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DETERMINING THE ACCURACY OF PREDICTIVE EQUATIONS FOR RESTING METABOLIC RATE IN ATHLETES

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Abstract

The Resting Metabolic Rate (RMR) is an amount of energy that the body burns at complete rest and it is necessary for to maintaining the vital functions. It is most accurately determined by Indirect Calorimetry (IC), a method that measures oxygen intake and carbon dioxide output in order to estimate energy expenditure. Predictive equations for RMR are mathematical formulas based on factors such as age, sex, weight and height. The aim of this study is to compare the accuracy of six commonly used predictive equations for RMR with its' measured value obtained by indirect calorimetry in athletes of both genders. Fifty-one male and 39 female athletes from different sports disciplines were included. The body composition analysis was performed by Bioelectrical impedance analyzer In Body 720, (Great Britain). RMR was measured by IC using Fit Mate, COSMED, (Italy) calorimeter. The predictive equations for RMR used for this study were Harris-Benedict, Mufflin-St Jeor, Katch-McArdle, Cunningham, Henry and Schofield equation.

Male athletes showed higher values for weight, height, body mass index (BMI) and lean body mass (LBM) ($p<0.05$) and significantly lower values for body fat (BF) ($p<0.05$) compared to female athletes. All equations predict lower values of RMR, while the Cunningham equation has the least mean difference compared to measured RMR values. The equations applied to sports population predict lower RMR values than the real ones. The Cunningham equation which is based on the LBM is the most appropriate equation for calculating RMR in the sports population.

Keywords: athletes, resting metabolic rate, predictive equations, indirect calorimetry.

ОПРЕДЕЛУВАЊЕ НА ТОЧНОСТА НА ПРЕДВИДЛИВИ РАВЕНКИ ЗА МЕТАБОЛНА СТАПКА ВО МИРУВАЊЕ КАЈ СПОРТИСТИ

Апстракт

Метаболичката стапка во мирување (МСМ) е количина на енергија што телото ја согорува во целосно мирување, а е потребна за одржување на виталните функции. Најпрецизно се одредува со индиректна калориметрија (ИК), метод што го мери внесот на кислород и излезот на јаглерод диоксид со цел да се процени потрошувачката на енергија. Предиктивните равенки за МСМ се математички формули кои се засноваат на фактори какви што се возраста, полот, тежината и висината. Целта на ова истражување е да се спореди точноста на шест најчесто користени предиктивни равенки за МСМ со измерената вредност добиена со индиректна калориметрија кај спортисти од двата пола. Вклучени се 51 машки и 39 женски спортисти од различни спортски дисциплини. Анализата на телесниот состав е извршена со анализатор на биоелектрична импеданса In Body 720 (Велика Британија). МСМ е измерена со ИК користејќи калориметар Fit Mate, COSMED (Италија). Предиктивните равенки за МСМ што се користат за ова истражување се равенките Harris-Benedict, Mufflin-St Jeor, Katch-McArdle, Cunningham, Henry и Schofield. Машките спортисти покажаа повисоки вредности за тежината, висината, индексот на телесна маса (ИТМ) и маса без маснотии (ММ) ($p<0,05$) и значително пониски вредности за масната компонента ($p<0,05$) во споредба со женските спортисти. Сите равенки предвидуваат пониски вредности на МСМ, додека равенката на Cunningam има најмала средна разлика во споредба со измерените вредности на МСМ. Равенките применети на спортската популација предвидуваат пониски вредности на МСМ од реалните. Равенката на Cunningam, која се базира на ММ, е најсоодветната за пресметување на МСМ кај спортската популација.

Клучни зборови: спортисти, предиктивни равенки, индиректна калориметрија, метаболна стапка во мирување.

Introduction

The accurate evaluation of the total daily energy expenditure (TDEE) is necessary for determining individual energy requirements. Athletes, people that engage recreational physical activity, but also a sedentary population need this evaluation in order to create a nutritional regimen and то monitor its' effectiveness. Unlike the sedentary population, athletes have a higher TDEE, which is due to their daily intensive physical activity (1). Sports nutritionists take measurements all the time to help athletes consume balanced and adequate amounts of food, which contains enough calories with all macro and micronutrients in order to maintain their weight with lean body mass (LBM). This will provide better performance and fast recovery during the whole season. To provide all of this, nutritionists are aware that their athletes need to be in energetic balance (2). Depending on the type of diet, if an individual has a reduced protein intake, it can lead to a decrease in lean muscle mass, which will result in a reduction of the strength (2). Carbohydrates are the main source of energy at high-intensity intervals in endurance, but also in strength sports such as boxing, bodybuilding, gymnastics, etc. An adequate intake of carbohydrates and proteins is necessary to replenish glycogen stores, as well as to maintain muscle mass and support muscle tissue synthesis (3). Therefore, in order to preserve muscle mass and optimize strength in athletes, it is essential for the athlete to follow a diet based on their individual active metabolic rate (training frequency and type) and resting metabolic rate (RMR).

Indirect Calorimetry (IC) is a method that measures oxygen intake and carbon dioxide output to estimate energy expenditure and is the most commonly used method for determination of RMR.

Dating back from the 1970s, portable devices for IC with gas exchanging methods were available for clinical use. These devices are very accurate with a deviation of only 5%, although accurate measurement requires standard conditions such as fasting, no physical activity, lying down, psycho-physical calmness and conditions of the device, such as proper calibration, resting phase, duration of the test phase (4). The equipment can be expensive, requires trained personnel, and is time-consuming, making it impractical for everyday use. Therefore, the calculation of mathematical equations derived from direct and indirect calorimetry measurements is accepted as the main method for determining individuals' energy needs. The predictive equations are based on easily accessible physical measurements such as age, sex, height, and weight (5).

Among the first and widely used predictive equations for RMR are the Harris and Benedict (HB) dating from 1918 and FAO/WHO/UNU equations based on Schofield database from 1985 (6,7). Many of the predictive equations used today are derived from an elderly and obese population, and few equations are derived from a young and physically active population, so these predictive equations would not be appropriate for athletes.

Mifflin et al., (8) for example have developed the RMR equation using parameters such as height, weight and sex in obese population. Similar to this Nelson et al. (9) have developed an equation from previously collected data from obese and non-obese, but physically inactive populations.

Because of the different body compositions and the level of physical activity at the young and physically active population, these equations are not accurate and applicable. The RMR value from these equations compared to the RMR utilized from IC will have a difference ~ 300 kcal (+/- 10%) (10). One of the reasons for the difference between the RMR values utilized from the equations and from IC is because of the different body compositions, especially the high fat free mass (FFM) of athletes compared to the general population. If the FFM is not taken as a parameter in the equation, when applied to athletes there will be a difference in the values utilized from the equation and from IC (11). From this, we can conclude that in the literature there is not enough data pertaining to the accuracy of the predictive equations for athletes, especially for female athletes. There are many variations of the predictive equations in relation to physical characteristics of the population (8,11,12,13,14,15). The RMR value measured with the use of IC is the necessary information which will help us to find out which equation would be most accurate for application and therefore for the accurate estimation of the total daily energy expenditure.

The aim of this study was to compare the estimated values of RMR derived from the most frequently used predictive equations with the actual RMR values obtained by IC in male and female athletes.

Material and methods

The study had a cross-sectional design and it was conducted over a one-month period, from January 15, 2021, to February 15, 2021, at the Institute of Physiology, Faculty of Medicine, UKIM, Skopje. Fifty-one male and 39 female athletes were included. They were divided into different types of sports, which included the following: male athletes (football n=22, handball n=21, fitness n=2 athletics n=2, bicycle n=3 and karate n=1) and female athletes (athletics n=19, basketball n=1, bicycle n=8, fitness n=4, volleyball n=4, tennis n=1 and karate n=2). All participants were asked for detailed medical history and they completed a questionnaire regarding their demographic data, their hygiene and dietary habits. All participants underwent body composition analysis and RMR measurements. Prior to the testing, all participants were informed about the details of the testing and signed informed consent.

All athletes rested and fasted in the last eight hours prior to testing. Initially, they had their height measured with a stadiometer-CEKA expressed in cm with a reading accuracy of up to 1 mm. Body composition analysis was measured with bioelectrical impedance InBody 720, Great Britain. All participants were asked to wear light-weighted clothes and to remove all the jewelry and metal objects. The obtained parameters from this testing included: weight, body mass index (BMI), lean body mass (LBM), percentage body fat (PBF) and body fat mass/kg (BF).

Resting metabolic rate was measured with the use of Indirect Calorimetry with Fit Mate, COSMED, (Italy). Respiratory coefficient was set at 0.85 because all participants consumed a mixed diet, including all the macronutrients (carbs, protein and fats). The participants were in supine position, calm and awake during the testing in a quiet and darkened room at normal room temperature and humidity. The duration of the testing was six minutes. The first minute was the test phase while the breathing frequency and depth was stabilized.

Physical characteristics and descriptive information for the participants (table 1) were further used in order to compare the estimated RMR values obtained by six predictive equations with the RMR values measured by IC. For the purpose of the study, we used the following RMR predictive equations: Mufflin-St Jeor (8), Cunningham (11), revised Harris-Benedict (12), Katch-McArdle (13), Henry (14) and Schofield (15) (table 2).

Table 1. Mean values and standard deviations of measured parameters in athletes.

Parameters	Males (n=51)	Female (n=39)	All (n=90)	p-value
Age (years)	24.86 ± 5,29	26,95 ± 4,65	25,76± 5,10	p=0,055
Height (cm)	183,37± 10,1	165,17± 8	175,37± 13,04	p=0*
Weight (kg)	82,43± 15,38	62,145±10,16	73,51± 16,70	p=0*
BMI (kg/m ^{2})	24,39± 2.86	22,52± 2,98	23,57± 3,04	p=0,003*
LBM (kg)	71,01± 13,59	47,22± 5,58	60,55±16,03	p=0,003*
PBF (%)	12,99± 4,76	22,8 ± 7,78	17,30±7,92	p=0*
BF (kg)	10,90± 5,5	15,13 ± 7,38	12,76± 6,70	p=0,002*

**p<0.05*

Table 2. An overview of most frequently used RMR predictive equations

Equation	Formula
Revised Harris-Benedict	**Males:** 88.362 + (13.397 × weight/kg) + (4.799 × height/cm) - (5.677 × age) **Females:** 447.593 + (9.247 × weight/kg) + (3.098 height/cm) - (4.330 × age)
Mufflin-St Jeor	**Males:** (10 × weight/kg) + (6.25 × height/cm) - (5 × age) + 5 **Females:** (10 × weight/kg) + (6.25 × height/cm) - (5 ×age) - 161
Katch-McArdle	370 + (21.6 x LBM/kg)
Cunningham	500 + (22 x LBM/kg)
Henry	**Males:** 10-18 age = 18.4 x weight/kg+581 18-30 age =16.0 x weight/kg+545 31-60 age =14.2 x weight/kg+593 ≥60 age = 13.5 x weight/kg +514 **Females:** 10-18 age = 11.1 x weight/kg+761 18-30 age =13.1 x weight/kg+558 31-60 age =9.7x weight/kg +694 ≥ 60 age = 10.1 x weight/kg +569
Schofield	**Males:** 10-18 age = 17.686 × weight/kg + 658.2 18-30 age =15.057 × weight/kg+ 692.2 31-60 age =11.472 × weight/kg+ 873.1 ≥60 age = 11.711 x weight/kg + 587.7 **Females:** 10-18 age =13.384 ×weight/kg + 692.6 18-30 age =14.818 ×weight/kg + 486.6 31-60 age =8.126 ×weight/kg + 845.6 ≥60 age = 9.082 x weight/kg + 658.5

kg- kilograms, cm-centimeters, LBM-lean body mass

Statistical analysis

Statistical analysis was performed in statistical programs Statistica 7.1 for Windows and SPSS 23.01. For the numerical series (weight, height, fat mass, lean body mass, BMI, fat mass, RMR) Descriptive Statistics (Mean; Std.Deviation; ±95,00%CI; Median; Minimum; Maximum) was applied. The difference between two values of the obtained data according to sex was analyzed with t- test, independent, by groups (t / p) according to distribution of the values. The correlation between two variables was performed by means of utilizing the Pearson's correlation coefficient (r) and Spearman Rank Order R (R), depending on the distribution of the data. Significance was determined at $p<0.05$.

Results

As can be seen from table 1, male athletes showed higher values for height, weight, BMI and LBM ($p<0,05$) and significantly lower values for FM ($p< 0,05$) compared with female athletes. (Table 1). The RMR utilized with IC in male athletes was significantly higher when compared to all RMR predictive equations. The Cunningham (11) equation had the smallest mean difference of 152 kcal (table 3).

Table 3. Comparison between RMR values from IC and from predictive equations in male athletes.

	Male (n=51)	p-value	Mean difference
RMR (IC)	2214 ± 346 kcal/day		
Revised Harris-Benedict	1931± 245 kcal/day	p<0.05*	282
Mufflin-St Jeor	1852± 206 kcal/day	p<0.05*	361
Katch-McArdle	1903±293 kcal/day	p<0.05*	310
Cunningham	2062±299 kcal/day	p<0.05*	152
Henry	1788±237 kcal/day	p<0.05*	425
Schofield	1847±208 kcal/day	p<0.05*	366

RMR- resting metabolic rate, IC-indirect calorimetry
*Mean± SD; * statistical significance between RMR value from predictive equations and IC (p<0.05)*

In female athletes, all the RMR predictive equations also underestimated RMR value utilized by IC. All equations have statistically lower values for |RMR compared to RMR utilized by |IC, but Cunningham equation (11) has the lowest mean difference of 91 kcal, while the other equations have much lower values (table 4).

Table 4. Comparison between RMR values from IC and from predictive equations in female athletes.

	Females (n=39)	p-value	Mean difference
RMR (IC)	1632±264 kcal/day		
Revised Harris-Benedict	1421± 114 kcal/day	p<0.05*	210
Mufflin-St Jeor	1365± 142 kcal/day	p<0.05*	266
Katch-McArdle	1903±293 kcal/day	p<0.05*	240
Cunningham	1392±121 kcal/day	p<0.05*	91
Henry	1541±123 kcal/day	p<0.05*	276
Schofield	1356±132 kcal/day	p<0.05*	232

RMR- resting metabolic rate, IC-indirect calorimetry
*Mean± SD; * statistical significance between RMR value from predictive quotations and IC (p<0.05)*

Discussion

The aim of this study was to compare RMR obtained by IC and RMR estimated by the predictive equation, and to find out which equation is the most suitable for accurate prediction of RMR in athletes from both sexes. The results showed that all RMR predictive equations from both sexes underestimate the RMR value measured by IC, and that the Cunnigham equation had the lowest mean difference, which made it the most accurate. The reason for that can be because the Cunnigham equation includes parameters like LBM.

Athletes tend to have higher skeletal muscle mass and lean body mass compared to the general population. High muscle mass and therefore LBM have high positive correlation with RMR and give plenty of variations in RMR value. Due to this the Cunnigham equation is the most accurate equation for prediction of RMR in athletes (10,11,16,17). Lean body mass has a major impact on the energy requirements (18). Webb (18) has found a strong positive correlation between 24-hour energy expenditure at rest and LBM in males and females. Cunningham et al. (11) have discovered that the LBM is the major factor that has influence on RMR and gives around 70% variations in RMR values. The Cunningham equation is developed using a cohort group of respondents which were classified as "active" compared to the respondents of the Harris-Benedict equation (7).

Some of the predictive RMR equations which are developed based on healthy and active populations also have limitations. For example, De Lorenzo A. (19) has developed an equation for only male athletes excluding LBM as a parameter. De Oliveira et al (20) found that the World Health Organization (FAO/WHO/UNU) equation and Harris-Benedict equation are the most accurate equations for RMR in overweight and obese populations (7,21). Weijs et al. (22) found that FAO/WHO/UNU predictive equation (21) is the best predictor for RMR in adult, underweight hospitalized patients. Ten Haaf et al. (17) has found that Cunningham equation (11) is most accurate for determining RMR (~10%) in Dutch recreational male and female athletes. Thompson et al. (10) have discovered that the Cunningham equation (11) is the best predictor for RMR in endurance athletes at both sexes. De Lorenzo (19) made an evaluation of several predictive RMR equations and has discovered that the Harris-Benedict (7) and Cunningham (11) equations are the most accurate for predicting RMR at fifty-one professional male athletes who are more than three hours per day active.

Physical activity right before the RMR measurement can lead to increased RMR from seventy-two up to ninety-six hours after the activity (23,24,25) which explains why there is a difference between the predicted and measured RMR value. From the obtained results, we can conclude that all utilized RMR predictive equations will result in underestimating values compared to real RMR value utilized by IC.

However, for determining the maximal accuracy of the RMR predictive equations we need a larger group and number of participants with different physiological and anthropological characteristics at different levels of physical activity.

Conclusion

All predictive equations used to determine RMR in athletes, resulted in lower values than the ones measured by IC. Cunningham equation has been shown to accurately predict RMR in athletic populations as the model is primarily based on LBM.

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