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Evaluation of Different Equations for Resting Metabolic Rate Prediction in Female Combat Sports Athletes

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Abstract

Only a few studies have produced equations that can estimate resting metabolic rate (RMR) in female athletes, but the accuracy of these equations for combat athletes has not yet been tested. The aim of this study was to evaluate the 12 different equations which are commonly using to determine resting metabolite rate (RMR) in the literature. Twenty-three female combat sport athletes (24.23± 3.39 years; 166.8 ± 5.3 cm; 63.13±6.53 kg; 8.78±3.19 experience years.; 56.40±3.43 VO2 mL/kg/min) were participated this study in voluntarily basis. A cross-validation approach used to compare the accuracy of 12 commonly prediction equations with measured RMR by indirect calorimetry to determine RMR in female combat sports athletes. All the predictive equation was underestimated RMR when compared with the measured RMR ($p < 0.05$) and the smallest mean difference (92.46 ± 210.38 kcal·d^{-1}) was observed for Altman & Dittmer equation amongst the 12 predictive equations. The Altman & Dittmer equation was accurately predicted 16 out of 30 subjects' RMR value within the range ±10%. However, based on the Bland–Altman plots, the prediction equations were not accurately nor precisely predicted RMR in the current sample of female combat sport athletes. The results in the present study showed that the Altman & Dittmer equation is most suitable equation to predict RMR amongst 12 equations. Although the Altman & Dittmer equation was resulted with smallest mean difference, it seems that there is need to further research with longitudinal approach to understand the effects of training intensity and body mass changes on RMR in order to develop the formulas already exist used commonly.

Keywords: *energy expenditure, indirect calorimetry, prediction, martial arts*

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Introduction

Resting metabolic rate (RMR) measurement methods, which are used as a helpful tool in the treatment planning of metabolic diseases in clinical settings (Jeziorek et al., 2023; Thurairajasingam et al., 2022), are also widely used in sports to calculate energy expenditure and requirements for maintaining optimal performance and to prevent imbalances that may negatively affect weight control (MacKenzie-Shalders et

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al., 2020). RMR determination can be performed with indirect calorimetry, which provides non-invasive, valid, and reliable measurements by measuring the changes in the percentages of oxygen (O_2) and carbon dioxide (CO_2) in the airflow during respiration (Haugen, Chan, & Li, 2007). On the other hand, various predictive equations are commonly used to estimate RMR based on different factors, such as; Cunningham, De Lorenzo, Freire, Harris-Benedict, Mifflin, Nelson, Owen, Tinsley, Watson (for females), and Schofield equations. Unlike indirect calorimetry, these equations do not require expensive devices or experienced personnel (Fields et al., 2022). Compared with measurements made by indirect calorimetry, the predictive equations used can give overestimated or underestimated results than those obtained by indirect calorimetry (Fields et al., 2022; O'Neill et al., 2022). The results produced through equations with predicted values for energy expenditure can affect the aspects of individual factors such as sex, body composition, age (Müller et al., 2004), genetics (Bouchard et al., 1990; Nonsa-Ard et al., 2022), type of physical activity, and physical activity level (MacKenzie-Shalders et al., 2020).

It has been reported that recommended two equations named Benedict and Schofield by the past by World Health Organization (WHO), the equations overestimate and underestimate the energy expenditure in male and female Germans. In the study conducted with 2528 individuals aged between 5-91 years, significant deviations were observed in the results of individuals even with regular and underweight categories (Müller et al., 2004). In the study conducted by Jagim et al. (2018) with 50 National Collegiate Athletic Association (NCAA), athletes stated that the predictive equations yielded underestimated results compared to indirect calorimetry in determining RMR (Jagim et al., 2018). Additionally, in another study conducted with 187 National Collegiate Athletic Association (NCAA) athletes, when the RMR results obtained through indirect calorimetry and ten different equations were compared, it was emphasized that the results of the equations should be carefully considered and different equations should be preferred carefully according to sex, body type, and activity level (Fields et al., 2022). Although the athlete groups were similar in both studies, the recommended predictive equations are different according to obtained results.

Furthermore, it stated in a meta-analysis that different exercise types and intensities have different effects on RMR. Also, it has been observed that there are few studies in the literature on the equations used to determine RMR in female athletes (MacKenzie-Shalders et al., 2020). Therefore, it is understood that further research is needed on the predictive equation formulas used in determining RMR in terms of sex and sport-disciplines, especially in female athletes. This issue is significant for combat athletes and other sports in which athletes are categorized based on their body weight, and weight control needs to be monitored periodically. These sports require more precise equations to determine RMR with a reduced margin of error that is more closely aligned with indirect calorimetry results. Male and women's energy expenditure values could differ regarding their physiological specifications and training loads. The literature shows that most studies focused on male athletes or subjects while evaluating the existing equations (Balci et al., 2021; Joseph et al., 2017; Tortu et al., 2017). It is understood that, especially for female athletes, it is necessary to extend the data on which equations are more suitable for female athletes by testing these formulas. The present study aimed to evaluate most of the commonly used RMR prediction equations in a group of female combat sports athletes. In addition, the measurement of RMR with indirect calorimetry may need more cost and experienced staff to measure it. Therefore, the present study also aims to provide practitioners with the most accurate equation with the closest prediction compared to indirect calorimetry in female combat sports athletes.

Methods

Experimental Approach to the Problem

The current study compared the accuracy of 12 commonly used prediction equations with indirect calorimetry to calculate RMR in female combat sports athletes using a cross-validation approach. The study's participants were assessed daily to determine body composition and RMR. All tests were administered between 7:00 AM and 11:00 AM to avoid fasting differences and ensure participants were rested. Participants were warned not to exercise strenuously or consume alcoholic or caffeinated beverages for 24 hours before the measurements. RMR was calculated using 12 different predictive equations based on the subjects' physical characteristics and descriptive information.

Participants

Participants were female (24.23± 3,39 years; 166.8 ± 5.3 cm; 63.13±6.53 kg; 8.78±3.19 experience years.; 56,40±3,43 VO2 mL/kg/min) and included from different combat sports (Boxing, n = 10; Wrestling, n = 10; Karate, n = 3). Exclusion criteria were treatment or diagnosis of a cardiac, respiratory, circulatory, musculoskeletal, metabolic, immunological, autoimmune, psychological, hematological, neurological, or endocrine condition or disease. Participants were also excluded from the trial if their respiratory quotient (RQ) was less than 0.70 (Compher et al., 2006). This study was authorised by Trabzon University's Institutional Review Board, and all procedures followed the Helsinki Declaration. The benefits, dangers, and requirements of participating in the current study were explained to all athletes, and informed consent was acquired.

Resting Metabolic Rate and Body Composition

Indirect calorimetry was used since it is a reliable method for calculating an accurate RMR value. All athletes were measured for RMR using indirect calorimetry (Q-NRG®, Cosmed, Roma, Italy). Gas exchange simulations vs. mass spectrometry gas analysis and an ethanol burning test were used to confirm the accuracy and precision of the Q-NRG®'s gas analysis and RQ readings in-vitro. (Delsoglio et al., 2020; Oshima et al., 2019). Inspired and expired air samples are collected and analysed in an interior micromixing chamber utilising a chemical fuel cell O_2 sensor and a non-dispersive infrared adsorption digital CO_2 sensor. Every 30 seconds, the mean values of VO_2, VCO_2, RQ, and EE are presented. This was a non-exertional test in which participants remained supine on an examining table. A transparent, rigid plastic hood and a soft, clear plastic drape were put over the participant's neck, head, and shoulders to evaluate resting oxygen uptake and energy expenditure. Depending on measurement stability, the resting metabolic rate was measured for 20-30 minutes. The first ten minutes of the measurement were

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eliminated, and RMR was calculated as the first ten minutes multiplied by a CV of 5%. This method was adopted from earlier research (Graf et al., 2017) and it saved time when a consistent RMR measurement was detected early on, which could be useful in top sporting scenarios. This method is also the most practical, with a 10-minute test duration and a coefficient of variance of 10% over 5 minutes. (Graf et al., 2017). The subjects were supine and in a relaxed state. The temperature in the room was kept constant at 20-23° C, the lighting was muted, and all subjects took off their shoes. Following the RMR, all participants' height and weight were assessed with a SECA stadiometer. Hamburg, Germany (SECA).

Prediction equations

In this study, resting metabolic rate (RMR) values for each participant were estimated using 12 widely recognized prediction equations, including Harris and Benedict, Jagim, Watson, Mifflin-St.Jeor, De Lorenzo, WHO/FAO/UNU, Owen et al. (Athletes), Schofield, Liu, Altman & Dittmer, IMNA and Maffeis. These equations are summarized in Table 1.

Table 1. Resting metabolic rate predictive equations

Name	Equation
Harris and Benedict	RMR (kcal·d^{-1})= 655.1+9.56 x BM (kg) + 1.85 x H (cm)-4.66 x A (year)
Jagim	RMR (kcal.d-1)= 21.10 x (BM) + 288.6
Watson	RMR (kcal·d^{-1})=88.1 + 2.53x H (cm)18.42 x M (kg) + 19.46 x A (years)
Mifflin-St.Jeor	RMR (kcal·d^{-1})= 66.7+13.75 x BM (kg)+5 x H (cm) - 4.92 x A-161
De Lorenzo	RMR (kcal·d^{-1}) = 2857 + 9 x BM (kg) + 11.7 x H (cm)
WHO/FAO/UNU	RMR (kcal·d^{-1})= 13.3 x BM (kg)+334 x H (m)+35
Owen et al. (Athletes)	RMR (kcal·d^{-1})= 50.4 + (21 × BM)
Schofield	RMR (kcal·d^{-1})[8.361 ×BM] + [4.654 × H (cm)] + 200.0
Liu	(13.88 x BM(kg) + (4.16 x H (cm) - (3.43 x A (years) - 112.4
Altman & Dittmer	RMR (kcal·d^{-1})=[(0.788 ×BM) + 24.11] × 24
IMNA	RMR (kcal·d^{-1})=189 - [17.6 × A] + [625 × (H(cm)/100)] + [7.9 ×BM]
Maffeis	RMR (kcal·d^{-1})={1552 + [35.8 ×BM] + [15.6 × H(cm)] -[36.3 × A]}/4.18

RMR, resting metabolic rate in kcal/day. BM, body mass (kilograms). H, height A, age (all equations [except the WHO/FAO/UNU equation, which uses height in meters] use height in centimeters).

Statistical Analyses

The paired sample t-test was used to evaluate the result obtained by each prediction equation to the measured indirect calorimetry values. The individual level's accuracy was determined by calculating the percentage of projected values that were within 10% of the measured values. For multiple paired t-test comparisons, the Bonferroni correction was applied. To analyse and compare the accuracy and precision of the prediction equations with indirect calorimetry, Bland-Altman graphs were constructed. The significance level's Alpha value was set at 0.05. The Statistical Package for the Social Sciences (SPSS, Version 21.0; SPSS, Inc., Chicago, IL) was used to analyse the data, and GraphPad Prism Version 8.0 (GraphPad Software, San Diego, CA) was used to generate the figures.

Results

The mean differences in measured vs. predicted RMR in female athletes are summarised in Table 2. All of the prediction algorithms produced statistically different results than the measured RMR value. RMR was severely underestimated by all prediction equations, with the Altman & Dittmer equation

Table 2. A comparison of measured and predicted RMR values (paired t-tests).

RMR Method	RMR (kcal·d^{-1}) (mean ± SD)	Mean of Differences (kcal·d^{-1}) (mean ± SD)	95% Confidence Interval	Effect Size (d)	p
Indirect calorimetry	1812.033±266.6				
Harris and Benedict	1463.08±75.9	348.96±224.1	265 to 433	1.78	0.00
Jagim	1620.71±137.8	191.32±207.7	114 to 269	0.9	0.00
Watson	1446.79±114.5	365.24±279.8	261 to 470	1.78	0.00
Mifflin-St.Jeor	1387.73±93.7	424.30±219.0	343 to 506	2.13	0.00
DeLorenzo	1625.32±104.7	186.71±226.0	102 to 271	0.92	0.00
WHO/FAO/UNU	1421.10±96.3	390.91±218.3	309 to 472	1.96	0.00
Owenetal.(Athletes)	1376.20±137.2	435.83±207.8	358 to 513	2.06	0.00
Schofield	1422.11±96.8	389.92±217.9	309 to 471	1.95	0.00
Liu	1371.63±107.3	440.40±212.5	361 to 520	2.17	0.00
Altman&Dittmer	1719.58±123.5	92.46±210.38	14 to 171	0.44	0.02
IMNA	1336.56±128.7	475.49±224.7	392 to 559	2.27	0.00
Maffeis	1338.17±88.1	473.86±222.6	391 to 557	2.39	0.00

having the smallest mean difference (92 kcals).

The Altman & Dittmer equation performed best, predicting 16 out of 30 subjects' RMR accurately within ±10%. The Harris and Benedict, Jagim, Watson, Mifflin-St.Jeor, De Lorenzo, WHO/FAO/UNU, Owen et al. (Athletes), Schofield, Liu, Altman & Dittmer, IMNA, Maffeis, equations predicted, respectively, 5, 9, 5, 3, 13, 5, 3, 3, 3, 16, 2 and 2 participant' RMR accurately (Table 3).

Table 3. Percentage of combat female athletes whose RMR was accurate, overpredicted, or underpredicted as per predictive equation*

Equation	Accurate	Overpredicted	Underpredicted
Harris and Benedict	16.67	6.67	76.67
Jagim	30.00	6.67	63.33
Watson	16.67	3.33	80.00
Mifflin-St.Jeor	10.00	0.00	90.00
De Lorenzo	43.33	6.67	50.00
WHO/FAO/UNU	16.67	0.00	83.33
Owen et al. (Athletes)	10.00	0.00	90.00
Schofield	10.00	3.33	86.67
Liu	10.00	0.00	90.00
Altman & Dittmer	53.33	13.33	33.33
IMNA	6.67	0.00	93.33
Maffeis	6.67	0.00	93.33

*For each equation, data are expressed as percent of the total sample. Each row sums to 100%. Accurately predicted resting metabolic rate falls within ±10% of the value obtained from measured RMR. Overpredicted resting metabolic rate is ≥10% of the value obtained from measured RMR. Underpredicted resting metabolic rate is ≤ -10% of the value obtained from measured RMR

In female athletes, all prediction equations demonstrated a heteroscedastic distribution when compared to observed RMR using indirect calorimetry. The prediction equations did not accurately or precisely estimate resting metabolic rate in the current sample of female athletes based on the Bland-Altman plots. Figure 1 depicts the findings of the Bland-Altman study.

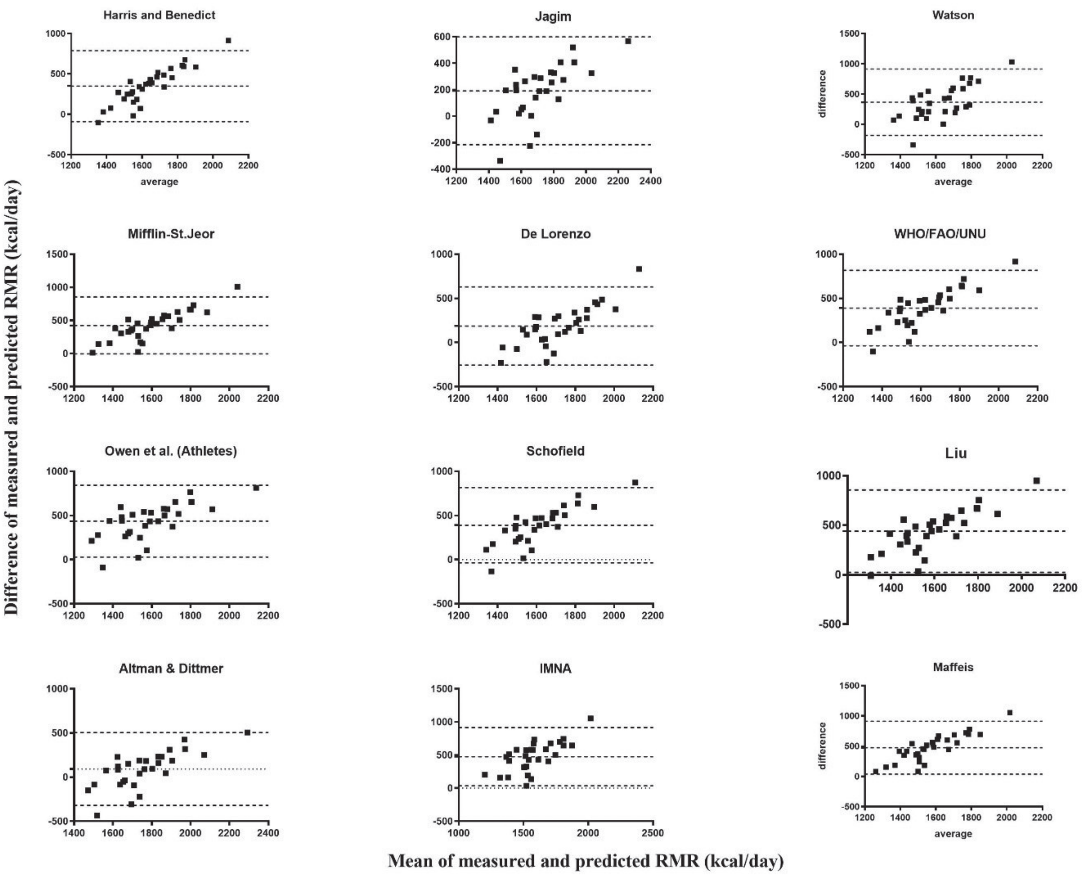

Figure 1.

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Discussion

The current study assessed the accuracy of various commonly used RMR prediction equations among female combat sports athletes. This study presents statistics on the accuracy of RMR prediction equations in female combat sports athletes for the first time. According to the current study, all prediction models greatly underestimated RMR, with the Altman & Dittmer equation having a minor mean discrepancy (92 kcals). However, the mean difference remained considerable, implying that the equation did not reliably predict observed RMR. Differences in anthropometric characteristics between athlete groups, as well as variables used in prediction equations, may explain the variation in accuracy. Our findings show that the accuracy of projected values varies depending on the equation utilized, emphasizing the significance for practitioners to consider numerous criteria when deciding the best equation to apply in a specific athlete group.

Previous studies found that most prediction algorithms underestimate RMR in female athletes (Cunningham, 1980; De Lorenzo et al., 1999). In this investigation, all of the prediction equations drastically underestimated RMR when compared to indirect calorimetry RMR observations. This indicates that the predicted RMR values and their accuracy level may differ based on RMR prediction models used in which population. De Oliveira et al. (de Oliveira et al., 2011), for example, discovered that the World Health Organisation (FAO/WHO/UNU) and Harris-Benedict equations predicted the best RMR (2180 kcals) in overweight and obese people (Harris & Benedict, 1918; Livesey, 1987). The current study's findings show that most of the RMR prediction models employed underestimated RMR values in female athletes. As a result, it is critical to recognize that the equations may underestimate the actual RMR. All equations should be handled cautiously when recommending athletes based on their energy needs. Other studies in the literature have revealed results consistent with the current study about the inaccuracy of RMR prediction equations in athletic populations, particularly in endurance-trained athletes (De Lorenzo et al., 1999; ten Haaf & Weijs, 2014; Thompson & Manore, 1996).

In a study of 51 well-trained male athletes from diverse sports, De Lorenzo et al. (De Lorenzo et al., 1999) discovered that the Harris-Bennett-Mifflin equation overestimated RMR. Similarly, Thompson and Manore (Thompson & Manore, 1996) discovered that among male and female endurance athletes, all mean projected RMR values were lower than measured RMR. Several factors may contribute to RMR underestimation, although the explanation is unknown. Individuals with high levels of physical activity or training status have greater RMR values than individuals with low levels of physical activity or sedentary individuals, which may depend on sport-specific activities. The athletes' current training status, in particular, could impact the measured RMR values (Bullough et al., 1995; Speakman & Selman, 2003; Speakman & Westerterp, 2010). RMR is also affected by the current state of energy balance, according to Bullough et al.(Bullough et al., 1995). The scientists discovered that a high degree of recent exercise activity and a sufficient caloric intake was linked to higher rates of RMR. Recent physical activity status may even influence acute RMR values up to 72-96 hours postexercise (Bullough et al., 1995; Herring et al., 1992; Speakman & Selman, 2003), which may explain the reason for the underestimation or overestimation of any of the specific RMR prediction equations and emphasizes the need for more sport-specific RMR prediction equations to reflect daily metabolic activity fluctuations accurately.

Watson (Watson et al., 2019) and Jagim (Jagim et al., 2019) verified equations in large samples of collegiate athletes from a number of sports (including track and field, swimming, soccer, tennis, softball, volleyball, and field hockey) and gave useful information on validated equations for usage in these groups. On the other hand, female combat athletes were not tested in the scope of the two studies described. As a result, the findings of this study may be valuable in providing information about the most widely utilized equations, particularly in terms of female combat sports athletes.

According to the ACSM's most recent policy statement on nutrition and athletic performance (Thomas, Erdman, & Burke, 2016) appropriate energy intake for athletes is a cornerstone. The Harris-Benedict equation was recommended to predict RMR in the athletic population. However, the advice presented is generalized for the entire athletic population, with no specialized instructions for any specific demographic regarding sport-specific requirements. Specific suggestions are required because each sport discipline has varied needs due to physiological characteristics, weight control, and energy metabolism (Joseph et al., 2017). In this study, the Harris-Benedict equation accurately predicted RMR values within the range ±10% for 5 out of 30 subjects. However, the detected mean difference for energy demand was underestimated as 348,96 kcals.

Devrim-Lanpir et al. (Devrim-Lanpir et al., 2019) found that the Mifflin-St. Jeor equation for women predicts a value close to observed RMR within acceptable limits in ultra-endurance athletes with improved accuracy. In agreement with Jagim et al., the Harris-Benedict equation did not reliably predict values near measured RMR in female ultra-endurance athletes (mean difference 554.86 kcals) (Jagim et al., 2018). In the present study, both the Harris-Benedict and Mifflin-St. Jeor equations (mean differences respectively; 348,96, 424,30 kcals) did not accurately predict the RMR values. Harris-Benedict and Mifflin-St. Jeor accurately predicted the RMR values in only 10.0-16,67% and underestimated in 76,67-90 % of the athletes in this study.

One of the few RMR prediction equations built utilising data from a group of athletes is the De Lorenzo equation (De Lorenzo et al., 1999). It is based on 51 male athletes averaging at least 3 hours of exercise daily. In line with the current study's findings, BM was identified as a significant predictor factor for RMR prediction equations. De Lorenzo et al. (De Lorenzo et al., 1999) also found that BM was a stronger predictor of RMR than FFM in male athletes. Fields et al. (Fields et al., 2022) found that for female athletes, the De Lorenzo and Watson equations yielded the lowest mean difference values of 171 and 211 kcals, respectively, accounting for 54% and 39% of the variance in observed RMR.

Furthermore, no significant mean differences were found for any equation. The De Lorenzo equation revealed the highest consistency with observed RMR values in the female sample, consistent with previous research in athletic groups (Frings-Meuthen et al., 2021; ten Haaf & Weijs, 2014). This equation was proposed as the best successful prediction equation in a sample with heterogeneous body features (Freire et al., 2022). In the current study, the De Lorenzo equation prediction produced the most negligible mean difference (186,71) when compared to the Altman and Dittmer equation (Altman & Dittmer, 1968). De Lorenzo equation accurately predicted the RMR values within the range ±10% for 13 out of 30 subjects.

Balci et al., found no difference in observed and projected RMR using the Mifflin and Owen equations in Turkish Olympic-level female athletes for both equations that gave large root-mean-squared error values in the current investigation (Balci et al., 2021). It is also likely that minor variations in RMR may occur in female athletes throughout the menstrual cycle due to oscillations in ovarian hormone levels, which could affect the accuracy of selected RMR prediction equations (Benton, Hutchins, & Dawes, 2020). As a result, future research should look into how the menstrual cycle affects RMR and total daily energy expenditure in female athletes.

Female participants in the current study had a mean RMR of 1812,033 kcal.d-1, which is higher than earlier studies that indicated a mean RMR range of 1,500-1,594 kcal.d-1 in female athletes (Fields et al., 2022; ten Haaf & Weijs, 2014; Tinsley, Graybeal, & Moore, 2019). Because particular equations may not be applicable across varied populations, more sport-specific or body-type RMR estimates are required. Developed a somatotype-specific equation, it could not be used in the current study due to a lack of skinfold data (Freire et al., 2022). As a result, their equation's agreeability level may be studied and compared with the measured RMR using indirect calorimetry in the population of female athletes in future investigations.

Furthermore, there may have been evolutions in body stature and composition in sports during the last 20-30 years, resulting in results acquired in the scope of the studies conducted over the two decades having wide range variances in terms of longitudinal viewpoint (Norton & Olds, 2001). When examining the accuracy of various RMR prediction equations, particularly those established +20 years ago from smaller or larger athletes with lower or higher RMR levels relative to certain periods representing differing demands for any activity, this may be a complicating variable. When the Bland-Altman plots were examined, it was obvious that most of the predictive equations were more accurate at lower recorded RMR values. Because of the heteroscedasticity demonstrated by the Bland-Altman plots, it is obvious that prediction equations are less likely to accurately estimate RMR for athletes with higher RMR values, as would be the case for athletes with greater body mass. According to the findings of this study, all RMR prediction algorithms produced underestimated RMR levels in female combat athletes.

RMR prediction equations should be used with caution when recommending to athletes regarding actual energy requirements for maintaining energy balance due to their underestimation characteristics. The most suitable equation should be preferred depending on the equation developed for which sport and sex [5]. Furthermore, future research should focus on athletes' training plans or existing training practices. RMR can be increased for several days following some forms of activity, particularly if there is a high degree of exercise-induced muscle damage (Hudson et al., 2019). Underestimation of RMR may result in inappropriate nutrition plans for athletes, which may be problematic and result in insufficient fueling, affecting sports performance and resulting in poorer health outcomes, as well as increasing the risk of low energy availability [43, 44], fat-free mass loss, and injuries (Mountjoy et al., 2018). On the other hand, overestimation of energy requirements might result in weight gain, which can impair performance or periodization for weight control in female combat athletes (Thomas, Erdman, & Burke, 2016). When indirect calorimetry cannot quantify RMR, an accurate RMR estimation equation becomes a critical tool for practitioners and combat athletes.

Conclusion

The results in the present study indicate that the Altman & Dittmer equation is the more suitable equation to predict RMR among 12 equations. If direct access to metabolic equipment is unavailable, Altman & Dittmer prediction equations can be used to estimate RMR for combat athletes. Although the Altman & Dittmer equation resulted in the slightest mean difference, there is a need for further research with a longitudinal approach to understand the effects of training intensity and body mass changes on RMR to develop the formulas already exist used commonly. However, to minimize the mean difference between the predictive equation calculations and indirect calorimetry results and determine the most appropriate equation for combat sports athletes, it is understood that classifications are needed to be based on weight categories to establish homogenized groups. Future studies may consider classifying participants based on their weight category and re-evaluating the accuracy of the equations in a more narrow context regarding participants' demographic factors.

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