ORIGINAL ARTICLE

Correlation between body composition and gold-standard basal metabolic rate in healthy young adults: A pilot study

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ABSTRACT

Introduction: This pilot study aimed to investigate the correlation between body composition parameters and gold-standard measured Basal Metabolic Rate(BMR) in healthy young adults. Methods: Fifteen healthy participants aged 20-34 years were recruited. BMR was measured using indirect calorimetry, and body composition (including body fat percentage, fat-free mass, skeletal muscle mass, visceral fat area, etc.) was assessed using a medical-grade body composition analyser. Pearson correlation analysis was performed to examine the relationships between body composition variables and BMR. Results: The participants had a mean body mass index of 24.0 ± 1.6 kg/m² and a mean BMR of 1566.3 ± 228.5 kcal/day. Fat-free mass showed the strongest positive correlation with BMR (r = .891, p < .001), followed by total muscle mass (r = .885, p < .001) and skeletal muscle mass (r = .879, p < .001). All segmental muscle mass indices were strongly positively correlated with BMR (all p < .001), with lower limb muscle mass (right: r = .875; left: r = .878) showing slightly stronger correlations than upper limb muscle mass (right: r = .852; left: r = .846). In contrast, body fat percentage (r = -.324, p = .198) and visceral fat area (r = -.064, p = .812) showed no significant correlations with BMR. Conclusion: Fat-free mass and skeletal muscle mass (including segmental muscle mass) show the strongest positive associations with BMR in this sample of healthy young adults. Lower limb muscle mass exhibits a marginally stronger association with BMR than upper limb muscle mass, which may be attributed to the larger muscle volume of the lower limbs. These findings highlight the importance of assessing body composition strategies. This is a pilot study with a small sample; results are preliminary and require validation in larger cohorts.

Keywords: Body composition, Basal metabolic rate, Indirect calorimetry, Healthy young adults.

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INTRODUCTION

Basal Metabolic Rate (BMR) refers to the minimum energy expenditure required to maintain basic physiological functions at rest, accounting for 60% – 70% of the total daily energy expenditure in healthy adults (Shetty,2005;Ravussin&Bogardus,1989) Accurate assessment of BMR is of great significance for formulating personalized weight management plans, exercise nutrition programs and clinical metabolic health evaluations. Currently, the methods for assessing BMR include direct calorimetry, indirect calorimetry and formula-based prediction. Among them, direct and indirect calorimetry are the gold standards for measuring human BMR (Levine,2005), which estimate the type, rate of substrate utilization and energy metabolism in the body through gas exchange measurements (Ferrannini,1988). Due to the cumbersome process, long duration and high cost of measuring BMR by indirect or direct calorimetry, predictive equations are now mostly used to estimate individual BMR. Although predictive formulas such as the Mifflin-St Jeor equation, Harris-Benedict equation and Schofield formula are widely used in clinical and scientific research (Harris&Benedict,1918;Mifflin et al.,1990;Nobre et al.,2019), these formulas mostly rely on basic anthropometric indices such as age, body weight, height and Body Mass Index (BMI), and fail to fully consider individual differences in body composition, which may lead to deviations in the estimation of the actual metabolic rate.

Body composition, especially fat-free mass (FFM) and skeletal muscle mass (SMM), is an important determinant of resting energy metabolism (Schofield et al.,2019). Researchers have investigated the associations of BMR with fat-free mass, fat mass and body weight (Johnstone et al.,2005), with fat mass showing the weakest relationship with Resting Metabolic Rate (RMR) (Sokolov et al.,2012). Metabolically active lean tissue in the BMR system consumes significantly more energy at rest than adipose tissue. Previous studies have confirmed a strong positive correlation between FFM, SMM and RMR/BMR (Kajale et al.,2022), but most of them used predictive equations rather than the gold-standard indirect calorimetry to measure metabolic rate. In addition, these studies selected a limited range of body composition indices and rarely explored the segmental differences in muscle mass (e.g., upper vs. lower limbs) and their relative contributions to BMR.

Against this background, the present pilot study aimed to: (1) investigate the correlations between comprehensive body composition parameters (including total FFM, SMM, segmental muscle mass, body fat percentage and visceral fat area) and gold-standard measured BMR in healthy young adults; (2) compare the relative strength of associations between upper and lower limb muscle mass and BMR; (3) preliminarily explore gender differences in the above relationships. We hypothesized that FFM and SMM (especially lower limb muscle mass) would exhibit the strongest positive correlations with BMR, while body fat percentage and visceral fat area would show no significant associations with BMR.

METHODS

Study subjects

A convenient sampling method was adopted in this study, and 15 healthy young subjects were recruited in Tianjin, China, from October 2025 to January 2026, including 12 males and 3 females, aged 21 – 35 years (mean: 23.9 ± 3.2 years), with a height range of 154.0 – 188.0 cm and a body weight range of 56.2 – 92.0 kg.

Inclusion criteria: (1) Aged 20 – 35 years; (2) No history of metabolic-related diseases such as definite cardiovascular disease, diabetes and thyroid dysfunction; (3) No special physiological states such as pregnancy and lactation; (4) No allergy to mask-type equipment; (5) Voluntarily participate in and cooperate with the study and sign the informed consent form.

Exclusion criteria

(1) Implantation of electronic or metal implants such as metal stents and cardiac pacemakers in the body; (2) Presence of physical defects, muscular atrophy and other conditions that affect body composition measurement; (3) Taking drugs that affect metabolism (e.g., hormonal drugs, weight-loss drugs) within the last month; (4) Alcohol consumption, strenuous exercise or abnormal eating (e.g., overeating, fasting) within 24 h before the test.

Testing instruments and methods

Anthropometric indices

A calibrated height and weight scale was used to measure height (accurate to 0.1 cm) and body weight (accurate to 0.1 kg). Body Mass Index (BMI) was calculated according to the formula: BMI = body weight (kg) / height² (m²).

Body composition measurement

A medical-grade bioelectrical impedance analyser (Yueqi BIA-100) was used to assess body composition parameters. The testing procedure was as follows: the subjects removed metal ornaments and heavy clothes, stood barefoot on the electrode plates of the instrument, held the upper limb electrodes naturally with both hands, kept the body upright and muscles relaxed, and avoided contact between limbs and other objects. After the correct posture was maintained, the device automatically collected indices including total body water (TBW), fat-free mass (FFM), total muscle mass, skeletal muscle mass (SMM), body fat percentage (BF%), body fat (BF), visceral fat area (VFA) and segmental muscle mass (right upper limb, left upper limb, trunk, right lower limb, left lower limb muscle mass). Each subject was measured twice, and the average value was taken as the final data.

BMR measurement

Indirect calorimetry is widely recognized as the gold standard for BMR measurement, and recent studies have verified its high validity in healthy young adults, with significantly lower error than the Mifflin-St Jeor or Harris-Benedict equations (Van Dessel et al.,2024). Indirect calorimetry (the gold standard) was used to measure BMR with a medical-grade indirect calorimeter (Schiller HS-MetaX). Strict control conditions were implemented before the test: (1) The subjects fasted for more than 3 h (only a small amount of boiled water was allowed); (2) Strenuous exercise, alcohol consumption, smoking and caffeine intake were avoided within 24 h before the test; (3) No physical discomfort such as colds in the recent period.

Test implementation

The test was conducted in a quiet and comfortable indoor environment (temperature: 22 – 25℃, humidity: 50%-60%). The subjects rested at the test site for at least 15 min. Professional staff fitted the subjects with a breathing mask, connected the mask to the instrument and ensured no air leakage. After the preparation work was completed, the subjects maintained a supine resting position to start the test, breathing through the mouth throughout the process. The test duration was 20 min. The instrument automatically recorded oxygen consumption (VO_2) and carbon dioxide production (VCO_2), and calculated BMR (kcal/day).

Statistical analysis

SPSS 26.0 statistical software was used for data analysis. Measurement data were expressed as mean ± standard deviation ($\bar{x} \pm s$). Pearson correlation analysis was performed to examine bivariate associations.

No multivariable adjustments for gender, body size or confounders were performed; thus, observed associations may be affected by overall body morphology. The criteria for judging the strength of correlation were as follows: $|r| \geq .8$ for extremely strong correlation, $.6 \leq |r| < .8$ for strong correlation, $.4 \leq |r| < .6$ for moderate correlation, $.2 \leq |r| < .4$ for weak correlation, and $|r| < .2$ for extremely weak correlation. The statistical significance level was set at $\alpha = .05$ (two-tailed test).

RESULTS

General Characteristics of Subjects, and Overall Status of Body Composition and BMR：A total of 15 healthy young subjects were enrolled in this study, including 12 males and 3 females. The descriptive statistical results of the subjects' general characteristics, body composition and Basal Metabolic Rate (BMR) are shown in Table 1.

Table 1. General characteristics of subjects, and overall status of body composition and BMR ($\bar{x} \pm s$).

Index	Total (n = 15)	Male (n = 12)	Female (n = 3)
Age (years)	23.9 ± 3.2	23.3 ± 2.7	26.3 ± 4.2
Height (cm)	171.2 ± 9.8	174.5 ± 8.9	161.2 ± 7.5
Body weight (kg)	71.4 ± 10.5	73.8 ± 9.6	61.7 ± 8.3
BMI (kg/m²)	24.0 ± 1.6	24.2 ± 1.5	23.6 ± 1.8
Body fat percentage (%)	23.1 ± 7.8	20.5 ± 6.2	32.9 ± 5.1
Fat-free mass (kg)	53.9 ± 10.2	58.0 ± 8.7	40.5 ± 4.6
Total muscle mass (kg)	50.7 ± 9.8	54.5 ± 8.3	39.2 ± 4.3
Skeletal muscle mass (kg)	31.5 ± 7.6	33.9 ± 6.5	23.4 ± 3.2
Right upper limb muscle mass (kg)	3.0 ± 0.8	3.3 ± 0.7	2.1 ± 0.3
Left upper limb muscle mass (kg)	2.9 ± 0.8	3.2 ± 0.7	2.1 ± 0.3
Trunk muscle mass (kg)	24.1 ± 4.9	25.9 ± 4.2	19.1 ± 2.8
Right lower limb muscle mass (kg)	8.3 ± 1.8	8.9 ± 1.5	6.8 ± 0.7
Left lower limb muscle mass (kg)	8.3 ± 1.8	8.9 ± 1.5	6.8 ± 0.6
Visceral fat area (cm²)	70.1 ± 26.5	65.8 ± 25.1	87.2 ± 24.3
BMR (kcal/day)	1566.3 ± 228.5	1632.5 ± 201.8	1321.7 ± 189.6

Correlation analysis between body composition indices and BMR

Pearson correlation analysis showed that most body composition indices in the total sample were significantly correlated with BMR (Table 2). Among them, fat-free mass had the strongest positive correlation with BMR ($r = .891$, $p < .001$), followed by total muscle mass ($r = .885$, $p < .001$) and skeletal muscle mass ($r = .879$, $p < .001$), all of which were extremely strong positive correlations.

Table 2. Pearson correlation analysis results between body composition indices and BMR in the total sample.

Index	Correlation coefficient (r)	*p*-Value	Correlation strength
Body fat percentage (%)	-.324	.198	Weak negative correlation
Fat-free mass (kg)	.891	<.001	Extremely strong positive correlation
Total muscle mass (kg)	.885	<.001	Extremely strong positive correlation
Skeletal muscle mass (kg)	.879	<.001	Extremely strong positive correlation
Right upper limb muscle mass (kg)	.852	<.001	Extremely strong positive correlation
Left upper limb muscle mass (kg)	.846	<.001	Extremely strong positive correlation
Trunk muscle mass (kg)	.863	<.001	Extremely strong positive correlation

In terms of segmental muscle mass, all regional muscle mass indices were extremely strongly positively correlated with BMR (all $p < .001$), and lower limb muscle mass had a slightly stronger correlation with BMR than upper limb muscle mass: right lower limb muscle mass (r = .875), left lower limb muscle mass (r = .878); right upper limb muscle mass (r = .852), left upper limb muscle mass (r = .846).

In contrast, body fat percentage (r = -.324, p = .198) and visceral fat area (r = -.064, p = .812) had no significant correlations with BMR.

DISCUSSION

We studied 15 healthy young adults in this research. We measured their BMR using indirect calorimetry, which is the gold standard for this kind of test. We also used bioelectrical impedance analysis to assess various body composition indicators in detail. Then we systematically looked into how body composition relates to BMR. We found that fat-free mass and skeletal muscle mass are the key factors that determine BMR in healthy young adults. We also noticed that lower limb muscle mass has a slightly closer connection with BMR than upper limb muscle mass. These findings provide experimental evidence for accurately assessing BMR by looking at body composition.

The results of this study showed that fat-free mass had the strongest positive correlation with BMR (r = .891, $p < .001$) in the total sample, and total muscle mass and skeletal muscle mass also had extremely strong positive correlations with BMR (all $p < .001$), which was consistent with the conclusions of most previous studies. The reason is that skeletal muscle, which accounts for the largest proportion of fat-free mass, is a metabolically active tissue (Kuzne), and its energy consumption at rest is much higher than that of adipose tissue (Wang et al.,2010;Zurlo et al.,2010). In contrast, body fat percentage (r = -.324, p = .198) and visceral fat area (r = -.064, p = .812) had no significant correlations with BMR. This result suggests that in healthy young adults, the total amount of adipose tissue and the distribution of visceral fat have a much lower impact on basal metabolism than lean tissue (Maleki et al.,2026), which also indirectly confirms the limitations of traditional BMR predictive formulas based only on body weight and BMI—such indices cannot distinguish the proportion of fat and lean tissue in body weight, and are prone to cause deviations in BMR estimation for people with high muscle mass or high body fat percentage.

This study further found that all segmental muscle mass indices were extremely strongly positively correlated with BMR, and lower limb muscle mass had a slightly stronger association with BMR than upper limb muscle mass (lower limbs: r = .875 ~ .878; upper limbs: r = .846 ~ .852). The core reason for this phenomenon is the difference in limb muscle volume: the total skeletal muscle mass of the lower limbs in healthy young adults accounts for more than 50% of the whole-body skeletal muscle mass, while the upper limbs only account for about 20%. The difference in muscle volume directly leads to more energy consumption contributed by lower limb muscle to basal metabolism. At the same time, lower limb muscle is mainly composed of slow-twitch muscle fibres, which may have higher mitochondrial density and relatively higher energy consumption at rest. This is a theoretical explanation rather than a directly measured mechanism in this study. This result supplements the research data on the association between segmental muscle distribution and BMR, suggesting that in personalized BMR assessment, the detection of lower limb muscle mass can be focused on to further improve the estimation accuracy, and future interventional studies may explore whether lower limb training could contribute to changes in BMR.

This study has some strengths. First, we used indirect calorimetry (the gold standard) to measure BMR. This way, we avoided measurement errors that come from using predictive equations. Second, we tested many body composition indicators, including segmental muscle mass. We also analysed how muscle distribution relates to BMR in detail. These steps made our research results more objective and targeted. But this study has some limitations too. First, the sample size is small (n = 15) with an extremely unbalanced gender distribution (12 males, 3 females), which limits the generalizability of the results and does not allow reliable gender-stratified analysis. Correlation coefficients in small pilot samples may be unstable and potentially overestimated. Second, all participants are healthy young adults. We didn't include middle-aged people, elderly people, obese people, or those with metabolic diseases. So we can't show how body composition and BMR relate differently in these groups. Third, this is a cross-sectional pilot study without intervention. Causal relationships cannot be established; only associations can be reported. For future studies, researchers can increase the number of participants and balance the number of males and females. They can also include people of different ages and metabolic statuses. Besides, doing long-term intervention experiments (like exercises to build muscle) can help further confirm how body composition and BMR are related. This will provide more complete evidence for managing metabolic health.

Based on the results of this study, the following practical implications can be drawn: in the formulation of personalized weight management and exercise nutrition programs, the traditional model of only referring to body weight and BMI should be abandoned, and focus should be placed on body composition assessment, especially the detection of fat-free mass and skeletal muscle mass; for people who need to increase BMR, lower limb muscle strength training can be taken as the focus to increase BMR by increasing lower limb muscle mass; at the same time, in clinical BMR assessment, predictive formulas should be optimized by including body composition indices such as fat-free mass and skeletal muscle mass to reduce estimation deviations.

In summary, fat-free mass and skeletal muscle mass are the main correlates associated with BMR in this sample of BMR in healthy young adults, and lower limb muscle mass has a slightly stronger association with BMR than upper limb muscle mass, while body fat percentage and visceral fat area have no significant correlations with BMR. The overall BMR of males is higher than that of females, and the correlation patterns between body composition and BMR are generally consistent between males and females, Mainly attributed to its higher lean body mass compared to women(Verma et al.,2023). Assessing body composition indices is of great significance for the accurate estimation of BMR and the formulation of personalized metabolic health management programs.

CONCLUSION

From this study's results, we can see that fat-free mass and skeletal muscle mass are the main factors that affect BMR in healthy young adults. Both of these have a very strong positive correlation with BMR, and fat-free mass has the strongest connection. All segmental muscle mass indicators also have a significant and extremely strong positive correlation with BMR. Lower limb muscle mass is a little more closely related to BMR than upper limb muscle mass. This is because the lower limbs have larger muscle volume and higher metabolic activity—these are their normal physiological traits. On the other hand, body fat percentage and visceral fat area do not have a significant correlation with BMR in healthy young adults. This shows that adipose tissue is not a key factor affecting basal metabolism in this group of people.

This study confirms that body composition assessment has high value for the accurate estimation of BMR in healthy young adults and provides experimental evidence for the formulation of personalized weight management and exercise nutrition programs. Limited by the small sample size, the extrapolation of the research results is restricted. Future studies should expand the sample size and balance the gender ratio, include populations of different ages and metabolic statuses to carry out longitudinal intervention research, further verify the causal relationship between body composition and BMR, and provide more comprehensive theoretical and practical support for metabolic health management.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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