean ± standard error of mean (SEM). Independent or paired *t*-test was used to compare mean differences (Kcal/day) between the measured and predicted values among subgroups. Multiple linear regressions were applied to derive new predictive equations to estimate the BEE for males and females. The bias, accuracy rate, concordance correlation coefficient (CCC), and root mean square error (RMSE) were used to evaluate the accuracy of the predictive equations. Accuracy was calculated as the percentage of subjects with pBEE values within 10 percent of mBEE[26]. A prediction < 90% of the measured mBEE was classified as an underestimation, whereas a prediction > 110% of

Table 1. Predictive equations chosen for the estimation of basal energy expenditure

Author (age)	Male	Female
Henry (18–30) (kJ/d)	51W + 3,500	47W + 2,880
Henry (30–60) (kJ/d)	53W + 3,070	39W + 3,070
Schofield (18–30) (kJ/d)	63W + 2,896	62W + 2,036
Schofield (30–60) (kJ/d)	48W + 3,653	34W + 3,538
HB (≥ 18)(×4.184 kJ/d)	66.473 + 5.003H + 13.752W – 6.775A	655.096 + 1.850H + 9.563W – 4.676A
Liu (≥ 18) (×4.184 kJ/d)	13.88W + 4.16H to 3.43A – 112.40S + 54.34 (male = 0 and female = 1)	

Note. HB: Harris-Benedict, W: Weight (kg), H: Height (cm), A: Age (years), S: Sex.

the measured mBEE was classified as an overestimation. Chi square analysis was used to determine whether the differences in categorical variables such as sex, region, and accuracy rate were significant. Significance for all analyses was set at $P < 0.05$.

RESULTS

Anthropometric Measurements

The distribution of participants is summarized in Table 2. There were 470 subjects in total, including 232 males and 238 females. The distribution of participants was similar between northern and southern areas, as well as between urban and rural places.

Table 2. Distribution of all the participants

Region	Total	Male (*n*, %)	Female (*n*, %)
Total	470	232 (49.4)	238 (50.6)
North/South			
North	250	126 (50.4)	124 (49.6)
South	220	106 (48.2)	114 (51.8)
Urban/Rural			
Urban	286	144 (50.3)	142 (49.7)
Rural	184	88 (47.8)	96 (52.2)

The characteristics of all the subjects are summarized in Table 3. Females and males were of similar ages. Significant differences were observed in weight, height, BMI, and body surface between females and males.

Energy Expenditure in Basal Metabolism

As presented in Table 4, males expended significantly higher energy (5,954 kJ/d) than females (5,089 kJ/d, $P < 0.001$). Females who lived in northern areas expended similar energy as those in southern areas. Females in rural area expended significantly higher energy than those in urban areas ($P < 0.001$). Males in southern areas had significantly higher energy than those in northern areas ($P < 0.001$), while males expended similar energy in both northern and southern areas.

Development of New Equations for Different Subgroups

Considering the statistical difference of the BEE values between males and females, we derived two different equations according to variables such as weight, height, BSA, and regions. The predictive equation was: BEE (kJ/d) = 2625.201 + 60.003 × weight (kg) −707.702 × region (North = 1, South = 0) for males (r^2 = 0.117, n = 232), and BEE (kJ/d) = −7141.710 + 82.444 × height (cm) − 1437.918 × region (city = 1, rural = 0) for females (r^2 = 0.203, n = 238).

Table 3. Characteristics of all participants

Variables	Total	Female	Male	*P*-value
Age (year)	27.76 ± 0.36	28.02 ± 0.53	27.49 ± 0.49	0.471
Weight (kg)	57.35 ± 0.36	52.92 ± 0.36	61.89 ± 0.46	< 0.001
Height (cm)	164.03 ± 0.37	158.76 ± 0.37	169.44 ± 0.41	< 0.001
BMI (kg/cm^2)	21.24 ± 0.08	20.99 ± 0.11	21.51 ± 0.11	0.001
Body surface (m^2)	1.62 ± 0.01	1.53 ± 0.01	1.72 ± 0.01	< 0.001

Table 4. The measured basal energy expenditure for all participants

Variables	Total (kJ/d)	*P*-value	Female (kJ/d)	*P*-value	Male (kJ/d)	*P*-value
Total	5,516 ± 70		5,089 ± 97		5,954 ± 93	
North/South						
North	5,495 ± 111	0.744	5,265 ± 172	0.057	5,721 ± 138	0.006
South	5,540 ± 81		4,897 ± 73		6,232 ± 115	
Urban/Rural						
Urban	5,279 ± 84	< 0.001	4,662 ± 89	< 0.001	5,887 ± 123	0.354
Rural	5,885 ± 117		5,720 ± 183		6,065 ± 139	

Comparison between mBEE and Predicted Values Using Predictive Equations

As shown in Table 5, the BEE values predicted by the equation of Henry, Schofield, H-B, and Liu were significantly different from those of the mBEE for males (all $P < 0.05$), while the values predicted by the equation developed in the present study were similar to the mBEE. The CCC of the new equation was the highest among all the predictive equations; however, the CCC of all predictive equations was lower than 0.8. The new equation had the smallest RMSE and the maximum positive error (MPE), while the maximum negative error (MNE) was similar among all the predictive equations. The accuracy of all the predictive equations was lower than 50%, and the Chi square analysis showed that there was no significant difference among them (all $P > 0.05$).

As presented in Table 6, the BEE values predicted by the equation of Henry, Schofield, and H-B were significantly different from those of the mBEE for females (all $P < 0.05$). No significant difference was observed between the mBEE and the predicted values from the Liu equation and the equation derived in the present study. The CCC of the new equation was the highest among all the predictive equations. However, the CCC of all predictive equations was lower than 0.8. The new equation had the smallest RMSE, maximum positive error (MPE), and the maximum negative error (MNE). The accuracy of all the predictive equations was lower than 50%, and the Chi square analysis showed that there was no significant difference among them (all $P > 0.05$).

DISCUSSION

In order to carry out a better representative investigation of the BEE for Chinese healthy adults, male and female subjects living in China's south and north, and urban and rural areas were selected to participate in the current study. The $K4b^2$ was used to determine the BEE of Chinese healthy adults aged between 20–45 years, and its reliability, as assessed by Yang et al., Sun et al., Steinberg et al. was good[17,20,26].

Table 5. Evaluation of the predictive equations for healthy Chinese males

Predictive equations	Average bias (kJ/d)	CCC (95% *CI*)	RMSE (kJ/d)	MNE (%)	MPE (%)	Accuracy rate (%)	Under/over-estimation (%)
Henry	−670 ± 91*	0.093 (0.034–0.151)	1,517	−42.3	170.0	34.5	65.5
Schofield	−797 ± 63*	0.100 (0.034–0.151)	1,594	−38.9	171.6	32.8	67.2
H-B	−652 ± 93*	0.129 (0.053–0.204)	1,552	−43.5	163.8	34.1	65.9
Liu	−422 ± 91*	0.142 (0.065–0.216)	1,450	−45.0	152.9	35.3	64.7
New equation in present study	0.03 ± 87	0.210 (0.136–0.282)	1,328	−50.4	122.2	37.9	62.1

Note. H-B: Harris-Benedict, CCC: Coherent correlation coefficient, RMSE: Root mean square error, MPE: Maximum positive error, MNE: Maximum negative error, *Compared to mBEE, $P < 0.05$.

Table 6. Evaluation of the predictive equations for healthy Chinese females

Predictive equations	Average bias (kJ/d)	CCC (95% *CI*)	RMSE (kJ/d)	MNE (%)	MPE (%)	Accuracy rate (%)	Under/over-estimation (%)
Henry	−199 ± 98*	0.006 (−0.038–0.050)	1,520	−52.6	158.0	34.5	65.5
Schofield	−235 ± 96*	0.051 (0.004–0.098)	1,495	50.4	158.0	32.8	67.2
H-B	−450 ± 99*	−0.011 (−0.057–0.035)	1,593	−50.7	170.0	29.0	71.0
Liu	−103 ± 99	0.033 (−0.032–0.098)	1,523	−54.7	155.9	37.8	62.2
New equation in present study	0.02 ± 86	0.338 (0.255–0.416)	1,328	−45.2	115.4	35.3	64.7

Note. H-B: Harris-Benedict, CCC: Coherent correlation coefficient, RMSE: Root mean square error, MPE: Maximum positive error, MNE: Maximum negative error, *Compared with mBEE, $P < 0.05$.

The present study showed that the BEE of Chinese adults between 20–45 years old was 5,954 ± 1,416 kJ/d in males and 5,089 ± 1,490 kJ/d in females, and there was a significant difference between males and females. A difference between sex was also observed in previous studies[6], which could be explained by the fact that males and females have different physiological status. Furthermore, regional differences existed in the subjects; for example, people living in rural areas expended more energy than those in the city, possibly because people living in the city often have light-activity lifestyles and expend less energy than those living in rural areas[27].

Whether the BEE of Chinese is lower than that of Caucasians is controversial. Compared to the predictive equation derived from Caucasians, the Chinese and early western scholars believed that the BEE of the Chinese was lower than that of Caucasians[14,28]. While Henry denied this difference, and considered that the basal metabolic rate of Chinese people was lower by 3.9% in females and 7.6% in males, because of the tropical effects found in Chinese regions[29]. The results of the current study showed that the equation of Henry, Schofield, and H-B overestimated the BEE for both males and females, which was in agreement with the findings of Yang et al.[14] and Liu et al.[17]. These equations were developed several decades ago and have been widely used for predicting an individual's BEE. Subject differences, climatic factors, the levels of physical activity, and foods ingested have all changed since completion of these predictive equations[30].

Compared to other predictive equations, the new equation displayed the smallest average bias, RMSE, MNE, and MPE from the mBEE. Although its CCC was higher than other predictive equations, it was lower than 0.8. The accuracy rate of all the equations was lower than 50%, and there was no significant difference among them. The new equations derived in the present study were low fitness for prediction because of their small R-square; therefore, more significant variables need to be found for developing predictive equation of BEE. In addition, the discrepant values of BEE derived from different equations and the measured values may be explained by the different methodologies and equipment employed, including $K4b^2$, MM3B, Cosmed Quark CPET, the VH_MC (a metabolic cart), and RMR_WRIC (a new whole room indirect calorimeter)[7,17,31,32]. Henes et al.[31] and Rising et al.[32] found some significant differences between different indirect calorimeters; thus, the consistency and applicable range of these indirect calorimeters deserves further study.

To the best of our knowledge, there are very few similar studies on the BEE of Chinese people with normal body weight, especially with a large sample size. The obtained values could be an important resource for assessing the energy requirements of Chinese people. Nonetheless, there were also several limitations in the present study, mainly the fact that most subjects in this study were college students, teachers, and farmers who were younger than the participants in other studies[14]. Therefore, further studies on the measurement of Chinese BEE values may be necessary to cover a wider age range and to involve more various occupations.

CONCLUSION

The mBEE of healthy Chinese adults was 5,516 kJ/d in total, with 5,954 kJ/d in males and 5,089 kJ/d in females. Sex and regional differences in BEE existed in healthy Chinese adults. The widely used predictive equations or the new equation derived in the present study were not accurate enough for estimating the BEE of Chinese healthy adults. Further study is required to develop a more accurate equation for predicting the BEE of Chinese healthy adults aged between 20–45 years.

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AUTHORS' CONTRIBUTIONS

MAO De Qian supervised the fields, analyzed the data, and wrote the paper; WU Jing Huan analyzed the data and wrote the paper; HUANG Cheng Yu, LI Ke Ji, LIU Xiao Li supervised the fields; ZHANG Shi Lian, WANG Yan ling, CHEN Wei, and LI Ming performed the experiments; YANG Xiao Guang and PIAO Jian Hua reviewed of the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

No conflict of interest to declare.

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