Accuracy of predictive equations for resting metabolic rate in Korean athletic and non-athletic adolescents

Jae-Hee Kim, Myung-Hee Kim, Gwi-Sun Kim, Ji-Sun Park and Eun-Kyung Kim§
Department of Food and Nutrition, Gangneung-Wonju National University, 7 Jukheon-gil, Gangneung-si, Gangwon-do, 210-702, Korea

BACKGROUND/OBJECTIVES: Athletes generally desire changes in body composition in order to enhance their athletic performance. Often, athletes will practice chronic energy restrictions to attain body composition changes, altering their energy needs. Prediction of resting metabolic rates (RMR) is important in helping to determine an athlete's energy expenditure. This study compared measured RMR of athletic and non-athletic adolescents with predicted RMR from commonly used prediction equations to identify the most accurate equation applicable for adolescent athletes.

SUBJECTS/METHODS: A total of 50 athletes (mean age of 16.6 ± 1.0 years, 30 males and 20 females) and 50 non-athletes (mean age of 16.5 ± 0.5 years, 30 males and 20 females) were enrolled in the study. The RMR of subjects was measured using indirect calorimetry. The accuracy of 11 RMR prediction equations was evaluated for bias, Pearson's correlation coefficient, and Bland-Altman analysis.

RESULTS: Until more accurate prediction equations are developed, our findings recommend using the formulas by Cunningham (-29.8 kcal/day, limits of agreement -318.7 and +259.1 kcal/day) and Park (-0.842 kcal/day, limits of agreement -198.9 and +196.9 kcal/day) for prediction of RMR when studying male adolescent athletes. Among the new prediction formulas reviewed, the formula included in the fat-free mass as a variable \( RMR = 730.4 + 15 \times \text{fat-free mass} \) is paramount when examining athletes.

CONCLUSIONS: The RMR prediction equation developed in this study is better in assessing the resting metabolic rate of Korean athletic adolescents.

INTRODUCTION

Determination of an athlete's energy expenditure can help improve performance by allowing for individualized dietary recommendations in order to reach an optimal nutritional status. Currently, many athletes desire to alter their body composition by practicing chronic energy restriction in order to enhance their physical performance. This may change their body's energy needs. Thus, an accurate estimate of a person's total daily energy expenditure is very important. To determine the energy requirements of an individual, knowledge of their physical activity and resting metabolic rate (RMR) is needed. While energy expenditure for physical activity is the most important factor among the total daily energy expenditure [1], the RMR is the largest component, contributing 60-70% of the total daily energy expenditure. One method commonly used to estimate a subject's total daily energy expenditure is determining the resting metabolic rate and then multiplying the RMR by an appropriate physical activity level (PAL). As a result, RMR measurement becomes paramount when determining the total daily energy expenditure of athletes [2].

Indirect calorimetry, which involves measuring oxygen consumption and carbon dioxide production, is the most commonly used method for evaluation of RMR. Unfortunately, factors such as high equipment cost, need for a trained clinician, and measurement time (45 to 60 minutes) often make the use of indirect calorimetry impractical. As a result, several equations for prediction of RMR have been developed based on normal subjects using variables such as weight, height, gender, and age. However, there is no standard prediction equation that fits all individuals, and the characteristics of a population should be considered [3,4]. One important individual characteristic affecting energy expenditure is fat-free mass, which accounts for about 50-80% of an individual's variability in RMR [2,5]. However, RMR in individuals with the same fat-free mass may vary by approximately 3 MJ/day (approximately 715 kcal/24 h), which suggests that additional components substantially influence the RMR [6]. For example, Illner and colleagues reported that metabolically active organs contribute significantly to the RMR [7]. In addition, the RMR might be influenced by exercise-
induced activation of the sympathetic nervous system [8]. Thus, besides chronic, exercise-induced changes in body composition, the RMR might be modulated by regular physical activity itself [2].

Currently, the prediction equations developed by Cunningham and Harris-Benedict are recommended by the American College of Sports Medicine (ACSM) for estimation of the RMR in athletes [9-11]. Cunningham’s prediction model incorporates the fat-free mass; thus, differences in body composition between athletes and non-athletes are considered. In contrast, the prediction equations by Harris-Benedict do not include fat-free mass, but instead include total body weight and gender. As shown by Thompson and Manore [3], the Cunningham equation is highly accurate for endurance athletes. However, anthropometric data such as height, weight, and fat-free mass may differ considerably in elite athletes, depending on the kind of sports, affecting the applicability of commonly used RMR prediction equations [12]. For example, elite heavyweight rowers have been shown to have a significantly larger total body mass and fat-free mass compared to non-athletes [13]. Cunningham’s equation was not developed for an athletic population, but rather for healthy untrained adult subjects. In addition, Harris-Benedict’s and Cunningham’s formulas were developed in 1918 and 1980, respectively [9,14]. Over the years, many prediction equations have become available, some of which might be regarded as more appropriate. For example, de Lorenzo and colleagues [15] established an RMR prediction equation for male athletes. Nevertheless, ACSM recommends the Harris-Benedict or Cunningham equation, although they have not been developed for the athletic population and the accuracy of RMR prediction models has not been validated specifically for athletic populations with a very high fat-free mass. Thus the applicability of both the Cunningham equation and the Harris-Benedict equation in athletes with a very high fat-free mass remains questionable.

Research concerning the accuracy of these RMR predictive equations in athletes is insufficient [16]. Thompson and Manore reported that traditionally used clinical equations for estimation of metabolic rates do not apply well to about 50% of athletes [3]. Therefore, measuring the RMR and comparing the values with those calculated using predictive equations will be helpful in determining clinical relevance and applicability to athletic patients. The purposes of this study were to assess the accuracy of predictive equations on a group of athletes and non-athletes and to develop prediction equations for athletes.

SUBJECTS AND METHOD

Subjects

Subjects enrolled in the study included 100 athletic and non-athletic high school students in Gangneung City, a rural area of South Korea. Fifty soccer players (30 males and 20 females) and 50 non-athletic subjects (30 males and 20 females) participated in this study. All subjects exercised regularly for at least three hours per day and six days per week except during holidays as part of their routine boardinghouse lifestyle and have an average athletic career greater than 5 years. The average exercise time per day of the non-athletes was only 30 minutes, as they were taking part in didactics and after-school studying for an average of 9 hours per day. All subjects who participated in this study were healthy students with no known preexisting disease. None of the subjects had a history of current illnesses, recent weight loss, pharmacologic therapy, or hormonal treatment. All subjects provided informed consent, and this study was approved by the Institutional Review Board of Gangneung-Wonju National University (GWNUIRB-2012-13).

Body composition

Anthropometric measurements were performed by the same investigator and included body weight, body height, mid-arm circumference, triceps skinfold thickness, and body composition assessment. Briefly, weight and height were measured using a digital scale and stadiometer (Inbody720, Biospace Corp., Korea). Body weight was measured without shoes and in light clothing on a standing scale calibrated to the nearest 0.1 kg. Body height was measured without shoes on a wall-mounted stadiometer calibrated to the nearest 0.1 cm. Triceps skinfold thickness (TSF) measurements were performed in triplicate on the left arm using a skinfold caliper (Skindex system1, Caldwell Justiss & Co., Inc., USA). In addition, measurement of body composition was performed using bioelectrical impedance analysis (Inbody720, Biospace Corp. Korea) according to the manufacturer’s instructions. Muscle mass was calculated using Heymsfield’s formula and body surface area was calculated using the Dubois formula [4,5].

Resting metabolic rate

The testing laboratory was set-up in the respective schools of the subjects, in separate rooms that were temperature-controlled (25-27°C). Subjects arrived in the morning for testing following an overnight fast (minimum 9 hours). Before starting data collection, the procedure for the RMR measurement was explained to the subjects. Prior to testing, subjects were free-living and on an unrestricted diet. They were instructed to avoid strenuous exercise on the day before testing. In order to acclimate to the environment, they lay supine for at least 30 minutes. RMR was measured between 06:00 and 08:00 using a TrueOne 2400 metabolic cart (Model QMC, ParvoMedics Corp., UT, USA). After achieving steady state (typically 5-10 min), expired gases were collected for 30 minutes for calculation of RMR. Oxygen consumption and carbon dioxide production, standardized for temperature, barometric pressure, and humidity, were measured at 1 min intervals and averaged over the entire measurement period. The energy expenditure was calculated using the equation proposed by de Weir [6].

Predictive RMR equations

The predictive equations for RMR used in this study are summarized in Table 1. The inclusion criteria were as follows: equations based on weight and/or height of adolescent, or equations that are the most commonly used in clinical settings although based on adults. Among the available equations, Harris-Benedict and FAO/WHO/UNU are commonly used in prediction of RMR in healthy subjects [7,8]. Of note, the Mifflin et al., Owen et al., Altman and Dittmer, Maffeis et al., Schofield-HW, and the IMNA (Institute of Medicine of the National
Table 1. Equations for resting metabolic rate (RMR)

| Source | Equation (weight in kg, height in cm, and age in yr.) |
|--------|--------------------------------------------------|
| Harris and Benedict (1919) | Males: RMR = 66.473 + [13.752 × Weight] + [5.003 × Height] - [6.755 × Age]  
Females: RMR = 655.096 + [9.563 × Weight] + [1.850 × Height] - [4.676 × Age] |
| FAO/WHO/UNU (1985) | Males: RMR = [15.43 × Weight] - [27 × Height] + 717  
Females: RMR = [13.3 × Weight] + [3.34 × Height] + 35 |
| IMNA (2002) | Males: RMR = 68 - [43.3 × Age] + [712 × (Height/100)] + [19.2 × Weight]  
Females: RMR = 189 - [17.6 × Age] + [625 × (Height/100)] + [7.9 × Weight] |
| Cunningham (1991) | Males: RMR = 370 + [21.6 × fat-free mass]  
Females: RMR = 436.6 - [34.1 × Age] + [2227.1 × WHR^2]  
IMNA (2002) | Males: RMR = -857 + [9.0 × Weight] + [11.7 × Height]  
Females: RMR = 370 + [21.6 × fat-free mass] |
| Mifflin (1990) | Males: RMR = [9.99 × Weight] + [6.25 × Height] - [4.92 × Age] + 5  
Females: RMR = [9.99 × Weight] + [6.25 × Height] - [4.92 × Age] - 161 |
| Owen (1987) | Males: RMR = 879 + [10.2 × Weight]  
Females: RMR = 795 + [7.18 × Weight] |
| Altman & Dittmer (1968) | Males: RMR = [[0.818 × Weight] + [21.09 ]] × 24  
Females: RMR = [[0.788 × Weight] + [24.11 ]] × 24 |
| Maffess (1993) | Males: RMR = [1287 + [28.6 × Weight] + [23.6 × Height] - [69.1 × Age]]/4.18  
Females: RMR = [1552 + [35.8 × Weight] + [15.6 × Height] - [36.3 × Age]]/4.18 |
| Schofield-HW (1985) | Males: RMR = [16.245 × Weight] + [1.371 × Height] + 515.3  
Females: RMR = [8.361 × Weight] + [4.654 × Height] + 200.0 |
| De Lorenzo (1999) | Males (Athlete): RMR = -857 + [9.0 × Weight] + [11.7 × Height]  
Males (Non-athlete): RMR = 1185.1 + [2.95 × Weight]  
Females (Athlete): RMR = 436.6 - [34.1 × Age] + [2227.1 × WHR^{2} ]  
Females (Non-athlete): RMR = 1185.1 + [2.95 × Weight] |

1) Institute of Medicine of the National Academies  
2) Waist-Hip Ratio

Academies) equations were developed specifically to improve the estimation of RMR in an overweight population [9-13,17]. The FAO/WHO/UNU and Schofield equations were developed from predominantly normal-weight samples. The Harris-Benedict equation was also included because it was the most widely used of the earlier studies [14]. Cunningham equation based on measurement of fat-free mass as an independent variable was selected, along with De Lorenzo and Park’s equations were developed for athletes [15,18,19].

Statistical analyses

All result values are expressed as mean ± SD, unless otherwise stated. Data were analyzed using the Statistical Analysis System (version 9.2, SAS Institute Inc, Cary, NC). Student’s t-tests were used for comparison of RMR and related variables between genders. Pearson’s correlation coefficients (r) were calculated to evaluate the relationship of measured RMR with predicted RMR and anthropometric measurements. After calculating the mean difference between measured RMR and predicted RMR, and 95% limits of agreement as the mean difference in individuals (± 1.96 SD), Bland-Altman analyses were used to determine how precise the mean difference was both graphically and numerically [20]. Significant ANOVAs were followed by paired t-tests. Stepwise multiple regression analyses were used in development of a new prediction equation. The new prediction equations developed were also tested using the Bland-Altman method to determine the degrees of systematic and magnitude bias when the RMR predicted by the new equations was compared with the measured RMR. A value of P < 0.05 was defined as significant.

RESULTS

Subject characteristics

The characteristics of the subjects of this study are listed in Table 2. The mean age among males was 16.7 years (± 1.0) in athletes and 16.0 years (± 0.1) in non-athletes, while for females it was 16.4 years (± 1.1) and 17.5 years (± 0.4) for athletes and non-athletes, respectively. There was no significant difference in age, body weight, and muscle mass (kg) between the two groups. The TSF (triceps skinfold thickness) of athletes (13.9 ± 2.4 mm in males and 20.7 ± 5.1 mm in females) was significantly (P < 0.001) less than that of non-athletes (20.4 ± 5.5 mm in males and 28.3 ± 5.0 mm in females). The percentage of body fat of athletes (11.1 ± 2.2% in males and 12.6 ± 3.4% in females) was also significantly (P < 0.001) less than that of non-athletes (19.9 ± 7.2% in males and 20.2 ± 5.8% in females), but the percentages of body muscle in the athletes (35.0 ± 3.4% in males and 27.0 ± 2.5% in females) were significantly (P < 0.01) higher than those of non-athletes (31.1 ± 2.6% in males and 24.6 ± 3.8% in females). In addition, the fat-free mass of the male athletes (60.5 ± 4.5 kg) was also significantly higher than that of non-athletic (54.9 ± 8.1 kg) males, however, no significant difference between athletes and non-athletes was observed among females.

Measured RMR vs. predicted RMR

Measured and adjusted RMRs by body weight and fat-free mass obtained in the studied groups are detailed in Table 3. In males, significantly higher measured RMR was observed in athletes (1647.6 ± 111.3 kcal/day) than in non-athletes (1391.0 ± 84.4 kcal/day). However, measured RMR in female athletes did not differ significantly from that of female non-athletes. Adjusted RMR by body weight was significantly higher in male athletes than in male non-athletes, but adjusted RMR by fat-free mass was not significantly different between athletes and non-athletes both males and females.

Measured and predicted RMR values obtained in the studied groups are detailed in Table 4. In male athletes, no significant difference was observed between measured and predicted RMR using either Cunningham’s or Park’s equations, however, in male non-athletes, predicted RMR using multiple equations underestimated values compared with the measured RMR except for the formula developed by Owen and colleagues. In female athletes, predicted RMR using Owen’s, Altman and Dittmer’s,
Table 2. Demographic, anthropometric, and body composition variables of subjects

| Variable                      | Male (n = 60) | Female (n = 40) | Total (n = 100) |
|-------------------------------|--------------|----------------|-----------------|
| Age (years)                   | 16.7 ± 1.0   | 16.0 ± 0.0     | 16.4 ± 1.1      |
| Height (cm)                   | 176.9 ± 5.3**| 172.3 ± 5.5    | 163.7 ± 5.2     |
| Weight (kg)                   | 68.1 ± 5.3   | 69.7 ± 15.7    | 65.1 ± 5.2      |
| Body mass index (kg/m²)       | 21.8 ± 1.5   | 23.4 ± 4.7     | 20.9 ± 1.5**    |
| Triceps skinfold thickness (mm)| 13.9 ± 2.4***| 20.4 ± 5.5     | 20.7 ± 5.1***   |
| Mid-arm circumference (cm)    | 27.8 ± 1.6*  | 28.9 ± 4.4     | 25.7 ± 1.9**    |
| Waist Hip Ratio               | 0.81 ± 0.02  | 0.84 ± 0.03    | 0.78 ± 0.38     |
| Body fat (%)                  | 11.1 ± 2.2***| 19.9 ± 7.2     | 12.6 ± 3.4***   |
| Fat-free mass (kg)            | 60.5 ± 4.5***| 54.9 ± 8.1     | 43.5 ± 2.7      |
| Fat-free mass (%)             | 88.91 ± 2.2***| 20.1 ± 5.7    | 77.7 ± 3.8      |
| Muscle mass (kg)              | 23.9 ± 3.2   | 21.8 ± 5.7     | 15.1 ± 1.7      |
| Body muscle (%)               | 35.0 ± 3.4** | 31.1 ± 2.6     | 27.0 ± 2.5      |

Significant difference between athletes and non-athletes at * P < 0.05, ** P < 0.01 and *** P < 0.001

Table 3. Comparison of measured RMR and adjusted RMR by body weight and fat-free mass

| Variable                 | Male (n = 60) | Female (n = 40) | Total (n = 100) |
|--------------------------|--------------|----------------|-----------------|
| RMR (kcal/day)           | 1,647.6 ± 111.3*** | 1,391.0 ± 84.4  | 1,364.9 ± 185.8  |
| RMR/weight (kcal/kg)     | 24.3 ± 2.5*** | 20.7 ± 3.6       | 24.4 ± 2.9       |
| RMR/fat-free mass (kcal/kg)| 27.4 ± 2.8 | 25.7 ± 3.3       | 31.4 ± 3.8       |

Significant difference between athletes and non-athletes at *** P < 0.001

Table 4. Differences between measured RMR and predicted RMR by equations (Unit : kcal/day)

| Equation                     | Male (n = 60) | Female (n = 40) | Total (n = 100) |
|------------------------------|--------------|----------------|-----------------|
| Measured RMR                 | 1,647.6 ± 111.3*** | 1,391.0 ± 84.4  | 1,364.9 ± 185.8  |
| Predicted RMR from           |               |                |                 |
| Harris-Benedict              | 1,555.6 ± 57.7*** | 1,565.5 ± 154.9*** | 1,417.9 ± 55.6  |
| FAO/WHO/UNU                  | 1,577.0 ± 65.2*    | 1,596.3 ± 191.8*** | 1,430.5 ± 63.3  |
| IMNA                        | 1,538.4 ± 69.9*** | 1,534.7 ± 142.1*** | 1,367.0 ± 65.1  |
| Cunningham                  | 1,677.4 ± 94.7*** | 1,556.4 ± 175.8*** | 1,309.4 ± 58.0  |
| Mifflin et al.              | 1,543.0 ± 77.9*** | 1,533.3 ± 174.3*** | 1,342.3 ± 75.6  |
| Owen et al.                 | 1,284.1 ± 38.4*** | 1,295.4 ± 112.9*** | 1,197.9 ± 37.2  |
| Altman and Dittmer          | 1,866.9 ± 101.1***| 1,896.7 ± 297.3***| 1,719.8 ± 100.8  |
| Maffessi et al.             | 1,469.7 ± 60.4*** | 1,472.2 ± 144.5**  | 1,320.5 ± 57.6  |
| Schofield-HW                | 1,592.9 ± 62.5*   | 1,584.5 ± 141.1*** | 1,431.2 ± 61.5  |
| Lorenzo                    | 1,826.1 ± 98.5*** | 1,786.0 ± 178.5***| 1,563.8 ± 96.9*** |
| Park                       | 1,648.4 ± 50.7    | 1,769.0 ± 134.1*** | 1,589.5 ± 364.7* |

Significant difference between measured RMR and predicted RMR at * P < 0.05, ** P < 0.01 and *** P < 0.001

De Lorenzo's, and Park's equations showed significant difference compared to the measured RMR. In female non-athletes, except when using IMNA's equation, the predicted RMR using Mifflin's, Cunningham's, and Maffessi's equations were significantly higher than measured RMR.

As seen in Table 5 and Table 6, results of the Bland-Altman analysis show that the 95% limits of agreement between measured RMR and predicted RMR using different equations were wide. Exploration using Bland-Altman analyses demonstrated that the predicted RMR typically deviated more profoundly in the lower and upper RMR measured ranges. Above all, the equations by Cunningham (-29.8 kcal/day, limits of agreement -318.7 and +259.1 kcal/day) and Park (-0.842 kcal/day, limits of agreement -198.9 and +196.9 kcal/day) demonstrated the smallest
Table 5. Agreement between measured and predicted RMR in male subjects (Unit: kcal/day)

| RMR prediction equation | Athletes | Non-athletes |
|-------------------------|----------|-------------|
|                         | Mean difference mRMR - pRMR | Limits of agreement (mean difference ± 1.96SD) | 95% confidence interval for the bias | Mean difference mRMR - pRMR | Limits of agreement (mean difference ± 1.96SD) | 95% confidence interval for the bias |
| Harris-Benedict         | 92.0     | -148.9 and 332.9 | 48.2 to 135.8 | -174.5 | -433.7 and 84.8 | -217.1 to -127.3 |
| FAO/WHO/UNU             | 70.6     | -177.3 and 318.4 | 25.5 to 115.6 | -205.3 | -528.4 and 117.8 | -264.1 to -146.5 |
| IMNA                    | 109.2    | -140.8 and 359.2 | 63.7 to 154.7 | -143.8 | -385.4 and 97.9 | -187.7 to -99.8 |
| Cunningham              | -29.8    | -318.7 and 259.1 | -82.4 to 22.8 | -165.5 | -479.3 and 148.4 | -222.6 to -108.3 |
| Mifflin et al.          | 104.6    | -160.0 and 369.3 | 56.5 to 152.8 | -142.3 | -437.2 and 152.6 | -196.0 to -88.6 |
| Owen et al.             | 363.5    | 134.6 and 592.4 | 321.8 to 405.2 | 95.6  | -98.2 and 289.4 | 60.3 to 130.9 |
| Altman and Dittmer      | -219.3   | -506.4 and 67.8 | -271.5 to -167.1 | -505.7 | -1026.8 and 15.4 | -600.5 to -410.9 |
| Maffeis et al.          | 177.9    | -65.2 and 421.0 | 133.7 to 222.2 | -81.2 | -324.4 and 162.0 | -125.5 to -37.0 |
| Schofield-HW            | 54.6     | -196.4 and 305.7 | 8.9 to 100.3 | -193.5 | -436.8 and 49.8 | -237.8 to -149.2 |
| Lorenzo                 | -178.5   | -475.3 and 118.2 | -232.5 to -124.5 | -395.0 | -702.2 and -47.7 | -450.9 to -339.1 |
| Park                    | -0.842   | -198.9 and 196.9 | -36.8 to 35.1 | -378.5 | -612.8 and -144.2 | -421.1 to -335.8 |

1) mRMR: measured RMR
2) pRMR: predicted RMR

Table 6. Agreement between measured and predicted RMR in female subjects (Unit: kcal/day)

| RMR prediction equation | Athletes | Non-athletes |
|-------------------------|----------|-------------|
|                         | Mean difference mRMR - pRMR | Limits of agreement (mean difference ± 1.96SD) | 95% confidence interval for the bias | Mean difference mRMR - pRMR | Limits of agreement (mean difference ± 1.96SD) | 95% confidence interval for the bias |
| Harris-Benedict         | -53.1    | -73.5 and 267.4 | -125.1 to 19.0 | -141.5 | -492.6 and 209.5 | -220.5 to -62.6 |
| FAO/WHO/UNU             | -65.7    | -381.4 and 250.0 | -136.7 to 5.3 | -173.4 | -514.3 and 194.5 | -256.1 to -90.7 |
| IMNA                    | -2.19    | -325.3 and 320.9 | -74.8 to 70.5 | -62.8 | -420.6 and 295.0 | -1433.4 to 17.6 |
| Cunningham              | 55.5     | -276.3 and 387.2 | -191.1 to 130.0 | 72.7  | -289.4 and 434.8 | -8.7 to 154.1 |
| Mifflin et al.          | 22.6     | -302.0 and 347.2 | -504 to 95.6 | -57.7 | -435.7 and 320.3 | -1427.2 to 27.3 |
| Owen et al.             | 167.0    | -163.1 and 497.0 | 92.8 to 241.2 | 80.5  | -245.7 and 406.7 | 7.2 to 153.8 |
| Altman and Dittmer      | -274.9   | -583.6 and 33.7 | -344.3 to -205.6 | -411.1 | -859.9 and 37.8 | -512.0 to -310.1 |
| Maffeis et al.          | 44.3     | -278.0 and 366.7 | -28.2 to 116.8 | -32.3 | -383.6 and 318.9 | -111.3 to 46.6 |
| Schofield-HW            | -66.4    | -394.4 and 261.7 | -140.1 to 7.4 | -147.5 | -503.2 and 208.3 | -227.5 to -67.5 |
| Lorenzo                 | -199.0   | -541.8 and 143.8 | -276.0 to -121.9 | -267.1 | -669.4 and 135.3 | -357.5 to -176.6 |
| Park                    | -224.7   | -986.5 and 537.1 | -396.0 to -53.4 | -338.0 | -670.8 and -5.3 | -412.9 to -263.2 |

1) mRMR: measured RMR
2) pRMR: predicted RMR

mean difference (measured RMR minus predicted RMR) with less deviation graphically, in the lower and upper measured RMR ranges in male athletes (Fig. 1).

The mean difference and limits of agreement of between measured and predicted RMRs using a selected equation in each group are detailed in Table 7. IMNA’s equation showed the lowest mean difference (-2.19 kcal/day, limits of agreement -325.3 and +320.9 kcal/day) and, graphically, the best agreement in female athletes (Fig. 2). After Mifflin (22.6 kcal/day, limits of agreement -302.0 and +347.2 kcal/day), the better equation was
Maffeis (44.3 kcal/day, limits of agreement -278.0 and +366.7 kcal/day), and the equation with the worst limits of agreement was that of Altman and Dittmer. Also, the best equation was Maffeis (-32.3 kcal/day, limits of agreement -383.6 and +318.9 kcal/day), and the worst was Altman and Dittmer’s equation (-411.1 kcal/day, limits of agreement -859.9 and +37.8 kcal/day) for non-athletic females.

### Table 7. Agreement between calorimetry and predictive equations which obtained the best results in each group (Unit: kcal/day)

| Athletes | Male | Cunningham | Mean difference | Limits of agreement (mean difference ± 1.96SD) | 95% confidence interval for the bias |
|----------|------|------------|-----------------|-----------------------------------------------|-------------------------------------|
|          |      |            | -29.8           | -318.7 and 259.1                               | -82.4 to 22.8                      |
|          | Park |            | -0.842          | -198.9 and 196.9                               | -36.8 to 35.1                      |
|          | Female | IMNA | -2.19           | -325.3 and 320.9                               | -74.8 to 70.5                      |
|          |      | Maffeis    | -81.2           | -324.4 and 162.0                               | -125.5 to -37.0                    |
|          |      | Maffeis    | -32.3           | -383.6 and 318.9                               | -111.3 to 46.6                     |

1) mRMR: measured RMR
2) pRMR: predicted RMR

### Table 8. Pearson’s correlation coefficient (r) of anthropometric measurements with measured resting metabolic rate

| Anthropometric measurements | Male | Female | Total |
|-----------------------------|------|--------|-------|
| Height (cm)                 | -0.062 | 0.206  | 0.175 |
| Weight (kg)                 | 0.089** | 0.549  | 0.523* |
| Body Mass Index (kg/m²)     | 0.157** | 0.529  | 0.514* |
| Body fat (%)                | 0.160** | 0.563  | 0.467* |
| Triceps skinfold thickness (mm) | -0.082* | 0.456  | 0.326 |
| Mid-arm circumference (cm)  | 0.027** | 0.491  | 0.494* |
| Body surface area (m²)      | 0.032** | 0.524  | 0.429 |
| Waist Hip Ratio             | 0.326** | 0.508  | 0.090 |
| Fat-free mass (kg)          | 0.041*  | 0.451  | 0.414 |
| Muscle mass (kg)            | 0.053** | 0.492  | 0.422 |
| Body muscle (%)             | -0.007 | 0.082  | 0.008 |

Significant difference at * P<0.05, ** P<0.01 and *** P<0.001

### Table 9. Development of new predictive formulas by stepwise multiple regression analyses for calculation of resting energy needs in athletes

| Regression equations | R² | Mean difference | Limits of agreement (mean difference ± 1.96SD) | 95% confidence interval for the bias |
|----------------------|----|----------------|-----------------------------------------------|-------------------------------------|
| Formula 1            | 0.465* | 1.9 | -248.1 and 251.8 | -32.8 to 36.5 |
| Formula 2            | 0.753* | -1.6 | -291.4 and 288.3 | -41.7 to 38.6 |
resulted in improvement of both the mean difference (-1.6 kcal/day) and a reduction in the limits of agreement (-291.4 and +288.3 kcals/day).

**DISCUSSION**

The purposes of this study were to compare RMR and its related variables of athletes with those of non-athletes and to determine accurate and unbiased equations for estimating the RMR of athletes, and to possibly develop prediction equations specifically for athletes.

The anthropometry results of subjects showed that despite no significant weight differences measured between athletes and non-athletes, the percentage of the body fat in athletes was less than that of non-athletes, while their fat-free mass (%) and body muscle (%) were higher. The results of this study are in agreement with those of Gilliat-Wimberly *et al.*, who stated that an active group has lower percentages of body fat and body mass index compared to a non-active group [21].

In Korea, studies measuring the resting metabolic rates of athletes are very rare. The mean RMR value for the male athletes in this study was 1647.6 kcal/day, which appears to be representative of other active males. The values for RMR of 1858 kcal/day, 1788 kcal/day, and 1808 kcal/day among active men have been previously reported [22-24]. RMR values for active females have been reported as 1333 kcal/day, 1338 kcal/day, and 1328 kcal/day [25-27]. The female athletes in this study had a mean RMR of 1364 kcal/day, slightly higher than those previously reported. The results of adjusted RMR by body weight in this study showed significant differences between athletes (24.3 kcal/kg weight) and non-athletes (20.7 kcal/kg weight) in males, but were not significantly different in the two groups of women. On the other hand, adjusted RMR by fat-free mass did not show a significant difference between athletes and non-athletes in both males and females.

Among the 11 prediction equations evaluated in this study, all formulas except for Cunningham’s and Park’s equations included body height, weight and age as variables [18,19]. In this study, given that the body weight and age were not significantly different between athletes and non-athletes, predicted RMR using these variables did not produce any significant differences. On the other hand, predicted RMR of athletes (1530.2 ± 200.0 kcal/day) was higher than in non-athletes (1425.7 ± 217.6 kcal/day) when using Cunningham’s formula [18]. This finding was due to the fact that the Cunningham’s equation used fat-free mass which was significantly different between the two groups. The lower body fat and higher body muscle mass increased the predicted RMR in athletes because muscle requires more oxygen than fat tissue when it metabolizes [9]. Given this finding, since it appears that a person’s fat-free mass is the most representative variable affecting the RMR, it is undesirable to estimate RMR for athletes using the prediction equation used for non-athletes or the general population, which tends to have lower fat-free mass compared with athletes [28]. Therefore, for prediction of the RMR of athletes, validation of the Cunningham equation was needed [15]. Unfortunately, studies on accuracy of prediction equations used in prediction of the RMR of athletes are very rare.

In this study, the predicted resting metabolic rates of the athletes using the Cunningham formula (1677.4 kcal/day in males and 1309.4 kcal/day in females) were similar to those of Thompson and Manore for an athlete’s resting metabolic rate (1868 kcal/day in males and 1486 kcal/day in females) [3,18]. Jang and Lee calculated the basal metabolic rate (BMR) of male juniors (1184.6 kcal/day) using weight, while Lee and Lee reported BMR in young people (mean age of 16 years, 1732.5 kcal/day; mean age of 17 years and 1832.6 kcal/day) that was higher than that observed in this study [29,30]. In addition, the resting metabolic rates of 10 soccer players (1834 kcal/day) were very similar to the results of this study [15]. However, their average weight (68.2 kg) and mean age (16.8 years) were similar to those of our study subjects, but with differences in lower training times (four times per week, one week training time from 90 to 120 minutes). Jang and Lee reported that a measured resting metabolic rate showed higher positive correlation with the fat-free mass than with height and body weight [29]. In this study, most equations for prediction of RMR focus on weight, height, or age. In addition, the average resting metabolic rates of 24 endurance athletes appeared to be approximately 1868 kcal/day, lower than that reported by De Lorenzo *et al.* for 51 athletes (1929 kcal/day) [3,15]. The reason for this discrepancy has been attributed to the different amounts of fat-free
mass in both groups (respectively 63.4 kg and 67.0 kg).

The Harris-Benedict formula, which is probably the most widely used equation for estimating energy requirements, either underestimated or overestimated the RMR when applied to all subjects in this study. The Harris-Benedict equation was derived from indirect calorimetric studies of 239 normal subjects. This equation was developed on RMR measurements performed in the first half of the century. Firoozbakht and colleagues have discussed the potential applicability of the Harris-Benedict formula in pediatric groups whether for changes in life condition (i.e., different nutrition), changes in nutritional status (weight, height, and body composition) despite the fact that the database of the Harris-Benedict study was composed predominantly of adult subjects [31].

The FAO/WHO/UNU equation, the most appropriate formula for predicting resting metabolic rate, was calculated using a formula extracted from the data of more than 7,500 children and adolescents, including 3-18 year-old obese children [32,33]. In addition, Rodriguez et al. reported that the FAO/WHO/UNU and Schofield equations were appropriate for predicting the RMR in children and adolescents [34]. However, the FAO/WHO/UNU formula more appropriately targets Western children and youth, and therefore is not suitable for Asians. Earlier studies also reported that the FAO/WHO/UNU formula overestimated the measured RMR [30,35]. In order to avoid these critical errors, the FAO/WHO/UNU expert committee suggested the induction of a new formula to assess the energy requirements for various races and regions [33]. As a result, the FAO/WHO/UNU formula is not suitable for application to Korean adolescents.

Based on the results of this and other additional studies, most of the existing RMR prediction equations revealed no significant difference between predicted RMR and measured RMR [15,31]. Different prediction equations should be applied to a general population given that each target group will have potentially differing data based on ethnicity, regional, climatic conditions, and nutritional status. Therefore, the use of indirect calorimetry is most desirable for assessment of an individual's RMR.

However, because the cost of indirect calorimetry is expensive and 30 to 40 minutes or more is required for measurement, indirect calorimetry is not easily available for many providers or situations. As a result, energy requirements have been estimated using prediction formulas in cases where indirect calorimetry cannot be used [31].

The results of our study suggest that the Cunningham and Park formulas are best suited for male athletic adolescent groups and the IMNA formula for male non-athletes. The Maffeis formula appears to most accurately represent the RMR among groups and the IMNA formula for male non-athletes. The Maffeis Park formulas are best suited for male athletic adolescent calorimetry cannot be used [31].

De Lorenzo et al. [15] developed an RMR prediction equation from 51 male athletes and the prediction equations of this study were derived from 50 athletes (male 30, female 20) and 50 non-athletes. Nevertheless a major limitation of our findings may be associated with our small number of subjects. In subsequent studies, more subjects and other age groups for cross-validation are needed in order to fully evaluate and analyze the findings of this study.

REFERENCES

1. Speakman JR, Selman C. Physical activity and resting metabolic rate. Proc Nutr Soc 2003;62:621-34.
2. Watson S, Buell J. Body composition, resting metabolic rate and dietary habits of lean and non-lean female athletes [honors thesis]. Columbus (OH): Ohio State University; 2009.
3. Thompson J, Manore MM. Predicted and measured resting metabolic rate of male and female endurance athletes. J Am Diet Assoc 1996;96:30-4.
4. Heymsfield SB, McManus C, Smith J, Stevens V, Nixon DW. Anthropometric measurement of muscle mass: revised equations for calculating bone-free arm muscle area. Am J Clin Nutr 1982;36:680-90.
5. Du Bois D, Du Bois EF. Tenth paper. A formula to estimate the approximate surface area if height and weight be known. Arch Intern Med (Chic) 1916;17:863-71.
6. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 1949;109:1-9.
7. Harris JA, Benedict FG. A Biometric Study of Basal Metabolism in Man. Washington, D.C.: Carnegie institution of Washington; 1919.
8. Food and Agriculture Organization (US); World Health Organization (CH); United Nations University (US). Energy and Protein Requirement. Report of a Joint FAO/WHO/UNU Expert Consultation. WHO Technical Report Series No.724. Geneva (CH): World Health Organization; 1985.
9. Mifflin MD, St Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. A new predictive equation for resting energy expenditure in healthy individuals. Am J Clin Nutr 1990;51:241-7.
10. Owen OE, Kayle E, Owen RS, Polansky M, Caprio S, Mozzoli MA, Kendrick ZV, Bushman MC, Boden G. A reappraisal of caloric requirements in healthy women. Am J Clin Nutr 1986;44:1-19.
11. Altman PL, Dittmer DS. Metabolism. Bethesda (MD): Federation of American Societies for Experimental Biology; 1968.
12. Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. Hum Nutr Clin Nutr 1985;39 Suppl 1:5-41.
13. Panel on Macronutrients; Panel on the Definition of Dietary Fiber; Subcommittee on Upper Reference Levels of Nutrients; Subcommittee on Interpretation and Uses of Dietary Reference Intakes; Standing Committee on the Scientific Evaluation of Dietary Reference Intakes; Food and Nutrition Board; Institute of Medicine of the
National Academies (US). Chapter 5. Energy. In: Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Washington D.C.: The National Academies Press; 2002. p.107-264.

14. Lawrence JC, Lee HM, Kim JH, Kim EK. Variability in results from predicted resting energy needs as compared to measured resting energy expenditure in Korean children. Nutr Res 2009;29:777-83.

15. De Lorenzo A, Bertini I, Pujia A, Testolin G, Testolin C. Comparison between measured and predicted resting metabolic rate in moderately active adolescents. Acta Diabetol 1999;36:141-5.

16. Kim EK, Kim GS, Park JS. Comparison of activity factor, predicted resting metabolic rate, and intakes of energy and nutrients between athletic and non-athletic high school students. J Korean Diet Assoc 2009;15:52-68.

17. Maffeis C, Schutz Y, Micciolo R, Zoccone L, Pinelli L. Resting metabolic rate in six- to ten-year-old obese and nonobese children. J Pediatr 1993;122:556-8.

18. Cunningham JJ. Body composition as a determinant of energy expenditure: a synthetic review and a proposed general prediction equation. Am J Clin Nutr 1991;54:963-9.

19. Park JS. Assessment of physical activity, resting metabolic rate (RMR), energy expenditure and comparison of predicted RMR with measured RMR and development of prediction equations for RMR between athletic and non-athletic male high school students [master's thesis]. Gangneung: Gangneung-Wonju National University; 2008.

20. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-10.

21. Gilliat-Wimberly M, Manore MM, Woolf K, Swan PD, Carroll SS. Effects of habitual physical activity on the resting metabolic rates and body compositions of women aged 35 to 50 years. J Am Diet Assoc 2001;101:1181-8.

22. Poehlman ET, Melby CL, Badylak SF. Resting metabolic rate and postprandial thermogenesis in highly trained and untrained males. Am J Clin Nutr 1988;47:793-8.

23. Horton TJ, Geissler CA. Effect of habitual exercise on daily energy expenditure and metabolic rate during standardized activity. Am J Clin Nutr 1994;59:13-9.

24. Schulz LO, Nyomba BL, Alger S, Anderson TE, Ravussin E. Effect of endurance training on sedentary energy expenditure measured in a respiratory chamber. Am J Physiol 1991;260:E257-61.

25. Wilmore JH, Wambgsans KC, Brenner M, Broedt CE, Pajimans I, Volpe JA, Wilmore KM. Is there energy conservation in amenorrheic compared with eumenorrheic distance runners? J Appl Physiol (1985) 1992;72:15-22.

26. Mulligan K, Butterfield GE. Discrepancies between energy intake and expenditure in physically active women. Br J Nutr 1990;64:23-36.

27. Myerson M, Gustin B, Warren MP, May MT, Contento I, Lee M, Pi-Sunyer FX, Pierson RN Jr, Brooks-Gunn J. Resting metabolic rate and energy balance in amenorrheic and eumenorrheic runners. Med Sci Sports Exerc 1991;23:15-22.

28. Ravussin E, Lillioja S, Knowler WC, Christin L, Freymond D, Abbott WG, Boyce V, Howard BV, Bogardus C. Reduced rate of energy expenditure as a risk factor for body-weight gain. N Engl J Med 1988;318:467-72.

29. Chang UI, Lee KR. Correlation between measured resting energy expenditure and predicted basal energy expenditure in female college students. J Korean Soc Food Sci Nutr 2005;34:196-201.

30. Lee DO, Lee CJ. An analysis on body composition development trend of youth. Korean J Phys Educ 2001;40:899-911.

31. Finan K, Larson DE, Goran MI. Cross-validation of prediction equations for resting energy expenditure in young, healthy children. J Am Diet Assoc 1997;97:140-5.

32. Dietz WH, Bandini LG, Schoeller DA. Estimates of metabolic rate in obese and nonobese adolescents. J Pediatr 1991;118:146-9.

33. Valencia ME, Moya SY, McNeill G, Haggerty P. Basal metabolic rate and body fatness of adult men in northern Mexico. Eur J Clin Nutr 1994;48:205-11.

34. Owen OE, Holup JL, D'Alessio DA, Craig ES, Polansky M, Smalley KJ, Kavle EC, Bushman MC, Owen LR, Mozzioli MA, Kendrick ZV, Boden GH. A reappraisal of the caloric requirements of men. Am J Clin Nutr 1987;46:875-85.