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Comparison of Predictive Equations and Measured Resting Energy Expenditure Among Obese Youth Attending a Pediatric Healthy Weight Clinic: One Size Does Not Fit All

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Abstract

Background—The Academy of Nutrition and Dietetics recommends the use of indirect calorimetry for calculating caloric targets for weight loss in obese youth. Practitioners typically use predictive equations since indirect calorimetry is often not available. The objective of this study was to compare measured resting energy expenditure (MREE) with that estimated using published predictive equations in obese pediatric patients.

Material and Methods—Youth aged 7–18 years ($n=80$) who were referred to a university-based Healthy Weight Clinic and who were greater than the 95th percentile BMI for age and gender participated. MREE was measured via a portable indirect calorimeter. Predicted Energy Expenditure (pEE) was estimated using published equations including those commonly used in children. pEE were compared to the MREE for each subject. Absolute mean difference between MREE and pEE, mean percent accuracy, and mean error were determined.

Results—Mean percent accuracy of pEE compared to MREE varied widely with the Harris Benedict, Lazzar and Molnar equations providing the greatest accuracy (65%, 61% and 60% respectively). Mean differences between MREE and equation-estimated caloric targets varied from 197.9 kcal/day to 307.7 kcal/day.

Conclusions—The potential to either over or underestimate calorie needs in the clinical setting is significant when comparing EE derived from predictive equations with that measured using portable indirect calorimetry. While our findings suggest that the Harris-Benedict equation has improved accuracy relative to other equations in severely obese youth, the potential for error remains sufficiently great to suggest that indirect calorimetry is preferred.

Background

Childhood obesity is one of the most compelling public health concerns of our time.¹ Particularly over the past 6 years, evidence based research has led to recommendations from the American Academy of Pediatrics (AAP) and the Academy of Nutrition and Dietetics (the Academy) regarding prevention and treatment of this epidemic.^{2,3} Currently, the Academy recommends using indirect calorimetry to determine resting energy expenditure (REE) in obese youth; however, particularly in the pediatric clinical setting, this measurement is not widely available. A traditional indirect calorimeter- also known as a metabolic cart, is often utilized in the research setting for measuring REE; however this piece of equipment is often not practical for use in the clinical setting due to cost and size. Portable devices which demonstrate good correlation with the metabolic cart have been developed to measure REE in an office/clinical setting.^{4,5,6,7,8} Currently there are no data to describe the use of this device in a healthy weight clinic for obese youth.

An important physiological aspect of obesity is that of energy balance- the relationship between calories consumed through food and beverage (intake) and the amount of calories used by the body (expenditure).⁹ Total energy expenditure (TEE) is the total number of calories an individual uses each day- to include physical activity needs. As part of TEE, basal metabolic rate (BMR) is the minimum required amount of energy needed to carry out physiological processes at the cellular level. It is a strict measurement under total inactivity and controlled research conditions that keep the body at a constant temperature.⁹ Resting energy expenditure (REE) is measured when an individual is sitting quietly, a more 'real world' condition and the calories required at rest in this condition are slightly higher than BMR. REE accounts for approximately 60–70% of an individual's TEE.⁹ BMR and REE are the basis for the development of many predictive equations. (Table 1).

In the clinical setting, the registered dietitian (RD) determines total energy needs (TEE) for an individual by multiplying REE with an appropriate physical activity factor based on the individual's physical activity level. As REE accounts for the greatest percentage of total energy needs and is an important component in determining caloric needs for weight loss in obesity, most clinicians use a variety of predictive equations.^{10–15} Some equations estimate REE and need to be multiplied by an appropriate activity factor^{16–22} while other equations have been developed to calculate TEE with the inclusion of an activity factor, or physical activity level (PAL).^{23,24}

Many predictive equations have been developed for use with children, both healthy weight and overweight^{16,17,18,19,20,23,24}; however there remains a lack of consensus regarding the best equation to use in an obese pediatric population, particularly in severely obese children. [99th percentile BMI for age and gender based on the Centers for Disease Control and Prevention (CDC) definitions²⁵]. Some predictive equations, such as the Molnar and the Institutes of Medicine for Obese Youth (IOM-OY) have been developed specifically for use in an obese pediatric population.^{18,19,23} Other equations such as the IOM for children and the Schofield equation are more commonly used across pediatric populations regardless of obesity status.^{16,24} There are some data comparing commonly used predictive equations in an adult population with measured resting energy expenditure (MREE) using a hand held indirect calorimeter in the clinical setting.^{26,27} One study demonstrated the usefulness of a

portable indirect calorimeter in determining MREE in overweight women over 25 years of age and that there was a significant discrepancy between predicted and measured REE.²⁶ The investigators concluded that further research was needed to investigate measured REE with the use of such devices and to compare the results with those from predictive equations. Thus, the present study investigated relationships between EE measured in the clinical setting using a portable calorimeter and that obtained using published predictive equations commonly used in clinical practice and some that have recently been developed for the use in obese children and adolescents. The equations that were investigated in this study's obese pediatric population are given in Table 1

Methods

Research Subjects

Subjects were youth aged 7–18 years who were referred to East Carolina University's Pediatric Healthy Weight Clinic and who were > the 85th percentile BMI for age and gender. Data from subjects who were fasted and who were able to perform the complete indirect calorimetry protocol were included in this study. Subjects who were not fasted, fidgeted during testing, were unable to complete the test, or who were taking medications that could potentially alter metabolic rate were excluded. The study was approved by the University Medical Center Institutional Review Board at the Brody School of Medicine, East Carolina University. Data was extracted from clinical records.

Protocol: Indirect Calorimetry

The KORR ReeVue portable indirect calorimeter²⁸ was set up in a dedicated clinic exam room and was calibrated to room air, standard temperature and pressure. Patients were fasted overnight (approximately 8 hours) and had not exercised or been physically active for at least 8–10 hours. Patients also were seated in the clinic exam room for approximately 10–15 minutes before testing began; thus were in a resting state as recommended.^{29,30} Each patient was provided a new disposable tubing, mouthpiece and nose clip. Testing was performed for ten minutes in the seated position.. The patient sat calmly and still in the quiet, lit room breathing as they would normally breathe and into a mouthpiece, with a nose clip in place. Data were recorded when steady state was reached, typically after 10 minutes.. Predicted REE was then computed for each subject using each of the predictive equations. (see Table 1).

Assessing Differences between MREE and pEE

The average absolute difference from MREE was calculated by the square root of the mean squared error for each predictive equation and mean percent accuracy was calculated as the percentage of subjects with estimated values (pEE) within $\pm 10\%$ MREE.

Statistical Analysis

Data are presented as mean $\pm$ SE. Statistical analyses were performed using SPSS, (SPSS Version 18, 2010, Chicago, Illinois)³¹ and included Pearson correlation for comparing MREE to the predicted values derived from each predictive equation. T-test were also used to compare mean differences (Kcal/day) between measured and predicted values among subgroups. Chi square analysis was used to determine if differences in categorical variables such as race and gender were significant.

Results

A total of 80 subjects participated in this study. The mean age was 12.2 (± 0.3) yrs.; 57% girls; 71% non-white. Anthropometric data are presented in Table 2. The mean BMI of all

subjects was 99th percentile for age and gender. Table 3 describes the mean kcal/day as determined by measured REE and each predictive equation- for the whole group (n=80) and by gender. The mean average mREE was $1,977 \pm 49.9$ kcal/day. There were significant differences between the absolute means (either overestimation or underestimation) of EE from these predictive equations and MREE (Figure 1). The Schofield and WHO equations both over-predicted REE in 54% of all subjects. The Mifflin St Jeor equation under-predicted REE in 79% of all subjects when compared to MREE. The smallest and non-statistically significant absolute mean differences were seen between MREE and values derived from the Harris Benedict equation and between MREE and values derived from the Molnar equation. The largest difference was observed between MREE and values derived from the WHO equation. When comparing MREE to all predictive equations by gender, there was a significantly greater absolute mean difference between MREE and predictive equations in boys than in girls. (Figure 2). Significant differences between MREE and values derived from all predictive equations were not observed when comparing by race (white vs. non-white).

The most accurate equation as determined by the percentage of subjects with estimated values (pEE) within $\pm 10\%$ MREE, was the Harris Benedict while the WHO was the least accurate. (Table 4). The mean percent differences in estimated calorie targets varied from 10 to 16 percent (Figure 1). Table 4 displays accuracy as the root mean squared error, or the average absolute differences between each predictive equation and MREE. There is a progression of error with the Harris Benedict, Molnar, and Lazzer equations demonstrating the least error; while the WHO and Mifflin St Jeor equations demonstrated the most error. Table 4 also highlights that there were significant differences between boys and girls in percent accuracy (within ± 10 percent). The Molnar and the Mifflin St Jeor equations demonstrated significantly greater root mean squared error in males as compared to females.

Discussion

Resting Energy Expenditure (REE) is an important component of Total Energy Expenditure (TEE) that is then used for determining energy needs for weight loss in an obese population. In the present study, REE was measured in obese youth in the clinical setting with a portable indirect calorimeter. This measured REE was then compared to that obtained from nine published predictive equations. To our knowledge, these are the first data to explore these relationships while utilizing indirect calorimetry in the clinical setting with an obese pediatric population.

Most predictive equations have been developed to estimate REE which is multiplied by an appropriate activity factor as determined by the clinician to yield total energy expenditure (TEE). Other equations- specifically the IOM and IOM-OY already include an activity factor (PA) within the equation to yield TEE. It is the calculated TEE that is often used to determine the appropriate caloric targets for weight loss.

In this obese pediatric population, the Harris Benedict equation best predicted energy needs compared to results from a portable indirect calorimeter suggesting that it may be preferred for use in the clinical setting when indirect calorimetry is not available. (Figure 1, Figure 3, Table 2). This is similar to what other investigators have found in a population of obese children^{10, 12}; particularly in a population of obese African American females. Our data (Figure 1, Figure 2) is also in agreement with other studies¹⁴ that suggest that the use of predictive REE equations in obese youth may result in either significant overfeeding, or significant underfeeding, suggesting the importance of basing nutritional counseling of obese youth on measured REE, rather than predicted REE whenever possible.

These data also indicate that the Molnar equation predicted REE relatively accurately in our obese pediatric population (Figure 1, Table 4). This is in agreement with Hofsteenge and associates who found that the Molnar equation most accurately predicted energy needs for Dutch obese adolescents with a mean BMI of 33.2 and when compared to several commonly used predictive equations.¹⁵ It is important to note that the Molnar equation was developed in an obese adolescent population.¹⁹ This suggests the need for further investigation regarding the value of developing population specific predictive equations in an effort to improve performance and clinical utility. The majority of predictive equations commonly used in the clinical setting have been developed using healthy weight children.^{16,17} Therefore, our results suggest that there may be less error when one uses predictive equations developed in an obese pediatric population that consider differences in body composition, growth, and metabolic profile as compared to healthy weight children.

Another important finding is that all predictive equations tended to significantly overestimate EE in boys. Predictive equations account for age, gender, height and weight, with the assumption that boys have a different body composition than girls (i.e. more skeletal muscle),^{11,32}; hence, the need for separate equations for boys and girls. In an obese adolescent population, these ‘assumptions’ may not apply in that the ‘ratio’ of metabolic tissue is likely to be different in obese vs. a healthy weight child/adolescent³² – the group from which many of these equations were developed.

In our population, both the Harris Benedict and the Molnar equation most accurately predicted MREE. While the Molnar equation was originally created in an obese pediatric Dutch population¹⁹, our study, in a large sample that included non-white children, supports the need for further research using this equation in an obese pediatric population in the United States. It is also important to note that the mean BMI of the Dutch pediatric population used was 33.2, which more closely resembles our population with a BMI of 37.4 compared to other studies cited (i.e. BMI <99th percentile for age and gender).^{10, 12}

While one cannot directly compare values derived from REE equations with those equations that include an activity factor such as the Institutes of Medicine- Overweight Youth (IOM-OY) and the IOM equations, it is important to consider that one of the most commonly used equations in the pediatric clinical setting to date is the IOM-OY.^{2,23, 33} An important and clinically relevant finding in this study is that using the IOM and IOM-OY equations with a “sedentary” physical activity coefficient of 1 will yield substantially higher caloric targets for weight loss than when using predictive resting energy equations or measured resting energy expenditure (pREE or MREE) and a simple activity factor (PAL) of 1 to calculate TEE. It is important to note that the physical activity factor (PA) of 1 (sedentary) for use with the IOM-OY equations is defined as a physical activity coefficient that represents a range of physical activity levels (PAL) from 1.0 to < 1.4.^{23,33} This suggests a limitation when one attempts to compare the results from MREE to that from predictive equations that account for resting energy expenditure only (pREE) and to that from predictive equations that include an activity factor to yield TEE. This should prompt further research comparing these TEE equations with MREE and various activity factors- especially since at this time there is no consensus as to which of the published equations is best to use in a severely obese pediatric population in the absence of indirect calorimetry.

A limitation to this study is that while the portable indirect calorimeter has been validated in a mixed population^{4,5,6,7,8}, there are no published data specifically for an obese pediatric population. There is no a priori reason to expect that portable indirect calorimetry devices, such as the Korr ReeVue device used here, which yield mREE determinations that are highly correlated with those obtained by metabolic cart in adults or mixed populations^{4,5,6,7,8}, would not measure accurately in a sample of only obese children.

However, this current study should prompt further research in this area. Future research should include formal testing of the reliability and validity of various portable indirect calorimetry devices in obese pediatric patients. Further evaluation of patients whose mREE is either substantially lower or higher than expected should be undertaken to determine what influence mREE has in treatment response in obese children. Another limitation is that this data is representative of a single healthy weight clinic in the southeastern US; however, patients attending the clinic are referred from over 120 different primary care practices across a 29 county region with both rural and urban populations represented.

To our knowledge, these are the first data to utilize a portable indirect calorimeter in the clinical setting with an obese pediatric population and compare this measured resting energy expenditure with the results derived from new and commonly used published predictive equations. Strengths of the study are that it includes a large sample size (n=80); that every test was performed by the same individual (SH) using the same device under identical conditions, thus eliminating potential inter-operator or inter-device variance; and the sample included a large number of severely obese patients who are at highest risk for obesity-related complications.

Others^{14,15} have reported significant discrepancies between MREE and predictive equations in obese youth, as well as discrepancies among various predictive equations used in an obese pediatric population^{10,11}; however ours is the first study to highlight these differences and the potential implications for caloric targets for weight loss in routine and specialty clinical practice. The discrepancies that exist among many predictive equations in determining an accurate EE suggests the value of using portable indirect calorimetry which was developed for use within the clinical setting^{29,30} as a less expensive, less time consuming and more practical option than metabolic cart testing. Others^{26,27} have described the usefulness and benefits of portable indirect calorimetry in obese adults in the clinical setting; while also describing discrepancy between MREE and predictive equations used in adults. Further research investigating the use of portable indirect calorimetry in obese youth may support the value of adding a standardized metabolic assessment in the clinical setting to potentially improve health outcomes in an obese pediatric population.

Conclusions

To our knowledge this is the first study to report the use of a portable indirect calorimeter to measure REE in severely obese youth in the clinical setting and compare these data to data derived from commonly used published predictive equations. Our findings suggest that the Harris-Benedict equation has improved accuracy in a severely obese pediatric population relative to other predictive equations, but still displays notable error. Furthermore there were marked differences between results from various equations as well as differences by gender. This potential for error as well as the potential for deriving inappropriate caloric targets when using these predictive equations remains sufficiently great to suggest that indirect calorimetry, when available, is preferred in the clinical setting. Currently, there remains no consensus in the literature as to the best predictive equation to use with an obese pediatric population, and this study also prompts further research in this area, especially in light of the current obesity epidemic with our youth.

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Figure 1. Absolute differences in calories per day between MREE and predictive equations^a

^a n= 80

* Significant differences in absolute mean difference in calories per day were found between the Mifflin St Jeor, Schofield, WHO, and Lazzer predictive equations and MREE ($p < 0.05$)

Figure 2. Absolute mean differences in calories per day between MREE and predictive equations by gender

^aMale (n=34), Female (n=46), Total (n=80). Data expressed as Mean ± SE bars

*Significant differences were found between MREE and the Harris Benedict, Mifflin, Schofield, Molnar and Lazzar predictive equations ($p < 0.05$)

Table 1

Common predictive equations compared in obese youth

Author and Year (Reference)	Gender	Age (year)	Predictive equation for REE ^a (kcal/day)
Schofield, 1985 (16)	Male	3–10	19.6 (wt) + 1.033 (ht) + 414.9
	Female	3–10	16.8 (wt) + 1.618 (ht) + 371.3
	Male	10–18	16.25 (wt) + 1.373 (ht) + 515.5
	Female	10–18	8.37 (wt) + 4.65 (ht) + 200
World Health Organization, 1985 (17)	Male	3–10	22.7(wt) + 495
	Female	3–10	22.5 (wt) + 499
	Male	10–18	17.5 (wt) + 651
	Female	10–18	12.2 (wt) + 74
IOM for Obese Children, 2005 (18)	Male	All	420–35.5(age) + 418.9 (ht in meters) + 16.7 (wt)
	Female	All	516–26.8 (age) + 347 (ht in meters) + 12.4 (wt)
Molnar, 1995 (19)	Male	All	50.9 (wt) + 25.3 (ht) – 50.3 (age) + 26.9
	Female	All	51.2 (wt) + 24.5 (ht) – 207.5 (age) + 1629.8
Lazzer, 2006 (20)	Male	All	54.96 (wt) + 1816.23 (ht) + 892.68 (Sex*) – 115.93(age) + 1484.5
	Female	All	*(Sex: Males= 1; Females = 0)
Harris Benedict, 1918 (21)	Male	All	66.47 + 13.75 (wt) + 5 (ht) – 6.8 (age)
	Female	All	665 + 9.6 (wt) + 1.8 (ht) – 4.7 (age)
Mifflin, 1990 (22)	Male	All	10 (wt) + 6.3 (ht) – 5 × age – 5
	Female	All	10 (wt) + 6.3 (ht) – 5 × age – 161
			Predictive equation for TEE^b
IOM for Obese Youth, 2005 (23)	Male	All	114 – (50.9 × age) + PA × (19.5 × wt + 1161 × ht in meters)
	Female	All	389 – (41.2 × age) + PA × (15 × wt + 701.6 × ht in meters)
IOM for Children, 2005 (24)	Male	3–8	88.5 – 61.9 (age) + PA × (26.7 × wt + 903 × ht in meters) + 20 kcal
	Female	3–8	135.3 – 30.8 (age) + PA × (10 × wt + 934 × ht in meters) + 20 kcal
	Male	9–18	88.5 – 61.9 (age) + PA × (26.7 × wt + 903 × ht in meters) + 25 kcal
	Female	9–18	135.3 – 30.8 (age) + PA × (10 × wt + 934 × ht in meters) + 25 kcal

^aWt= kg, Ht= cm, age= years

^b A physical activity factor (PA) of 1, or sedentary, was reflective of the population studied and this was used to calculate TEE. It is important to note that the physical activity factor (PA) of 1 (sedentary) for use with the IOM-OY equations is defined as a physical activity coefficient that represents a range of physical activity levels (PAL) from 1.0 to < 1.4. The investigators thought it would be interesting to look at associations between MREE measured in the clinical setting, and these commonly used published equations. In order to compare equations it is necessary to calculate TEE. In this study population, an appropriate activity factor of 1, or sedentary, was utilized with all equations to calculate TEE.

Table 2

Subject characteristics^a

Subject Characteristics	All		Boys		Girls	
	Mean	Range	Mean	Range	Mean	Range
Age (y)	12.2 (± 0.3)	7 – 18	12.2 (± 0.4)	7 – 16	12.2 (± 0.5)	7 – 18
Height (cm)	159.1 (± 1.5)	128.1 – 189.4	161.4 (± 2.4)	128.1 – 189.4	157.3 (± 1.8)	128.2 – 175.9
Weight (kg)	96.2 (± 3.5)	41.3 – 214.0	102.6 (± 6.2)	41.3 – 214.0	91.5 (± 3.9)	44.3 – 150.2
BMI (kg/m ²)	37.4 (± 1.1)	25.1 – 84.3	38.8 (± 2.0)	25.1 – 84.3	36.4 (± 1.1)	25.3 – 51.7
BMI z score	2.474 (± 0.1)	0.900 – 3.500	2.554 (± 0.1)	1.570 – 3.500	2.414 (± 0.1)	0.900 – 3.080

^a All (n=80), Boys (n=34), Girls (n=46)

Table 3

Measured resting energy expenditure and predicted energy expenditure- overall and grouped by gender.^a

Method of Energy Expenditure Determination ^b	All			Boys			Girls		
	Mean ^c	Range		Mean	Range		Mean	Range	
Measured (mREE)	1,977 (± 49.9)	1,080 – 3,140		2,172.0 (± 87.4)	1,325 – 3,140		1,977.1 (± 48.9)	1,080 – 2,600	
Harris Ben. (pREE)	1,950.4 (± 50.2)	1,220 – 3,698		2,201.6 (± 90.3)	1,220 – 3,698		1,950.4 (± 38.5)	1,283 – 2,346	
Mifflin StJeor (pREE)	1,800.6 (± 42.8)	1,048 – 3,051		1,968.5 (± 69.7)	1,168 – 3,051		1,800.6 (± 42.8)	1,048 – 2,352	
Schofield (pREE)	2,057.4 (± 60.5)	1,329 – 4,211		2,415.9 (± 100.5)	1,390 – 4,211		2,057.4 (± 44.9)	1,329 – 2,990	
WHO (pREE)	2,204.7 (± 61.7)	1,431 – 4,396		2,495.3 (± 109.8)	1,431 – 4,396		2,204.7 (± 51.7)	1,495 – 3,073	
Molnar (pREE)	1,935.1 (± 44.9)	1,186 – 3,378		2,081.9 (± 80.7)	1,186 – 3,378		1,826.5 (± 44.7)	1,317 – 2,543	
Lazzer (pREE)	2,060.9 (± 49.1)	1,297 – 3,625		2,276.2 (± 80.3)	1,443 – 3,625		1,901.7 (± 50.1)	1,297 – 2,688	
IOM-OY (pREE)	2096.2 (± 58.1)	1321 – 4126		2400.4 (± 100.8)	1,377 – 4,126		1871.3 (± 46.4)	1,321 – 2,603	
IOM-OY (TEE) ^d	2791.2 (± 83.5)	1662–5324		3,367 (± 124.5)	1999–5324		2,365.0 (± 58.0)	1662–3278	
IOM (TEE)	2,738.9 (± 106.2)	1560–6252		3,521.8 (± 164.8)	1599–6252		2,160.3 (± 106.2)	1560–2943	

^a All (n=80), Boys (n=34), Girls (n=46)

^b Energy expenditure expressed as kcal/day

^c All values expressed as Means ± SE

^d IOM and IOM-Y equations include an activity factor to provide a calculated total energy expenditure (TEE). An activity factor (PA) of 1 was used in each equation, which was representative of the sedentary population studied. TEE equations cannot be directly compared to measured REE or to predictive equations that estimate REE.

Table 4Root mean squared error and mean percent accuracy between MREE and pREE^a

Predictive Equation	Root Mean Squared Error-All Subjects ^b (Kcal/day)	Proportion of All Subjects Within $\pm 10\%$ Accuracy
Harris Benedict	286.0	65.0%
Molnar	275.0	60.0%
Lazzer	288.0	61.3%
Mifflin St Jeor	314.9	47.5%
Schofield	369.3	51.3%
WHO	435.5	40.0%

Predictive Equation	Root Mean Squared Error- By Gender ^c (Kcal/day)		Proportion of Subjects By Gender Within $\pm 10\%$ Accuracy	
	Male	Female	Male	Female
Harris Benedict	369.5	203.9	65%	65%
Molnar ^d	354.8	196.8	53%	65%
Lazzer	368.3	201.7	53%	67%
Mifflin St Jeor ^d	386.0	249.7	35%	57%
Schofield	479.1	259.7	44%	57%
WHO	548.2	328.2	44%	37%

^a Within ± 10 percent accuracy of energy expenditure (EE), using measured resting energy expenditure (MREE) and predictive resting energy expenditure (pREE)

^b All subjects: n= 80

^c Subjects by gender: Male (n= 34); Female (n= 46)

^d Denotes significant differences between genders for root mean squared error ($p < 0.05$)