Fat-Free Mass Can Be Utilized to Assess Resting Energy Expenditure for Male Athletes of Different Body Size

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Summary The fat-free mass (FFM) of athletes is typically large, and thus the FFM is often utilized to estimate their resting energy expenditure (REE). While the proportional contribution of organ-tissues to the total influence of FFM on REE is known for untrained individuals and female athletes, the extent to which this is valid for male athletes is unclear. The purpose of this study was to clarify the contribution of the components of FFM to REE in male athletes. Fifty-seven male athletes participated in this study. REE was assessed by indirect calorimetry and body composition by dual X-ray absorptiometry. The athletes were equally divided into three groups based on FFM: Small (S), Medium (M), and Large (L). When measured REE (REEm) was compared with REE estimated (REEe) based on the four organ-tissue compartments with set metabolic rates, REEm and REEe had a strong association (r=0.76, p<0.001). In addition, the absolute value of total REE became larger in accordance with body size (S: 1,643±144, M: 1,865±140, and L: 2,060±156 kcal/d) accompanied by increases in mass of all four organ-tissue compartments as body size increased. The consistency of REE/FFM in male athletes in spite of the difference in body size can be explained by the steadiness among the three groups of the relative contribution of each organ-tissue compartment to the FFM. Based on these results, the FFM is the major determinant of REE regardless of body size in male athletes.

Key Words resting energy expenditure, male athletes, fat-free mass, organ-tissue mass

Resting energy expenditure (REE) is often used as a basis for estimating an individual’s energy requirement (EER). EER can be roughly assessed by multiplying REE by physical activity level (PAL), as noted in Dietary Reference Intakes for Japanese, 2010 (DRIs) (1). Therefore, an accurate way to estimate and predict an athlete’s REE would be of great value.

REE is known to be influenced by age, sex, body size, and hormone levels, as well as body composition (2, 3). The major determinant of REE is fat-free mass (FFM) (4). Consequently, FFM is routinely used to estimate REE for athletes who have a large FFM to body weight (BW) ratio. A formula established by the Japan Institute of Sports Sciences utilizes REE per kg FFM and is often employed to estimate REE for athletes (5). However, FFM is not an energetically homogeneous compartment, but rather consists of a variety of heat-producing components (6). The metabolic rate of internal organs can differ substantially. For example, liver, brain, heart, and kidney have metabolic rates of 200, 240, 440, and 440 kcal/kg/d, respectively, as compared to adipose tissue, which is quite low at 4.5 kcal/kg/d (6). Even skeletal muscle, which is commonly considered a metabolically active mass, has a metabolic rate of only 13 kcal/kg/d. In order to establish a more accurate estimation of the relationship of FFM to REE, FFM may need to be compartmentalized at the organ-tissue level.

An advance in this regard was made by Heymsfield et al. (7), who evaluated the contribution of organ-tissue mass on REE using a four organ-tissue compartment scheme. The compartments they utilized were bone mass (BM), adipose tissue (AT), skeletal muscle (SM), and residual mass (RM). Their subjects were untrained males and females. They found that REE/FFM decreased as FFM increased, due to the fact that the RM to FFM ratio was not constant, but instead decreased with increases in FFM. Because the RM is a more metabolically active compartment than the others, the REE/FFM would decrease as FFM increased; therefore estimating REE based simply on FFM is inadequate. However, their finding was based on untrained individuals, and it is not clear to what extent their findings would apply to athletic individuals with sport-specific distinct body features. Athletes in general have a body composition characterized by a greater FFM as compared to untrained individuals (8). Therefore, if the REE/FFM is not constant due to the difference in the proportion of organ-tissue mass to FFM, the error between measured

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and calculated REE becomes larger when estimating REE based on FFM. However, there has been little research investigating the relationship between FFM and REE at the organ-tissue level on male athletes, so the details of this relationship remain unclear. For female athletes, Taguchi et al. (9) reported that FFM can predict REE since between-individual differences in REE can be explained by differences in the metabolically active organ-tissue mass. However, for male athletes, the accuracy of an estimation of REE based on FFM has not been studied in detail.

In this study, the purpose was to evaluate the above approach by assessing the relationship between FFM and REE at the organ-tissue level for male athletes. The working hypothesis was that the REE to FFM ratio would remain constant due to the uniformity of contribution of the organ-tissue masses that make the major contribution to FFM. Thus, the FFM would be a valid predictor for determining the REE of male athletes.

**METHODS**

**Subjects.** Fifty-seven healthy collegiate male athletes aged between 18 and 22 y participated in this study. They belonged to either the American football (AF) \( n=42 \) or Handball (HB) \( n=15 \) teams. Both teams were ranked within the top three at the National Collegiate championships in 2010. None of the subjects had a history of cardiovascular, endocrine, or orthopedic disorders nor had any been taking any medication before and throughout the measuring periods.

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**Organ tissue mass and estimated REE.** The masses of the four organ-tissue compartments were estimated based on values obtained from dual energy X-ray absorptiometry (DXA) using the previously reported prediction model (7) as follows: BM was calculated by dividing the body mass index (BMI) by the square of height in meters (kg/m²).

**Dual-energy X-ray absorptiometry (DXA)** (Hologic QDR-4500, DXA Scanner, Hologic Inc., Whaltham, MA, USA), a relatively easy and non-invasive technique (11), was used to measure bone mineral content (BMC) (g), lean soft tissue mass (g), and % body fat. FFM and fat mass (FM) were then calculated based on BW and % body fat. Subjects wore loose-fitting light cloth without any metal objects and were positioned supine on the scanning table to perform the total body scans.

**REE measurement.** REE was measured by open-circuit indirect calorimetry using a Douglas bag. Subjects came to the testing facility in the early morning. In the 12 h period before testing, no food or liquid (other than water) was consumed (12). The subjects were asked to minimize any exertion prior to the laboratory visit for REE determination. After a 30–40 min period of rest in the supine position with the mask on (Rudolph mask; Hans Rudolph Inc., Kansas City, MO, USA), two 10-min samples of expired gas were collected in the bags. Resting heart rate and body temperature were measured during the rest period to confirm an adequate duration of the rest period. The laboratory was kept at a neutral temperature (20–25°C) based on the previous report (12), and noise was kept to a minimum. The subjects were instructed to remain awake, quiet, and motionless before and throughout the measuring periods.

Oxygen and carbon dioxide concentrations were analyzed using an expiration gas analyzer (Minato AE-300S; Minato Medical Science, Tokyo, Japan). The volume of expired air was determined by a dry gas volume meter (DC-5; Shinagawa Corp., Japan) and converted to a standard temperature, pressure, and dry condition (STPD). Gas exchange results were converted to REE (kcal/d) using Weir’s equation (13). The mean of the two measured values was used for analysis.
The data were expressed as mean ± standard deviation (SD) for all variables. SPSS ver. 17.0 was used for statistical analysis (SPSS Inc., Chicago, IL, USA). The differences among the three body size groups were analyzed utilizing a one-way analysis of variance (ANOVA). The Tukey test was employed to locate the source of the significant differences where appropriate. The level of significance was defined as \( p \leq 0.05 \) for all statistical analyses.
Subjects’ characteristics

The characteristics of the subjects are shown in Table 1. The mean age of each body size group tended to increase with increases in body size. Ht was significantly greater in the Large group. BW and BMI significantly increased as body size increased. FM and % body fat were significantly higher in the Large group.

Measured and estimated REE

The overall average of absolute REE increased significantly in accordance with FFM (Table 2 and Fig. 2). Only the Large group showed a significantly lower REE/BW ratio when compared to the other two body size groups (Table 2). However, when REE was divided by FFM, there were no longer significant differences among the three groups. REEm and REEe showed a significant correlation (r=0.76, p<0.001), and the difference between REEm and REEe was 8±158 kcal.

FFM contribution to REE

The absolute and relative values of each of the four organ-tissue compartments are shown in Fig. 1. The masses of BM, SM, and RM increased significantly in accordance with larger body size. The average mass of AT was found to be significantly larger in the Large group as compared to the masses of AT in the other two groups. Relative masses of BM and SM were relatively similar among the three groups. On the other hand, AT and RM were higher in the Large group as compared to the Small and Medium groups for AT, and the Medium group for RM. Figure 2 shows the energy expenditures in kcal/d of these four organ-tissue compartments. The relative contributions of SM and RM to REE were not significantly different among the groups. Figures 3 and 4 show the relationship between FFM with REEm and REEm/FFM. REEm was highly correlated with FFM (r=0.84, p<0.001). However, REEm/FFM did not show any correlation with FFM. The contribution percentages of FFM organ-tissue to FFM are shown in Fig. 5. There were no significant differences in relative contribution of each FFM organ-tissue compartment among the three groups.

DISCUSSION

In the present study, male athletes with a wide range of FFM were utilized to understand the relationship
between FFM and REE at the organ-tissue level. It was found that, for male athletes, REE/FFM does not change due to the fact that the percentage of organ-tissue mass contribution to FFM is consistent regardless of body size.

It is well known that the REE is attributed to the mass of organ-tissue (7, 15). While an approach to the subject has been previously explored at this level, (4, 7, 16, 17) such studies were largely done on untrained individuals. Therefore, it was not known that the same findings would apply to athletic population. Athletes typically train daily, and have a body composition which is different from the norm and is characterized by a large FFM (8). Therefore, there may be different, relatively unique factors for athletes that might influence the value of REE. In fact, Grund et al. (18) found that resistance-trained men had a higher REE compared to untrained men even after REE was evaluated as a ratio by dividing it by FFM. However, the explanation for this finding has yet to be uncovered. Taguchi et al. (9) reported that organ-tissue mass is responsible for determining REE, and thus it can be accurately measured by FFM. The investigator utilized Japanese female athletes over a wide range of body sizes. However, a number of factors that might influence REE, such as average FFM and % body fat, as well as sex hormones (19) differ between males and females. These are the reasons why the investigation of REE in relation to FFM must be done separately for athletes and untrained individuals, and also for males and females.

In the present study, we used four compartments constituting a whole body to see the relationship of organ-tissue mass with REE for male athletes (Fig. 1). It was found that all four compartments except for AT between Small and Medium groups, increased as body size increased. The four organ-tissue compartments have a specific metabolic rate; BM and AT have relatively smaller weight-related metabolic rates (2.3 and 4.5 kcal/kg/d), on the other hand, SM and RM have higher metabolic rates (13 and 54 kcal/kg/d) (7). REE can be obtained utilizing these metabolic rates with the actual mass of each organ-tissue compartment based on the previously established model (9, 11). According to previous studies which used the same organ-tissue REE prediction method, the correlation coefficients between REEm and REEe were 0.75 (p<0.001) for untrained males and females, and 0.77 (p<0.01) for Japanese female athletes (7, 9). On the other hand, the correlation coefficient was 0.76 (p<0.001) in the present study. The estimation error in a study by Usui et al. (11) using the same methodology was 19±105 kcal in the group of young high-fitness females, in comparison with 8±158 kcal in the present study. Based on these reports, the organ-tissue prediction model is a well established method to predict REE and we assumed REE was adequately predicted by using the same method. Therefore, we hold that for male athletes differences in the dependence of REE on body size can be attributed to changes in organ-tissue mass, just like that of untrained individuals and female athletes. RM includes different internal organs such as the brain, heart, liver, and kidneys (240, 440, 200, and 440 kcal/kg/d) and these organs have exceptionally high weight-related metabolic rates when compared to the tissues of other organs of the body (6). Thus, RM has highest metabolic rates among the four organ-tissue compartments (54 kcal/kg/d). In fact, RM alone contributes 71% of the total REE (Fig. 4). A previous study with Sumo wrestlers has shown that the FFM contribution to the sum of four organs (brain, heart, liver, and kidney) was 6.3% in comparison with 6.6% for a control group; thus the difference was not prominently large. Therefore, it is reasonable to assume that a metabolic rate of 54 kcal/kg for RM can also apply to the athletes of the present study. On the other hand, although, the metabolic rate of SM is much smaller than RM (SM: 13 kcal/kg/d vs RM: 54 kcal/kg/d), athletes have large absolute mass as in SM. As a result, SM accounts for about 25% of REE, and together, SM and RM account for about 95% of the total REE. As for AT, it increases not just as absolute mass, but also as % AT and % body fat in accordance with increase in body size (Fig. 3). For this reason, it suggests that athletes with larger body size in regards to FFM tend to have more FM. However, since
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REFERENCES


