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COMPARISON BETWEEN EQUATIONS FOR ESTIMATION OF RESTING ENERGY EXPENDITURE AND INDIRECT CALORIMETRY IN GYMNASTS

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ABSTRACT

Aim: to compare equations for estimating resting energy expenditure with values obtained by indirect calorimetry from rhythmic and artistic gymnasts. Methods: cross-sectional study with a convenience sample of 11 female gymnasts of a sports club in Porto Alegre, Brazil, that were evaluated about body fat percent, resting energy expenditure obtained by indirect calorimetry and by predictive equations of Harris-Benedict, Henry & Rees, FAO/WHO, Schofield, Katch & McArdle and the Institute of Medicine. Results: all athletes had healthy body fat percentages and none of the equations tested was correlated with the results of indirect calorimetry, especially not when resting energy expenditure according to indirect calorimetry was greater than 1400 calories. The Harris-Benedict equation differed the least from indirect calorimetry among all tested equations. resting energy expenditure by indirect calorimetry did not correlate to body composition, age, time since menarche or training. Conclusions: based on obtained data the predictive equations studied for estimating resting energy expenditure were not similar to the indirect calorimetry results, although the Harris-Benedict equation exhibited the smallest difference. Further studies are needed to elucidate this findings.

Key words: Energy metabolism. Indirect calorimetry. Gymnastics. Body composition.

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RESUMO

Comparação entre equações preditivas do gasto energético basal e calorimetria indireta em ginastas

Objetivo: comparar as equações para estimativa do gasto energético de repouso com os valores obtidos por calorimetria indireta em atletas de ginástica artística e rítmica. Métodos: estudo transversal realizado com uma amostra de conveniência de 11 atletas do sexo feminino de um clube esportivo de Porto Alegre, Brasil, avaliadas em relação ao percentual de gordura corporal, gasto energético de repouso obtido por calorimetria indireta e pelas equações preditivas de Harris-Benedict, Henry e Rees, FAO/OMS, Schofield, Katch e McArdle e do Instituto de Medicina. Resultados: todas as atletas tinham percentual de gordura adequado e nenhuma das equações testadas se correlacionou com os resultados obtidos por carolimetria indireta, especialmente quando o gasto energético de repouso por calorimetria indireta foi maior do que 1400 calorias. Dentre todas as equações, a equação de Harris-Benedict foi a que menos diferiu da calorimetria indireta. O gasto energético de repouso por calorimetria indireta também não se correlacionou com a composição corporal, idade, tempo de menarca ou tempo de treinamento. Conclusões: baseado nos dados obtidos, nenhuma das equações preditivas estudadas para estimativa do gasto energético de repouso foram similares aos resultados da calorimetria indireta, embora a equação de Harris-Benedict exibiu a menor diferença. Mais estudos são necessários para melhor entender estes resultados.

Palavras-chave: Metabolismo energético. Calorimetria indireta. Ginástica. Composição corporal.

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INTRODUCTION

Resting energy expenditure (REE) is the largest component of total daily energy expenditure, accounting for 70% in sedentary individuals and 50% in the physically active. This is the energy needed to maintain the body's vital functions and it is influenced by several different factors, such as ethnic origin, total body mass, lean body mass, age, fasting and the menstrual cycle (Psota and Chen, 2013).

Indirect calorimetry is considered the most accurate method to measure REE because estimates it based on O2 consumption and CO2 production and has a technical error of measurement of less than 1%, in addition to being a noninvasive technique. Nevertheless it is not widely employed in clinical practice because of its high cost (Fullmer and collaborators, 2015).

For this reason, predictive equations were designed to estimate REE, based on regression models, and validated against a method considered a gold standard (IC or doubly labeled water), but were developed within specific populations. However, since equations do not exist for all types of population, these equations tend to be employed in different situations, further increasing the imprecision of the estimates they produce.

Rhythmic and artistic gymnasts must achieve a specific body composition, with low body fat percentages and low total body mass, because of the demands of the sport itself, and because of this they are exposed to restricted diets (Galetta and collaborators, 2015, Silva and Paiva, 2016), which in themselves can reduce REE (Müller and collaborators, 2015).

Additionally, the energy deficit is also capable of reducing lean body mass in the form of an adaptive response, which also reduces REE (Müller and collaborators, 2015).

Other factors that can also influence expenditure include the high intensity of exercise involved in these sports, combined with energy restriction during the growth phase, which maybe can affect these athletes' bone formation and height, delaying menarche or causing sporadic menstruation, and all of these specific changes can impact on REE (Frutuoso and collaborators, 2016).

The lack of a more exact idea of the magnitude of energy expenditure makes it difficult to maintain the body composition that is appropriate for the type of sport and, along the same lines, to achieve a calorie intake that is neither restrictive nor excessive.

Since female gymnasts are a distinct group for the purposes of determination of REE, in view of the fact that they have specific characteristics that can influence this expenditure (low body mass and restricted energy intake), the use of existing equations is questionable on the grounds of the reliability of their estimates.

Therefore, the purpose of this study was to compare REE estimated by different equations with REE measured by IC, in order to determine whether any of these equations are better suited to this population.

MATERIALS AND METHODS

A cross-sectional study was conducted and female rhythmic and artistic gymnasts aged 13 to 22 years were recruited from the first team of a sports club in Porto Alegre, Brazil. The sample was selected by convenience and comprised 11 athletes. Data were collected after the study had been approved by the Research Ethics Committee at the Hospital de Clínicas de Porto Alegre (HCPA), under protocol number 14-0048, as mandated by National Health Council resolution 466/2012. Athletes over the age of 18 and the parents or guardians or younger athletes signed free informed consent forms.

The assessment protocol covered the following elements:

- **Clinical variables:** Age and age at menarche were collected by self-report and recorded on a specific data collection form.
- **Anthropometry:** Body mass and height were measured using a Welmy® anthropometric balance with a built-in stadiometer and waist circumference was measured (at the midpoint between the last rib and iliac crest) using a Cescorf® anthropometric measuring tape. Additionally, seven skin folds (triciptal, subscapular, pectoral, axillary, abdominal, suprailiac and thigh) were measured in triplicate by a trained examiner using a Cescorf® scientific skinfold caliper, according to the protocol of Jackson and collaborators (1980) for individuals over

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18 years, to estimate body density. After that, body fat percentage was calculated using equations proposed by Siri (1961). For the younger, the protocol of Slaughter and collaborators (1988) (measure of triceps and subscapular skin folds, besides calf), which directly provides body fat percentage, was used. All body fat percentages were classified according to the cutoff points proposed for female rhythmic/artistic gymnasts by Wilmore and Costill. After calculation of body fat percentage, the result was used to estimate body fat mass in kilograms (kg) and the result of this calculation was subtracted from total body mass (kg) to give fat free mass (FFM), also in kg, which is required to REE estimation by McArdle, Katch e Katch (1996) equation.

Assessment of REE by IC and equations: IC calculates energy expenditure on the basis of noninvasive measurements of the VO_2 (volume of oxygen consumption) and VCO_2 (volume of carbon dioxide produced) of a person's inspiration and expiration in a controlled environment for a specific period of time. A simplified form of Weir's equation is used to calculate energy production from the gaseous exchange between the body and the environment, from the energy equivalents of VO_2 and VCO_2, as follows:

REE (kcal/day) = 3.9 x VO2 (L/min) + 1.1 x VCO2 (L/min) x 1,440.

IC determination of REE was conducted with the aid of an Elite-PC digital electrocardiograph (Micromed, Brasília, DF, Brazil) and a Cortex Metalyzer 3B gas analyzer (CortexBiophysik, Leipzig, Sachsen, Germany), using the software packaged with the Metasoft® 3 system.

In preparation for this assessment, the gymnasts were instructed to present early in the morning after 10-12 hours' fasting, with no consumption of caffeine and without engaging in physical exercise during the previous 24 hours. The calorimetry protocol was as follows: stabilization in decubitus dorsal for 15 minutes in a dimly-lit and quiet room at a thermo-neutral temperature (24-26ºC) at absolute rest, without sleeping. The time taken for the test after fitting the gas collection mask was dependent on how long it took to achieve a state of metabolic and respiratory equilibrium, recognized as stabilization of the readings.

This state of equilibrium was defined as VO_2 and VCO_2 varying by less than 10% and RQ (respiratory quotient) by less than 5% over a period of 5 minutes, as set out on the calorimeter's standard protocol. The O_2 and CO_2 analyzers were calibrated before each energy expenditure test. The energy expenditure measured over this 5-minute interval and extrapolated to 24 hours was considered representative of daytime at-rest energy expenditure.

REE was also estimated using the following predictive equations:

Harris-Benedict (1918) 665.9 + [9.56x Weight (kg)] + [1.84 x Height (cm)] – [4.67 x Age (years)]
Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) (1985) 10 to 18 years - 12.2 x Weight (kg) + 746 18 to 30 years - 14.7 x Weight (kg) + 496
Schofield (1985) 10 to 18 years - [0.056 x Weight (kg) + 2.898] x 239 18 to 30 years - [0.062 x Weight (kg) + 2.036] x 239
Henry, Rees (1991) 10 to 18 years - [0.047 x Weight (kg) + 2.951] x 239 18 to 30 years - [0.048 x Weight (kg) + 2.562] x 239
Katch, McArdle (1996) [Free Fat Mass (Kg) x 21.6] + 370
Institute of Medicine (IOM) (2005) - Adults with BMI of 18.5 - 40 kg/m² Women - [247 - 2.67 x Age (years)] + [401.5 x Height (m)] + [8.6 x Weight (kg)]

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Statistical analysis

The distribution of variables was analyzed using the Kolmogorov-Smirnov test. Data were expressed as mean and standard deviation, median (minimum-maximum) or absolute frequency and percentage. Comparisons between continuous variables for the two types of gymnastics were made using Student's t test for independent samples. Repeated measures ANOVA was used for comparisons between calorimetry results and REE values estimated using the predictive formulas. Relationships between energy expenditure according to IC and age, menarche, anthropometric data and body composition were tested for correlations using Pearson coefficients. Agreement between the different values of REE were analyzed using Bland-Altman plots, with REE according to IC as the reference standard. All analyses were performed with SPSS v16.0 and the significance level was set at 5% (P < 0.05).

RESULTS

The study enrolled a total of 11 participants, all females, five of whom were rhythmic gymnasts (RG) and six were artistic gymnasts (AG). Both subsets of gymnasts trained 36 hours per week, on 6 days of the week. Their ages ranged from 13 to 22 years, with a mean of 16 ± 2.5 years. Mean body fat percentage was 17.9 ± 6.1%, ranging from 7.9% to 26.7%, with 63.6% of the gymnasts classified with healthy body fat percentages, 9.1% with low body fat and 27.3% with high body fat. Mean waist circumference was 62.8 ± 4.6 cm. When RG and AG athletes were compared, the only statistically significant difference was in height (P<0.001), with no differences in any of the other variables. The characteristics of the sample are shown in Table 1.

Table 1 - Characteristics of the Rhythmic Gymnasts (RG) and Artistic Gymnasts (AG) (n=11).

	Gymnasts (n=11)	RG (n=5)	AG (n=6)	p
Age (years)	16.6 ± 2.5	17.8 ± 2.5	15.7 ± 2.3	0.177
Weight (kg)	53.3 ± 5.7	56.6 ± 3.4	50.6 ± 6	0.07
Height (m)	1.61 ± 0.06	1.67 ± 0.03	1.56 ± 0.02	<0.001*
Body fat (%)	17.9 ± 6.1	19.9 ± 5.7	16.1 ± 6.4	0.331
Age at menarche (years)	14.3 ± 0.7	14.2 ± 0.45	14.3 ± 1	0.563
Time since menarche (years)	2 (1 - 3)	3 (2 - 5.5)	1.5 (0 - 2.5)	0.304

Legends: BMI: body mass index. Data expressed as mean±standard deviation or median (minimum-maximum).* P<0.05 for RG versus AG.

Table 2 - Comparisons between Indirect Calorimetry (IC) results and equations to predict Resting Energy Expenditure (REE).

	IC (kcal)	Harris-Benedict (kcal)	Henry, Rees (kcal)	FAO/WHO (kcal)	Schofield (kcal)	Katch, McArdle (kcal)	IOM (kcal)
Gymnasts (n=11)	1618 ± 175 -	1394 ± 55 -223 (13.8%)*	1283 ± 57 -335 (20.7%)*	1368 ± 65 -250 (15.5%)*	1373 ± 72 -245 (15.1%)*	1310 ± 48 -303 (18.7%)*	1308 ± 63 -310 (19.1%)*
RG (n=5)	1575 ± 173 -	1431 ± 36 -144 (9.1%)	1310 ± 57 -265 (16.8%)*	1394 ± 74 -181 (11.5%)	1400 ± 82 -174 (11%)	1346 ± 16 -229 (14.5%)*	1356 ± 31 -219 (13.9%)*
AG (n=6)	1654 ± 184 -	1364 ± 51 -290 (17.5%)*	1260 ± 51 -393 (23.8%)*	1346 ± 54 -308 (18.6%)*	1349 ± 59 -304 (18.4%)*	1279 ± 45 -375 (22.7%)*	1268 ± 54 -385 (23.3%)*

Legends: RG: rhythmic gymnastics; AG: artistic gymnastics; FAO: Food and Agriculture Organization; WHO: World Health Organization; IOM: Institute of Medicine. Data expressed as mean±SD. * Difference between the results of IC and predictive equations (P <0.05).

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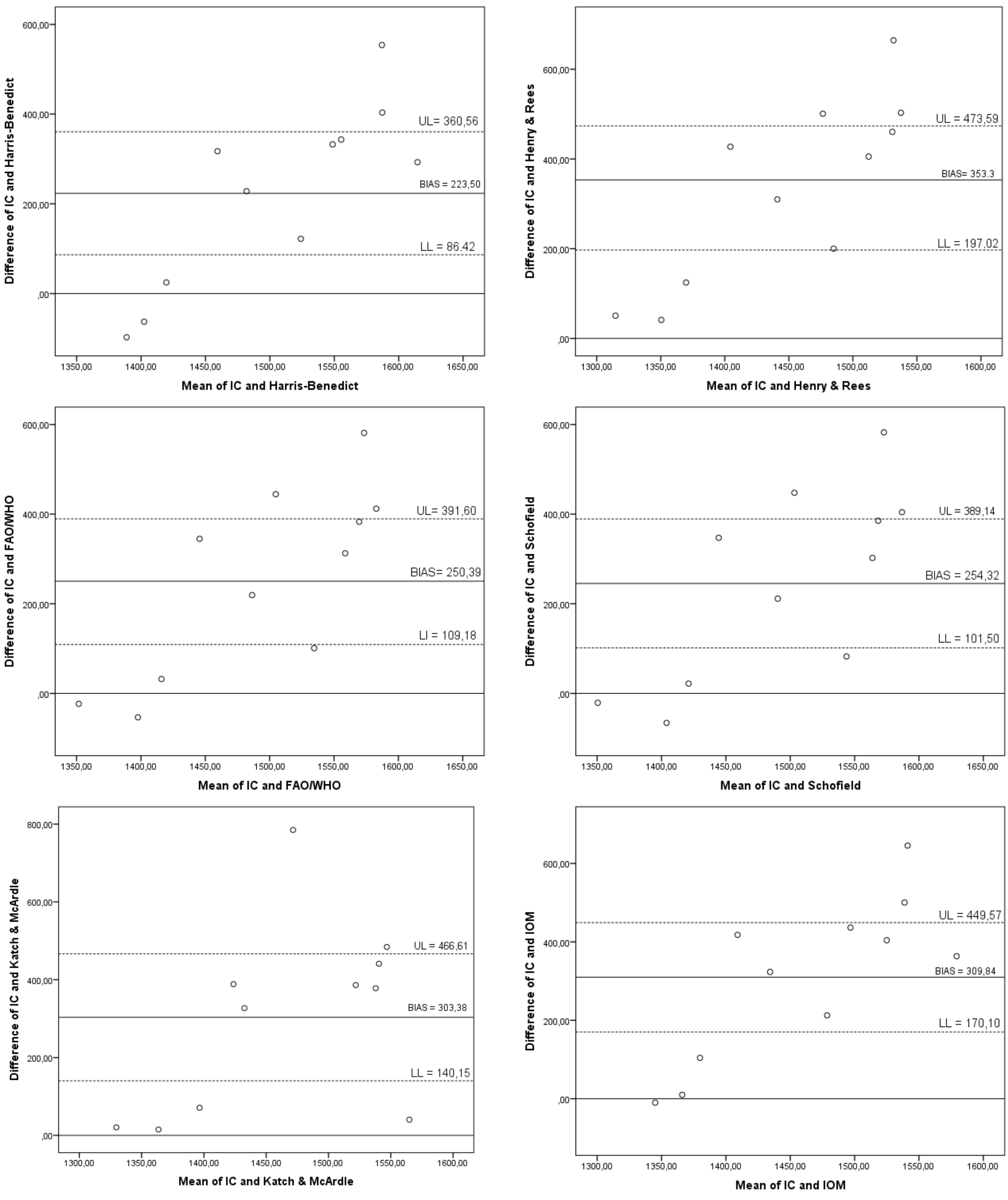

Legends: Harris Benedict (A), Henry, Rees (B), FAO/WHO (C), Schofield (D), Katch, McArdle (E) and IOM (F) against Indirect Calorimetry (CI) results. The continuous line represents the mean difference between values while the dotted lines show upper and lower limits of the interval (1.96SD).

Figure 1 - Analyses of agreement of Resting Energy Expenditure (REE) estimated by the predictive equations against Indirect Calorimetry (CI) results.

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Table 2 shows the results of the comparisons of the different REE estimation methods. There were statistically significant differences between the results of all predictive equations of REE and the IC results. When separated by type of gymnastics, AG x RG, there was no difference between calorimetry REE results (P=0.48).

The AG athletes had differences between their IC results and the estimates for all of the equations, whereas the IC results for the RG athletes were only different from the Henry & Rees, Katch, McArdle and IOM equations. It can be observed from the dispersion of the individual results illustrated in Figure 1 that when the IC result was greater than 1400 kcal, all of the predictive equations underestimated REE. The equation that exhibited the smallest difference from the calorimetry results was the Harris-Benedict equation (13.8%), while the Henry & Rees equation exhibited the largest difference (20.7%). There were no significant correlations between REE values measured by IC and anthropometric variables, body composition, menarche or age (data not shown).

DISCUSSION

This is the first study to assess agreement between predictive equations for estimating REE and values obtained by IC in gymnasts. Considering IC as the gold standard to assed REE, all of the equations underestimated the athletes' real energy expenditure, and this did not appear to be correlated with any of the anthropometric variables investigated, or with age or time since menarche.

When AG and RG athletes were compared, the only parameter out of all of those measured that was different was height, with rhythmic gymnasts taller than artistic gymnasts. This finding is expected and in agreement with a result published by Georgopoulos and collaborators (2012) who studied 328 gymnasts (215 RG and 113 AG) and also found a statistical difference in height.

Another study (Hind and collaborators, 2012), which compared gymnastics, endurance running and swimming, and non-athletic controls, also observed some statistical differences in terms of height in this athletics, gymnastics and endurance running are heigher than swimming and non-athletic controls. It is suggested that this characteristic may be related to the body composition required for each type of gymnastics, and according to this study a certain type of beauty is valued in RG. Girls who are tall, slim and long-limbed are sought after, because the greater the body mass, the greater the difficulty executing the movements, which will also appear less fluid visually. In contrast, according to Malina and colleagues (2013) and Paoli and collaborators (2012) artistic gymnasts should be short, with low body mass and great muscle strength. These characteristics, combined with body proportionality, are biomechanically more favorable to execution of this sport's movements (Trexler and collaborators, 2015).

The results of all of the predictive equations exhibited statistically significant differences from the results of indirect calorimetry. The Harris Benedict equation was the least different (13.8%), which is a curious finding, since in clinical practice this equation is used to estimate the energy requirements of people with pathologies and in healthy people it tends to overestimate REE (Oliveira and collaborators, 2011), but this was not the case in our study. This equation employs height, weight and age, which may have contributed to this result, since these are three variables that tend to influence REE. The fact that the sample used to generate the original equation was very variable and heterogeneous may also have contributed to the greater similarity between estimates, since the sample of this study was very heterogeneous. Of all the equations assessed, the Henry & Rees equation exhibited the greatest difference from the IC results (20.7%). This equation was primarily developed for populations from the tropics, which may explain the result observed, considering that the sample studied here is from the South of Brazil. Of the others, the Schofield equation resulted in a 15.1% underestimation in our study, whereas it has tended to overestimate REE in population studies (Cruz and collaborators, 2015; Yao and collaborators, 2013), in common with the Harris-Benedict equation.

The FAO/WHO equation underestimated IC by 15.5% and the IOM equation underestimated by 19.1%, even though the latter uses the same variables as the Harris-Benedict equation (weight, height and age), whereas the Schofield, Henry & Rees and FAO/WHO equations use age and

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weight as variables, which could contribute to making them less accurate.

The Katch, McArdle equation considers body composition as a variable in the formula and exhibited a large difference with relation to the calorimetry result (18.7%). A study conducted by Taguchi and collaborators (2011) found a correlation between fat free mass and REE, but, in contrast with the protocol employed here, estimated body composition using DEXA, which is the gold standard for this purpose. Notwithstanding, Smith-Ruan and collaborators (2016) have pointed out that while several methods have been proposed for assessment of body composition, few studies have assessed their reproducibility and accuracy in the population.

It is important to acknowledge that the present study had a limitation in terms of sample size, which may have influenced the results observed. We are unaware of other studies published to date in the literature that have investigated different methods of estimating REE in RG or AG athletes and this is another factor that makes comparison with our results difficult. In general, studies with artistic and rhythmic gymnastics athletes are scarce and many of them are already considered old.

Anyhow, the absence of other studies on this topic can also be seen as a positive point of our study, that even with a limited sample size, highlights the possible differences that may occur in the estimates of REE, according to the method used, and the importance of being aware of this. In words of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine, energy expenditure is one of the basis of sports nutrition therapy and to achieve nutritional needs; underestimate it can compromise not only calories provision but all the other nutrients intake (Yao, Buchholz and Edwards, 2013).

CONCLUSIONS

The equations for estimating REE that were assessed here were unable to provide estimates statistically similar to the CI results, although the Harris Benedict equation exhibited the smallest difference. Additionally, in this sample of gymnasts, the REE results obtained by IC do not appear to depend on the variables that normally influence them (body composition, anthropometric measurements, age, time since menarche, training).

However, in view of the limited sample size, studies with larger sample sizes are needed to fully elucidate this question and a predictive equation for these sports should be developed.

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