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Verification of the Theoretical Energy Requirement of Underweight, Normal Weight and Overweight Young Women Using Ergospirometry

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Abstract: The research aim was to verify the theoretic energy requirement of young women and to calculate correlations between body mass index (BMI) and energy requirement, on the one hand, and the parameters obtained from bioelectrical impedance analysis on the other. The study was conducted in a group of 32 women grouped based on their BMI: underweight *n* = 8, normal weight *n* = 15, and overweight *n* = 9. Predictive formulas were observed to underestimate the energy requirement compared to values obtained with the use of ergospirometry. The smallest difference in Resting Energy Expenditure (REE) estimates using an ergospirometry apparatus was observed for the Cunningham equation (underweight: 1507 vs 1350 kcal) and the Harris-Benedict equation (normal weight: 1641 vs 1437 kcal; overweight: 1882 vs 1609 kcal). A significant statistical correlation was recorded in the juxtaposition of BMI to weight in the normal weight and in the overweight group. REE estimation based on formulas has only limited predictive value. Indirect calorimetry is recommended for measuring the REE rather than predictive equations.

Keywords: energy requirement, ergospirometry, bioelectric impedance, basal metabolic rate, resting energy expenditure

1. Introduction

Metabolism is a joint term relating to all the processes taking place in the body to sustain life, and is often equated to the body's energy requirement to maintain vital processes. The relevant values are usually expressed in kilocalories (kcal) or kilojoules (kJ), where 1 kcal = 4.1862 kJ (Ciborowska and Rudnicka, 2014).

By definition, basal metabolic rate (BMR) relates to the lowest level of calorie conversion taking place in a human body on an empty stomach, at physical and mental rest (after remaining prone for 30 minutes), and under normal microclimatic conditions (Jarosz et al., 2020). BMR is responsible for the largest portion of the total metabolic rate (TMR) – between 45% and 70% of the body's total energy requirement (Redondo, 2015; Rzesoś, 2013).

Resting Energy Expenditure (REE) is understood as the energy consumption needed to maintain the basic life functions. The body uses it at complete physical and mental rest, in thermal comfort and fasting conditions, in a horizontal position after at least eight hours of sleep (Malińska and Młynarczyk, 2020). It accounts for about 55-75% of the total energy expenditure and is linked directly to fat-free body mass that is more metabolically active than adipose tissue (Müller and Bosy-Westphal, 2013; Polak et al., 2021). The volume of REE can be measured by direct or indirect calorimetry or calculated from theoretical equations, depending mainly on body weight and height, age, sex, build, and physiological condition (for women) (Pavlidou et al., 2018). Health and nutrition status, functioning of endocrine glands as well as genetic factors, medication and climate are also relevant (Apovian, 2016). Changes in REE can be mediated by certain hormones which include insulin, leptin and vitamin D levels (Calton et al., 2016). However, it is thyroid hormones – trioidothyronine (T_3) and thyroxine (T_4) – that are the key REE regulators (Soares and Müller, 2018). Starvation induces significant variations in REE (Mohan et al., 2017). Physiological conditions such as pregnancy and lactation can also result in REE changes (Apovian, 2016). It is also known that smoking, stress and the thermic effect of some components, such as caffeine, capsaicin and some drugs, can increase REE (Müller and Bosy-Westphal, 2013). Individual discrepancies in terms of REE can reach up to +/– 10% in persons with the same anthropometric indices, age, and sex, and are usually associated with genetic diversity (Jarosz et al., 2020). Theoretical predictive equations facilitate REE estimation, but with varying accuracy (Ławiński et al., 2015).

TMR is related to the body's functioning in its environment and the person's activity (Gawędzki, 2022). It covers REE, postprandial thermogenesis, and energy expenditure related to physical activity. The concept of TMR is important both in respect of adjusting the calorie intake to the energy requirements related to an individual's daily activity, as well as the overall health condition (Rzesoś, 2013).

The accurate estimation of REE, particularly for obese people, is necessary to improve individual clinical assessments and set adequate dietary targets for effective weight loss (Poli et al., 2016). For practical nutritional purposes in healthy patients, the calculation of REE from a theoretical formula tends to be sufficient. The most commonly used REE formulas include the Harris-Benedict universal equation (Harris and Benedict, 1918), the Mifflin-St. Jeor's corrected equation (Mifflin et al., 1990), Cunningham's equation (Cunningham, 1991), and the Katch-McArdle formula (McArdle et al., 2006) – the latter two are most often used when the fat-free mass (FFM) of the body is known. The value of BMR depends primarily on the person's weight, height, body composition, age and sex (Nikooyeh and Tirang, 2019).

Direct calorimetry relies on a metabolic criterion, namely heat. The calorimeter directly measures the amount of heat the body generates and, simultaneously, determines the amount of oxygen used and carbon dioxide and water produced (Jarosz et al., 2020). Direct calorimetry chambers can be used for measuring both REE and TMR. This method assumes that all energy processes in the human body are accompanied by heat energy releases (Soares and Müller, 2018). The amount of heat radiated is expressed in a unit of time and measured based on the increase in temperature of water surrounding the chamber's walls (Hackney, 2016). The drawbacks of this method include artificial measuring environment, technically complicated measurements and high testing cost, thus it is rarely used in daily practice but more often during experiments (Soares and Müller, 2018).

An alternative to this is offered by indirect calorimetry. The premise of the method is that energy used by the body is obtained from the oxidation of macroelements: carbohydrates, fats, and proteins. Indirect calorimetry relies on the metabolic criterion of respiratory exchange. Oxygen is consumed and carbon dioxide released pro rata to the amount of energy expended (1 litre of oxygen produces 4.825 kcal) (Jarosz et al., 2020). The measurement entails a determination of respiratory gas exchange in a unit of time (Soares and Müller, 2018). The method of indirect calorimetry is considered particularly useful in determining the energy expended during exertion, particularly aerobic (Byrska, 2013). The determination of energy consumption with indirect calorimetry entails the use of special equipment – the so-called ergospirometers – combining systems for wireless pulse measurement, a facemask and an analyser measuring the composition of respiratory gases (Hills et al., 2014). Measurements should be conducted in the morning, on an empty stomach (after fasting for 10-12 hours), in the prone position, with the patient not having used substances (coffee, tea, alcohol, and tobacco) for the preceding 12 hours and not having engaged in intensive physical activity for the preceding 24 hours. The patient should be in an environment where he/she can remain at physical rest, free of emotional stress and in adequate ambient temperature (26-27°C) (Redondo, 2015). This method has limited applications in clinical practice due to the expensive equipment, the requirement for skilled and trained personnel and time constraints (Poli et al., 2016). Nevertheless, with the progress of technology, small and light devices could be designed making indirect calorimetry very useful for clinical applications (Redondo, 2015). This is also a reference method for establishing the energy requirement of overweight adults (Soares and Müller, 2018). The accuracy of ergospirometry apparatuses in rest and exercise testing has been corroborated by many researchers (Rodriguez et al., 2022; Soares and Müller, 2018).

The aim of the study was to verify the theoretical energy requirement in young women classified as underweight, normal weight, or overweight, with the use of ergospirometry. Additionally, the correlation between body mass index (BMI) and energy requirement, on the one hand, and the parameters obtained from bioelectrical impedance analysis (BIA) on the other, was calculated to facilitate a better understanding of the observed relationships. The use of ergospirometry allowed a precise estimation of the energy requirement, which is not always possible when relying on predictive formulas alone.

2. Materials and Methods

The measurements were conducted between May and June 2019 at the Nutrition Counselling Centre of the University of Life Sciences in Lublin (eastern Poland). The study group was composed of 32 female students (*n* = 32) aged between 18 and 25 years.

The BMI index is used to determine a person's body mass status. The value can fall within a specific range describing body weight: malnourishment, thinness, underweight, normal weight, overweight, class I obesity, class II obesity and class III obesity (Brończyk-Puzoń et al., 2018). For the purposes of this study the women were classified into three groups (underweight <18.49 *n* = 8, normal weight 18.5-24.99 *n* = 15, and overweight >25 *n* = 9) (Table 1).

Table 1. Basic anthropometric data of the respondents
Tabela 1. Podstawowe dane antropometryczne respondentów

Parameter	BMI <18.49				BMI 18.5-24.99				BMI >25			
	Average±SD	Median	Min	Max	Average±SD	Median	Min	Max	Average±SD	Median	Min	Max
Height [cm]	166±7.0	166	156	180	167±7.0	168	155	180	165±4.0	165	159	172
BW [kg]	47.9±5.4	48.5	40	57	59.5±7.4	57	50	70	79±9.1	79	68	93
BMI [kg/m²]	17.4±0.9	17.5	15.6	18.4	21.3±1.4	21.2	19.5	23.4	28.8±3.8	27	25	34.3

BW – body weight; BMI – Body Mass Index; SD – standard deviation; Min – minimum value; Max – maximum value.

Source: own study.

Measurement

A Cosmed Fitmate Pro calorimeter (Rome, Italy) was used to conduct indirect calorimetric measurements. The tests were conducted in a quiet space, at room temperature and under adequate lighting. The device was calibrated before each use, as per the manufacturer's instructions. The measurements were carried out with the use of a ventilated facemask matched to the size of the patient's head. Each subject was asked to lie down on her back, remain calm and stay awake during the test. The volumes of oxygen consumption and carbon dioxide production were measured with the ergospirometers over a 20-minute period, with the measurement proper, i.e. the registration of results for subsequent analysis, beginning one minute after starting the procedure. The results were printed out immediately after completing the measurement using the device's built-in printer. The body composition analysis was performed using a Seca mBCA 515 analyser (Hamburg, Germany) with the electric bioimpedance method. The obtained results reflected the following parameters: weight, fat mass (FM), fat-free mass (FFM), resting energy expenditure, energy requirement, skeletal muscle mass, total water content, extracellular water, phase angle, and abdominal fatty tissue. The women were additionally measured using a height meter.

Food Diary

The subjects were asked to maintain a diary, in any form, listing all the food and beverages consumed over a period of seven days. Next, they input data recorded in the diaries into DIETA 5.D software developed by Instytut Żywności i Żywienia (Wajszczyk et al., 2015). Mean 7-day values were calculated and compared to the Dietary Standards adopted for the Polish population (Jarosz et al., 2020).

Theoretical Predictive Formulas

The energy requirement was estimated using theoretical predictive formulas based on mathematical equations – Harris-Benedict's (Harris and Benedict, 1918), Mifflin-St. Jeor's (Mifflin et al., 1990), Cunningham's (Cunningham, 1991), and Katch-McArdle's (McArdle et al., 2006) as presented in Table 2. The mathematical equations used in the theoretical predictive formulas are listed in Table 3.

Table 2. Comparison of the energy demand of the respondents to the predictive formulas
Tabela 2. Porównanie zapotrzebowania energetycznego respondentów do formuł predykcyjnych

Method or formula	BMI <18.49				BMI 18.5-24.99				BMI >25			
	Average ±SD	Median	Min	Max	Average ±SD	Median	Min	Max	Average ±SD	Median	Min	Max
Indirect calorimetry	1507±211	1569	1068	1762	1641±208	1582	1354	2037	1882±183	1914	1595	2208
Mifflin-St. Jeor	1256±95	1268	1134	1439	1369±112	1333	1233	1579	1562±108	1560	1434	1733
Harris-Benedict	1328±63	1335	1249	1444	1437±80	1404	1332	1578	1609±86	1623	1506	1749
Katch-McArdle	1205±84	1195	1102	1377	1255±102	1232	1105	1436	1427±71	1417	1297	1498
Cunningham	1350±86	1340	1246	1525	1401±104	1378	1249	1586	1576±72	1566	1444	1649

BMI – Body Mass Index; SD – standard deviation; Min – minimum value; Max – maximum value.

Source: own study.

Table 3. Mathematical equations of theoretical predictive formulas
Tabela 3. Równania matematyczne teoretycznych wzorów predykcyjnych

The name of the predictive formula	The mathematical equation determining the REE
Harris-Benedict	REE (men) = 66.5 + (13.75 × body mass [kg]) + (5.003 × height [cm]) – (6.775 × [age]) REE (women) = 655.1 + (9.563 × body mass [kg]) + (1.85 × height [cm]) – (4.676 × [age])
Mifflin-St.Jeor	REE (men) = (10 × body mass [kg]) + (6.25 × height [cm]) – (5 × [age]) + 5 REE (women) = (10 × body mass [kg]) + (6.25 × height [cm]) – (5 × [age]) – 161
Cunningham	REE = 500 + (22 × FFM [kg])
Katch-McArdle	REE = 370 + (21.6 × FFM [kg])

REE – Resting Energy Expenditure; FFM – fat free mass.

Source: (Cunningham, 1991; Harris and Benedict, 1918; McArdle et al., 2006; Mifflin et al., 1990); own elaboration.

Calculations and Statistical Analyses

The calculations of correlation (R) and coefficient of determination (R^2) between the values of BMI and energy requirement, and also data obtained from BIA and averaged dietary indices, were conducted using Microsoft Office Excel 2019 (Table 4).

Table 4. Correlations and coefficients of determination (R^2) between BMI and energy demand, and the parameters obtained from the analysis of the body composition of the tested by bioelectrical impedance analysis (BIA)
Tabela 4. Korelacje i współczynniki determinacji (R^2) pomiędzy BMI a zapotrzebowaniem energetycznym oraz parametrami uzyskanymi z analizy składu ciała badanych metodą bioimpedancji elektrycznej (BIA)

Parameters	BMI <18.49		BMI 18.5-24.99		BMI >25	
Body composition analysis	R	R^2	R	R^2	R	R^2
BMI vs body weight	0.67	0.45	**0.74**	0.56	**0.94**	**0.88**
BMI vs FM	0.08	0.01	0.48	0.23	–0.27	0.07

BMI vs lean mass	0.11	0.01	–0.48	0.23	0.30	0.09
BMI vs energy consumption at rest	0.12	0.01	0.25	0.06	–0.09	0.01
BMI vs energy demand according to Harris-Benedict equation	0.26	0.07	0.22	0.05	0.26	0.07
BMI vs total water content	0.12	0.02	–0.04	0.00	0.42	0.18
BMI vs extracellular water	–0.19	0.03	–0.09	0.01	0.50	0.25
BMI vs phase angle	0.43	0.19	–0.11	0.01	–0.56	0.31
BMI vs abdominal fat tissue	0.38	0.15	0.57	0.32	–0.46	0.21
TER vs body weight	0.31	0.09	0.68	0.46	0.65	0.55
TER vs FM	0.24	0.06	–0.15	0.02	0.03	0.00
TER vs lean mass	– 0.38	0.14	0.15	0.02	0.43	0.19
TER vs energy consumption at rest	– 0.16	0.03	– 0.22	0.05	0.31	0.07
TER vs abdominal fat tissue	– 0.40	0.16	– 0.14	0.02	0.18	0.05
TER vs total water content	–0.32	0.10	– 0.14	0.02	0.27	0.20
TER vs extracellular water	– 0.19	0.04	0.08	0.01	– 0.02	0.25
TER vs phase angle	0.23	0.05	– 0.03	0.00	– 0.19	0.16
BMI vs TER	0.26	0.07	0.22	0.05	0.61	0.37

BMI – Body Mass Index; TER – total energy expenditure calculated from the values obtained from the ergospirometer and the coefficient Physical Activity Level index; FM – fat mass; R – correlation coefficient; R^2 – coefficient of determination.

Source: own study.

3. Results

The energy requirement determined with ergospirometry was multiplied by the Physical Activity Level (PAL) and the result was compared to the nutritional value of the research participants' diet (Table 5). The largest discrepancies (mean values) between the total energy requirement and the nutritional value of the diet were observed for women classified as overweight – the difference was 1313 kcal (2650 vs 1337 kcal). For women classified as having normal weight, the difference was 797 kcal (2222 vs 1425 kcal), and in underweight women – 402 kcal (2186 vs 1784 kcal).

Table 5. Energy demand according to the ergospirometer and PAL index, and the energy content of the participants' diet

Tabela 5. Zapotrzebowanie energetyczne według ergospirometru i wskaźnika PAL oraz zawartość energii w diecie badanych

Calorific value	BMI <18.49				BMI 18.5-24.99				BMI >25			
	Average ±SD	Median	Min	Max	Average ±SD	Median	Min	Max	Average ±SD	Median	Min	Max
Energy demand [kcal]	2186±323	2035	1850	2675	2222±272	2200	1735	2675	2650±416	2615	2176	3254
Energy of the current diet [kcal]	1784±431	1704	1245	2689	1425±326	1371	985	2036	1337±254	1345	1060	1675

BMI – Body Mass Index; SD – standard deviation; Min – minimum value; Max – maximum value.

Source: own study.

The largest discrepancies (mean values) between the energy requirement determined using an ergospirometry apparatus and calculations using predictive formulas were observed for the Katch--McArdle equation in all three groups of subjects (302 kcal for the underweight group; 386 kcal for the normal weight group; 306 kcal for the overweight group). In turn, the smallest discrepancies in this respect were recorded for the Cunningham equation (157 kcal for the underweight group) and the Harris Benedict equation (normal weight and overweight groups – 204 kcal and 273 kcal, respectively) (Table 2).

The lowest values of FM, FFM, total water content, extracellular water, and abdominal fatty tissue were recorded for underweight women, while the highest for overweight women. The phase angle which reflects the quality of an organism's cells, and therefore its overall health, was similar in all subjects – 4.7-4.8° (Table 6).

Table 6. Results obtained from the analysis of the body composition of the tested by bioelectrical impedance analysis (BIA)
Tabela 6. Wyniki uzyskane z analizy składu ciała metodą bioimpedancji elektrycznej (BIA)

Parameter	BMI <18.49				BMI 18.5-24.99				BMI >25			
	Average ±SD	Median	Min	Max	Average ±SD	Median	Min	Max	Average ±SD	Median	Min	Max
FM [kg]	18.7±4.6	18.8	11.1	25.4	19.3±4.2	20.6	11.8	24.9	38.0±6.2	36.5	31.1	44.8
Lean mass [kg]	38.7±3.9	38.2	33.9	46.6	41.0±4.7	39.9	34.0	49.0	48.9±3.3	48.5	42.9	52.2
Energy consumption at rest [kcal]	1193±75.4	1186	1102	1333	1378±106.0	1343	1231	1559	1665±122.2	1661	1488	1861
Energy demand according to Harris-Benedict equation [kcal]	1895±191.0	1914	1638	2132	2242±196.0	2225	1970	2594	2587±199.9	2552	2233	2835
Total water content [L]	28.0±3.0	27.5	24.5	34.1	30.1±3.7	29.1	24.7	36.2	37.3±4.7	36.3	31.8	48.3
Extracellular water [L]	11.8±1.2	12.0	10.5	13.5	13.1±1.5	13.0	10.8	15.6	16.3±2.0	16.0	13.4	20.8
Phase angle [°]	4.8±0.6	4.7	3.8	5.6	4.7±0.3	4.7	4.2	5.5	4.8±1.7	5.3	0.3	5.9
Abdominal fat tissue [L]	0.3±0.1	0.4	0.0	0.5	0.4±0.2	0.4	0.1	0.7	0.7±0.7	0.6	0.0	2.1

BMI – Body Mass Index; FM – fat mass; SD – standard deviation; Min – minimum value; Max – maximum value.

Source: own study.

R and R2 were calculated between BMI and energy requirement on the one hand, and all the parameter measurements obtained by (BIA) – the results are presented in Table 4. Significant (high) correlations were observed between BMI and weight in the normal weight group (R = 0.74) and the overweight group (R = 0.94; R2 = 0.88). In the remaining cases, significant correlations were not observed.

4. Discussion

The study was designed to compare and verify the REE measurements obtained with an ergospirometry apparatus with estimations acquired from predictive formulas. Notably, both the gathered data and available literature reports indicate that REE may different significantly even between people of the same age and with similar BMI, which further underscores the importance of the REE measurements. Table 7 sets out differences between PPM determined using indirect calorimetry and PPM calculated using predictive equations.

Table 7. Comparison of indirect calorimetry and predictive equations in determining energy expenditure
Tabela 7. Porównanie kalorymetrii pośredniej i równań predykcyjnych w określaniu wydatku energetycznego

Differentiating indicators	Indirect calorimetry	Predictive equations
Accuracy	High, reference method	Inaccurate
Equipment	Light and compact devices with mask and printer	None
Cost	Purchase and maintenance of equipment Consumables such as paper for portable printer Personnel training	None
Easy to use	Requirement for experienced and skilled personnel Device calibration required at times	Very easy to use
Testing time	Long (ca. 20 minutes)	Short, immediate
Accessibility	Low, only at selected medical and nutrition centres	Readily available online and in scientific sources
Parameters tested	REE, oxygen consumption, carbon dioxide consumption, respiratory quotient	REE and TER
Indications	For precise energy requirement estimation, customised	For daily use by healthy people

REE – resting energy expenditure; TER – total energy requirement.

Source: own study.

The conclusions reported by Zhang, Tian and Tan (2018) indicate that ergospirometry, unlike predictive formulas, provides reliable and repeatable measurements of oxygen consumption and REE. The obtained results corroborate the viability of ergospirometry measurements by health experts for the purposes of determining REE.

In the presented study, measurements were conducted in a group of young women. Women in this age group are often weight-conscious and commonly calculate their own REE to facilitate weight loss strategies (Przybyłowicz et al., 2014). As observed by Jarosz et al. (2020), the reference calorie consumption among adult women in Poland is estimated at 2000 kcal daily. In this study, the averaged energy requirement measured with the use of ergospirometry and multiplied by PAL was 2186 kcal in the case of underweight women, 2222 kcal for women with normal weight, and 2650 kcal for overweight women.

As the study demonstrated, the nutritional value of diets failed to meet the aforementioned standards (Jarosz et al., 2020) or the total energy requirement determined using an ergospirometer. The results indicated energy deficiencies, similarly to reports by other authors (Samolińska and Kiczorowska, 2014; Correa-Rodríguez et al., 2018). Kucharska et al. (2016) conducted in a group of female students of dietetics (aged 20.2±1.0 years, n=153), and observed that their food rations did not cover their energy requirements, while the average daily calorie consumption among young women with normal weight (BMI = 20.8±1.0 kg/m^2) was around 1771.3±422 kcal, i.e. higher than those calculated in this study for normal-weight women. In the study conducted by Stańczyk, Kolmaga and Burzyńska (2021), for nearly 75% patients aged from 18 to 35 (average BMI = 27.01±6.11 kg/m^2), the energy requirement at the REE level was not accomplished (on average they consumed 1210 kcal/day). This can slow down the metabolic rate, hence inhibiting weight loss in people with excessive BMI. However , it should be taken into account that the respondents could have intentionally withheld information on the food products they consumed, as is supposed based on the results of this study. In a group of Japanese women (aged 20-79, *n* = 107 890) studied by Saito et al. (2018) in the early 1970s, the average total calorie consumption was 2287 kcal, while at the beginning of the 21st century the same decreased to 1948 kcal, i.e. by 15% over the course of nearly 30 years. Undoubtedly, in a long-term perspective energy deficiency may have adverse health effects, particularly in young women, which can take the form of e.g. dysmenorrhoea, libido disorders, gastrointestinal and cardiovascular problems, as well as the deterioration of bone condition (Logue et al., 2020).

In the presented study, the declared diets may have differed from the actual ones. Such discrepancies could result from inaccurate input of product and food categories into the Dieta 5.D software. It is also possible that the recorded consumption was inaccurate or underestimated. The respondents may have tampered with the amount and quality of the food recorded due to unwillingness to reveal their actual food intake. The omission of a fatty additive or misrepresentation of a food product may have resulted in certain inaccuracies. Conversely, the same may also have stemmed from the fact that the data recorded in the software reflected the amount of food prepared rather than actually eaten, which would mean that the women consumed even fewer calories than declared. It also cannot be excluded that the subjects may have consumed some of their meals at eateries, bars or restaurants and did not know the exact composition of the food or the amounts of products used in its preparation. The possibility of the young women's unawareness was excluded given the fact that most of the subjects (n = 30) were students of nutrition-related subjects (dietetics/food technologies). In an effort to avoid such problems, all the issues encountered by keepers of food diaries should be considered in order to fully understand their experiences and create future systems to facilitate keeping a food journal (Mackenzie et al., 2022).

Research carried out by Reneau et al. (2019) tackled the specificity of human origin in determining REE. The researchers measured REE (n = 114, 46 ± 16 years) using indirect calorimetry and compared the results with those calculated using predictive equations – the Mifflin-St. Jeor equation and the Harris-Benedict equation. In addition, FFM and FM were measured by DEXA scans. For African Americans predictive equations based on age, sex, body weight and height only overestimated REE by 138 ± 148 kcal in the Mifflin-St. Jeor equation and 242 ± 164 kcal in the Harris-Benedict equation, so the expected energy requirement for that population was higher. Lower ergospirometry-based REE values for African Americans can be associated with FFM representing metabolic activity of organs in the abdomen. The researchers found that their origin, hip measurement, age, sex and body weight are significant predictors of REE ($p < 0.005$).

A study conducted by Poli et al. (2016) aimed to identify predictive equations being the best alternative to indirect calorimetry in obese women from Brazil (n = 40, age 30-50, BMI = 30-39.9 kg/m²). The Harris-Benedict equation was the only one revealing no significant differences in comparison with indirect calorimetry and showing a systematic error <5%. The Harris-Benedict formula is one of equations most frequently used in clinical practice, and, being the oldest one, it was the most thoroughly validated (Harris and Benedict, 1918). Although the equation in Mifflin et al. (1990) was developed after testing a large population of obese people and hence is proposed as the most relevant equation for estimating REE in overweight and obese people aged from 19 to 69, both these authors results and those obtained by Poli et al. (2016) support the Harris-Benedict equation in this case. Pinto et al. (2016) also found the Harris-Benedict equation to be the most reliable alternative method for REE estimation.

Yao et al. (2013) posited that in the case of young, non-obese women (*n* = 52, age 19-30, BMI 16-29 kg/m²) the Owen formula should be employed as it yielded REE estimations that differed from the results obtained with the method of indirect calorimetry by under 10%. The discrepancies between the REE estimations from the Harris-Benedict and the Mifflin-St. Jeor equations, and the ergospirometry results were, respectively 225 ± 133 kcal and 159 ± 139 kcal, with the higher values obtained from the predictive formulas. Namazi et al. (2016) recommended using the Mifflin-St. Jeor equation for normal weight and overweight women (it was particularly accurate for the latter). This shows that a clinical evaluation and significant caution is required when applying prognostic formulas to specific populations or small subject groups.

Flack et al. (2016) demonstrated that at the level of an entire group (n=30, age 18-65, BMI 19-39 kg/m²), the Harris-Benedict formula proved the most accurate, but the same was no longer the case at individual level. With increasing FM, prognostic formulas tended to further underestimate REE.

Al-Domi and Al-Shorman (2018) demonstrated that the Harris-Benedict formula was the most accurate in predicting REE and showed no significant discrepancies when compared to the results of calorimetric measurements in women, regardless of BMI (n = 406, age 18-25), contrary to the study by Flack et al. (2016), the equations did not fare well at group level.

BIA is an easy-to-use method increasingly often used by nutritionists and gyms. It can be used for determining parameters such as skeletal muscle mass, FM, bone mineral density and total body water (Całyniuk et al., 2018). The values of FM estimated with the use of the BIA method showed a statistically significant correlation with BMI in a study by Rynkiewicz-Andryśkiewicz, Andryśkiewicz and Czernicki, (2013). Stupnicki and Tomaszewski (2016) demonstrated a positive correlation between BMI and the amount of fatty tissue in women aged between 19 and 30. The correlation coefficient was 0.71. According to Vybornaya et al. (2017), the metabolic rate predicted based on its correlation with FFM accounts for up to 70% of its variability. The authors posit that FM also affects basal metabolic rate, but no such correlation was observed in the course of the statistical analysis conducted in the presented study, where – similarly to that by Xue et al. (2019) – the relation between FFM and PPM was not significant. According to Weise et al. (2014), FFM is positively correlated with daily calorie supply and protein and carbohydrates intake, while FM – with daily calorie supply and protein and fat intake. Researchers from Finland report that daily energy intake correlates with BMI, and total fat intake – with BMI and FM in the human body (Matinolli et al., 2015). To date, there have been no studies pertaining to the correlation between energy requirement and the body's hydration (total and extracellular water content).

5. Conclusions

It was observed that predictive formulas tended to underestimate the energy requirements of the studied sample relative to the values obtained with the use of indirect calorimetry. In contrast, Molina-Luque et al. (2021) found that predictive equations tended to overestimate REE, regardless of the women's age or nutrition status. The literature points to significant variations in the accuracy of equations, which is affected by various factors (de la Cruz et al., 2015). The estimation of REE based on such equations has limited predictive value for individuals, which is why detailed clinical evaluation and considerable caution in relying on prognostic equations is recommended. Of all the predictive formulas considered, the Cunningham equation (in the underweight group) and the Harris-Benedict equation (in the normal weight and overweight group) yielded results that were the closest to BMR measured with the use of ergospirometry.

When considering an energy deficit of 500-600 kcal/day recommended for weight loss (Wirth et al., 2014), using a predictive equation underestimating REE can compromise the diet's effectiveness (Poli et al., 2016).

As in the study by Poli et al. (2016), the authors observed that the result of body composition analysis included in predictive equations for normal weight and overweight groups did not improve the accuracy of REE prediction. Only in the underweight group was the Cunningham equation based on FFM closest to ergospirometry measurements. This is a significant discovery since equations relying on anthropometric parameters (body weight and height) are more workable in clinical practice than equations that also take body composition into account.

Indirect calorimetry is advisable for REE measurement during the patient's first visit at the nutritionist. In addition, more accurate equations should be developed to fit with the results of indirect calorimetry (Molina-Luque et al., 2021).

Ergospirometry measuring REE is more accurate than predictive equations, and should be recommended especially to people for whom the accurate calculation of energy requirement is significant, e.g. soldiers, pregnant women (Fernández-Verdejo and Galgani, 2022) and women in the postpartum period (Pereira et al., 2019), including those overweight (Most et al., 2019), professional sportspeople (Tinsley et al., 2018), critically ill patients (Oshima et al., 2017) as well as those suffering from chronic civilisation diseases such as obesity (Lam and Ravussin, 2017). Thanks to this, diets and meal plans can be as much personalised as possible to meet individual needs.

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Weryfikacja teoretycznego zapotrzebowania energetycznego młodych kobiet z niedowagą, prawidłową masą ciała i nadmierną masą ciała za pomocą ergospirometrii

Streszczenie: Celem pracy była weryfikacja teoretycznego zapotrzebowania energetycznego młodych kobiet oraz obliczenie zależności między wskaźnikiem masy ciała (BMI) i zapotrzebowaniem energetycznym a parametrami uzyskanymi z analizy impedancji bioelektrycznej. Badanie przeprowadzono w grupie 32 kobiet wybranych na podstawie BMI: niedowaga n = 8, prawidłowa masa ciała n = 15, nadwaga n = 9. Zaobserwowano, że równania predykcyjne zaniżają zapotrzebowanie energetyczne w porównaniu z wartościami uzyskanymi za pomocą ergospirometrii. Najmniejszą różnicę w stosunku do Podstawowej Przemiany Materii (PPM) oszacowanej przy użyciu ergospirometru zaobserwowano w przypadku wzoru Cunninghama (niedowaga: 1507 *vs* 1350 kcal) i Harrisa-Benedicta (prawidłowa masa ciała: 1641 *vs* 1437 kcal; nadwaga: 1882 *vs* 1609 kcal). Zaobserwowano istotną korelację statystyczną między BMI i masą ciała w grupie z prawidłową masą ciała oraz w grupie z nadwagą. Oszacowanie PPM na podstawie wzorów ma ograniczoną wartość predykcyjną. Wskazane jest wykorzystywanie kalorymetrii pośredniej do pomiaru PPM zamiast używania wzorów predykcyjnych.

Słowa kluczowe: zapotrzebowanie energetyczne, ergospirometria, impedancja bioelektryczna, podstawowa przemiana materii, spoczynkowy wydatek energetyczny