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Development and validation of an equation to predict total energy expenditure in a sample of Mexican adults

Luis ORTIZ HERNÁNDEZ[1], César Iván AYALA GUZMÁN[2], Rafael Alejandro MARTÍNEZ BOLAÑOS[1], Ricardo LÓPEZ SOLÍS[1], Mariana TEJEDA ESPINOSA[1]

1 Health Care Department, Universidad Autónoma Metropolitana Xochimilco. Mexico City, Mexico.
2 Student, Doctorate in Biological and Health Sciences, Universidad Autónoma Metropolitana. Mexico City, Mexico.

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ABSTRACT

Our aim was to develop and validate an equation to predict total energy expenditure (TEE) based on anthropometric measurements and physical activity questionnaires that can be applied among non-institutionalized Mexican adults. To meet this aim, a validation study was conducted with a sample of Mexican adults (n=115, 37% men) that were randomly divided into two groups to develop and validate new equations to estimate TEE. TEE was measured by indirect calorimetry and heart rate monitoring for at least three days. These measurements were considered as the reference method. The predictors of TEE were age, sex, fat and fat-free mass, body weight and physical activity level (PAL), which was assessed with two questions. The accuracy of factorial methods (e.g. FAO/WHO or Ainsworth's metabolic equivalents list) and empirical equations to estimate TEE was compared. Multiple linear regression and Intra-class correlation coefficients were estimate as agreement measurement. The equation developed is as follows: TEE (kcal / d) = 1331.712 - (686.344 x sex, men: 1, women: 2) + (18,051 x body weight, kg) - (16.020 x age, years) + (894.007 x PAL). The accuracy of the equation was modest in the development (R^2 = 54.4, standard error = 511.3) and validation (R^2 = 59.2, standard error = 372.8) samples. However, this equation had higher accuracy than factorial methods or empirical equations. The equation was developed to estimate the TEE of Mexican adults, which can be used as a general guide to provide nutritional counselling.

Correspondencia:
Luis Ortiz Hernández
lortiz@correo.xoc.uam.mx

KEYWORDS

Total energy expenditure; adults; physical activity; resting energy expenditure; indirect calorimetry; heart rate.

INTRODUCTION

In clinical practice, algorithms have been established for the treatment of overweight and obesity[1], where an initial energy deficit of 500 to 750 kcal/d is recommended to promote healthy weight loss[2]. This process requires the estimation of TEE. The main components of the TEE are basal energy expenditure or resting energy expenditure (REE), diet-induced thermogenesis and physical activity-induced energy expenditure (PAEE)[3]. The latter can be subdivided into exercise-related activity thermogenesis (EAT) and non-exercise activity thermogenesis[4]. The contribution of REE to TEE is higher in sedentary adults (60% to 75% of TEE)[5] than in physically active people (50% of the TEE)[5]. Conversely, EAT varies between 25% and 75% of the TEE, being higher in athletes or in people who perform vigorous activities[6].

The main methods used to evaluate TEE are direct and indirect calorimetry and doubly labelled water. However, the high costs of the equipment and complexity of these techniques represent limitations for their use in clinical and population studies. Therefore, prediction equations or factorial methods to assess the TEE are commonly used due to their low cost and the relative simplicity of procedures required for professionals and participants (i.e., administration of questionnaires and calculations)[7]. So far, most prediction equations have been developed to estimate REE[8-12]; whereas few studies have sought to estimate TEE based on anthropometric and physical activity data. The clinical utility of REE prediction equations is limited because they do not include PAEE, therefore they cannot be applied to estimate the TEE of most people.

Factorial methods have been developed to estimate TEE, such as the Food and Agriculture Organization/World Health Organization (FAO/WHO)[10], Institute of Medicine (IOM)[11], and Ainsworth's list of metabolic equivalents (Ainsworth's MET)[13]. Other way to estimate TEE is using the Mifflin's equation[9] (with an adjustment for PAEE[2]) or empirical equations based on body weight[14]. The validity of estimates obtained with some of these methods is unknown, although in their estimates are routinely used. Therefore, the main objective of this study was to develop and validate an equation to predict TEE based on anthropometric measurements and a physical activity questionnaire that can be applied among noninstitutionalized Mexican adults. A secondary objective was to compare the accuracy of the different methods to estimate TEE that can be used in clinical settings.

MATERIAL AND METHODS

A validation study with a sample of 115 Mexican adults (women: 62.6%) aged 18 to 45 years was conducted. Advertisements in the university and near neighbourhoods were posted inviting to participate in the study. Participants did not receive any incentive to participate. During recruitment, participants with different ages, occupations, levels of physical activity and fitness were sought. The exclusion criteria were to have weight changes in the previous month, have any disease or physical impediments for performing the exercise test (e.g., respiratory diseases, muscle disorders or physical injuries), be pregnant or breastfeeding in the case of women. The data collection was carried out from September 2013 to January 2017.

The work was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for research involving humans. The ethical approval of the project was granted by the Ethics on Research Committee of the Divisional Council of Biological and Health Sciences of the Metropolitan Autonomous University campus Xochimilco (agreement number 12/11,8.1). Signed informed consent was obtained from the people who declared be apt to do physical activity based on a preparticipation health screening questionnaire.

The sample was randomly divided into two groups. Data from two-thirds of the sample was used to develop prediction equations (n = 71), whereas one third was used to validate the developed and previously published equations (n=44). Previous to collecting data, we estimated that a sample size of at least 39 participants was required to estimate a multiple linear regression model with a determination coefficient (R^2) of 50% and an accuracy of 0.10 and to compare models with 5% of difference in R^2 [15].

Each participant visited the laboratory twice in the same week. At the first visit, anthropometric, body composition and REE assessments were performed. At this visit, a physical activity questionnaire was applied[16]. At the second visit, a laboratory exercise test was performed, from which measures of oxygen consumption (VO_2), CO_2 production (VCO_2) and HR during the physical exercise test were determined. In this session, it was explained to the people how they should use the HR monitor in the following week. After a week, the participants returned the HR monitors.

To measure TEE, the energy expenditure while the participants slept was added to their energy expenditure while they were awake. REE was measured by indirect calorimetry and was considered as the energy expenditure while the participants slept. To estimate the energy expenditure during awake time, VO_2 (ml/min) and VCO_2 (ml/min) were estimated by extrapolation based on the HR recorded under free-living conditions.

REE was evaluated by indirect calorimetry with a gas analyser (Korr Medical Technologies Inc., model CardioCoach CO_2, UT, USA). Before each test, the gas analyser was calibrated with the ambient air of the room. A HR monitor (Polar Electro, Inc., model H1, NY, USA) and a face mask from the CardioCoach® equipment were used. The recommendations[17] for an indirect calorimetry test (i.e., measurement time, fasting, consumption of caffeine, nicotine and/or alcohol, and physical activity) were followed. A coefficient of variation <10% in 5 minutes was the criterion to define that a steady state had been reached. With the averages of VO_2 and VCO_2 in the supine position, REE was calculated using the Weir equation[18].

To determine the energy expenditure during awake time, VO_2 and VCO_2 were predicted from the HR per minute in free-living conditions[19]. To make this prediction, two regression equations were estimated for each of the participants, in which the dependent variables were VO_2 or VCO_2 and the independent variable was HR. The values for these linear regressions were those obtained during the exercise test. VO_2 and VCO_2 were also measured while the participants remained seated and standing for 6 minutes (both considered light activities); of these measurements, data from last 3 minutes were considered. The HR flex (HRFLEX) was calculated as the average of the highest value of HR during the light activities and the lowest value during the exercise test for each participant.

To perform the exercise test, our laboratory followed most of the guidelines of the American Heart Association[20,21]. The test was performed on an electric treadmill (Trackmaster® Inc., model TMX428CP, KS, USA) with a HR monitor (Polar Electro, Inc., model H1,) and a gas analyser (Korr Medical Technologies Inc., model CardioCoach CO_2). The equipment recorded gas exchange every 15 seconds. Bruce's protocol was used[20]. The participants were verbally motivated to perform their maximum effort during the test, with the aim of reaching their estimated maximum HR[22].

Under free-living conditions, HR was recorded minute-by-minute with a monitor (Polar Electro, Inc., model RS400, NY, USA). Participants were asked to use the HR monitor for at least a week and to carry out their activities normally. Records with a length of ≥ 12 hours and those without abnormal values (<40 bpm) were considered as valid. Only the cases in which the HR information was recorded for least 3 days (i.e., 2 days during the working week and 1 day at the weekend) were considered.

From the HR records of the three days, VO_2 and VCO_2 were estimated using the previously described equations. HRs greater than or equal to HRFLEX were converted to VO_2 and VCO_2 using the linear regression equations. The periods in which the HR was below the HRFLEX were considered ight-intensity activities. For these activities, the averages of VO_2 and VCO_2 while sitting and standing were used. The energy expenditure was estimated from VO_2 and VCO_2 with the Weir equation[18]. The weighted average of TEE of weekdays and weekend days was estimated and used in the analyses.

To develop a simple equation to estimate TEE, anthropometric and body composition variables were measured, and a physical activity questionnaire was applied. Weight and height were evaluated following standardized techniques[23]. Prior to fieldwork, four observers were trained following a standardized procedure[24]. Body water, fat-free mass (FFM), skeletal muscle mass (SMM) and fat mass (FM) were assessed using a bioelectrical impedance analyser (InBody, Inc., model 720, CA, USA).

The physical activity level (PAL) reported by the participants was evaluated with a questionnaire developed in a Swedish sample and validated against doubly labelled water[16]. We translated and adapted the two items of this questionnaire about physical activity that is done at work and in leisure time, in which people identified the intensity with which they usually perform these activities. To analyse the answers to these two questions, the scheme presented in Table 2 of the Johansson & Westerterp's paper[16] was used, which allowed us to identify the PAL of each person.

The procedure for the calculation of the TEE using the FAO/WHO[10] and IOM[11] factorial methods is reviewed elsewhere[25]. In the method proposed by Ainsworth (Ainsworth's MET)[13], the product of the metabolic equivalent (MET) value of physical activity, body weight and activity duration can be used to determine the TEE (when data from 24 hours are considered). In the case of the equations of the FAO/WHO, also the estimation of the TEE was obtained using its PAL values (from now on "FAO/WHO-PAL"). In the Appendix 1, the PAL values used for this calculation are presented. The selection was based on the two-item questionnaire about physical activity done at work and leisure time[16].

With the empirical equations, the TEE was estimated using the body weight[14]. This method requires to multiply the body weight by 25-35 according to physical activity habits. Based on the answers to the two-item questionnaire about physical activity[16], the kilocalories per body weight was selected (Appendix 2). To estimate the TEE with the Mifflin's equations, the PAL values proposed by the Academy of Nutrition and Dietetics[2] were used (see Appendix 3).

The statistical analysis was run with the statistical package STATA version 15 (College Station, TX). Descriptive statistics of the development and validation sample were calculated, as well as unpair T-test and chi-squared test to analyse differences between both samples. To develop new equations, seven multiple linear regression models were estimated in which the measured TEE was considered as the dependent variable. In all regression models, sex was included as a predictor of TEE. All possible interactions among predictors were tested.

To evaluate the accuracy of the equations, using the data of the validation sample, we estimated simple linear regression models in which the dependent variable was the measured TEE, and the independent variables were the TEE estimates from the factorial methods (FAO/WHO, IOM, and Ainsworth's MET), methods based on PAL values (FAO/WHO and Mifflin equation), empirical equations, and the equations developed in this study. Pearson and intraclass correlation coefficients of the measured TEE with the TEE estimates were calculated. Akaike's information criterion (AIC) of each model was computed to identify differences between the models. Bland-Altman graphs were plotted to examine the distribution of bias and agreement. Normality of the difference between evaluated and estimated TEE was verified by the Shapiro-Wilk test.

RESULTS

In both samples, the proportion of women compared to men was greater. One third of participants had overweight or obesity, whereas four out ten had excessive body fat percentage (Table 1). In the two samples, less than a quarter of the adults performed moderate-to-vigorous physical activity at work, and just over 50.0% reported performing moderate-to-vigorous intensity activities in their leisure time. There were no differences between the development and the validation samples in any characteristic ($p<0.050$).

Equations 2 (with weight, age, and PAL) and 3 (with the interaction of weight x PAL) had the highest coefficient of determination and lowest standard estimation error (Table 2). In equation 2, the intercept did not differ from the origin, while the intercept of equation 3 did. There were no differences between equations 1 (with body weight) and 4 (with FFM). The intercepts of both equations did not differ from the origin. Considering the AIC and the R^2, the predictive capacity of

Table 1. Anthropometric, body composition, and physical activity characteristics of a sample of Mexican adults

	Development sample (n=71)				Validation sample (n=44)				*p*
	X̄	SD	Min	Max	X̄	SD	Mín.	Máx.	
Age (years)	28.2	7.2	18.0	45.0	28.5	8.1	19.0	45.0	0.814
Weight (kg)	64.9	13.3	41.8	100.8	66.1	17.6	37.4	146.4	0.673
Height (cm)	162.4	9.9	141.0	183.0	164.5	10.4	149.0	186.0	0.298
BMI (kg/m²)	24.4	3.5	18.6	33.8	24.2	4.6	16.6	44.7	0.828
FM (kg)	18.5	7.0	8.2	39.5	19.3	9.8	7.4	66.6	0.611
FM (%)	28.7	8.4	12.3	46.3	28.9	8.3	10.4	45.5	0.881
FFM (kg)	46.4	11.1	27.0	78.2	46.8	11.6	29.4	79.8	0.847
SMM (kg)	25.8	6.7	14.0	45.3	25.8	7.2	15.3	45.8	0.959
SMM (kg/m²)	9.6	1.5	7.0	13.5	9.4	1.6	6.7	14.0	0.382
PAL	1.7	0.2	1.4	2.2	1.7	0.2	1.4	2.3	0.772
Measured TEE (kcal/d)	2451.8	735.2	1012.6	4598.8	2249.7	586.4	1285.0	3824.1	0.125
	n	%			n	%			*p*
Sex									
Males	26	36.6			17	38.6			0.828
Females	45	63.4			27	61.3			
BMI									
Low weight and normal	40	56.3			29	65.9			0.309
Overweight and obesity	31	43.6			15	34.1			
PA at work									
Very light	25	35.2			14	31.8			0.168
Light	31	46.3			19	43.2			
Moderate	15	21.1			8	18.2			
Heavy	0	0.0			3	6.8			
PA in leisure time									
Very light	11	15.5			9	20.4			0.706
Light	15	21.1			9	20.4			
Moderate	19	26.7			15	34.1			
Active	16	22.5			6	13.6			
Very active	10	14.1			5	11.3			

Abbreviations: X̄, mean; SD, standard deviation; Min, minimum; Max, maximum; n, frequency; %, percentage; BMI, body mass index; FM, fast mass; FFM, fat-free mass; SMM, skeletal muscle mass; PAL, physical activity level; TEE, total energy expenditure; PA, physical activity.

Table 2. Linear regression models considering the total energy expenditure as dependent variable and the anthropometric, body composition and physical activity characteristics as independent variables in the development sample (n = 71)

	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5	Equation 6	Equation 7
Intercept (α)	1115.372	1331.712	6111.309*	712.729	3460.274**	1127.877	-1235.791
Sex	-697.292***	-686.344***	-648.676***	-449.679 *p=0.061*	-1048.457***	-534.632*	-629.162**
Weight (kg)	15.336*	18.051**	-62.636				
Age (years)		-16.020 *p=0.075*					
Weight X PAL			45.943*				
FFM (kg)				26.442**			
FFM (%)					-9.156		
SMM (kg)						37.067*	
PAL	870.283*	894.007**	-2118.706	732.960*	798.770*	728.136*	812.856*
Height (cm)							20.515*
R^2	52.1	54.4	55.0	52.1	47.9	51.1	50.4
SEE (kcal/d)	519.9	511.3	508.1	520.3	542.3	525.5	529.1
AIC	1093.4	1092.0	1091.1	1093.5	1099.4	1094.9	1095.9

Abbreviations: sex (males: 1, females: 2); FFM: fat-free mass; SMM, skeletal muscle mass; PAL, physical activity level; SEE, standard errors of estimate; AIC, Akaike's information criterion; * $p<0.050$; ** $p<0.010$; *** $p<0.001$.

equation 6 (with SMM) was very similar to those of equations 1 (with body weight) and 4 (with FFM). In equation 7, height was included as an independent variable, but its predictive capacity (considering R^2 and AIC) was lower than those of equations 1, 2, 3 and 4. Based on the values of AIC, the optimal models were those of equations 1 (weight), 2 (weight and age), 3 (weight x PAL) and 4 (FFM).

The correlation of the TEE measured with the estimated TEE based on Ainsworth's MET was low, whereas the correlation was moderate with the rest of the existing methods and with equations 3 (weight x PAL) and 4 (FFM) (Table 3). Only estimations based on equations 1 (weight) and 2 (weight x PAL) had a high correlation with measured TEE. The agreement (based on the intraclass correlation coefficient) of the measured TEE with the TEE estimated by Ainsworth's MET, and FAO/WHO - PAL was low, but moderate associations were observed with the rest of the methods and the developed equations. Equations 1 (weight) and 2 (weight and age) had the highest agreement.

Of the factorial methods, the least accurate (considering R^2 and SEE) was that of Ainsworth's MET, and the most accurate was the IOM method. The FAO/WHO-PAL method had low TEE predictive capacity ($R^2 \leq 40.0\%$). Of the existing methods, the intercept (α) differed from the origin for the Ainsworth's MET, Mifflin equations and empirical equations. In all cases, the intercept (α) was positive. Of the developed equations, the accuracy was greater, and the estimation error was lower with equation 2 (weight and age), followed by equation 1 (weight) ($R^2$50.0%). The intercept did not differ from the origin for any of the equations developed in this study.

Based on the values of AIC and R^2, the optimal model was that of equation 2 (weight and age), followed by equation 1 (weight). The difference in AIC of equation 2 (weight and age) compared to those of all existing methods was greater than 10 (14.4 to 30.2), while it was 7.6 for equation 1 (weight) and greater than 10 for equations 3 (weight x PAL) and 4 (FFM).

Differences between measured and estimated TEE from all methods showed a symmetric distribution ($p>0.050$ for the Shapiro Wilks test) (figure 1). The IOM had the lowest average systematic error (-147.63 kcal/d, Figure 1A). Empirical equations tend to underestimate TEE (Figure 1.B). The IOM and equation 2 tend to overestimate TEE at low TEE, but with TEE of 2500 or higher they get closer to the equality line (Figures 1.A and 1.C).

Table 3. Intraclass correlation coefficients and linear regression models between the measured total energy expenditure (TEE) and the predicted TEE in the validation sample (n = 43)

			Coefficients		Regression models[(a)]				AIC
	$\bar{X}$	S	r_p	r_{ic}	R^2 (%)	SEE	α	β	
Measured TEE	2229.1	577.0							
TEE predicted with existing methods									
FAO/WHO	2110.1	471.5	0.61***	0.59***	37.5	461.6	647.4	0.75***	651.6
IOM	2376.7	480.4	0.66***	0.62***	43.1	440.6	355.3	0.79***	647.6
Ainsworth	2199.9	608.6	0.48***	0.49***	22.9	512.6	1230.2***	0.45**	660.6
FAO/WHO-PAL[(b)]	2832.4	645.2	0.63*	0.32***	39.8	453.2	631.9	0.56***	650.0
Mifflin x PAL[(c)]	2534.1	617.2	0.64***	0.54***	40.5	450.5	721.4*	0.59***	649.5
Empirical equations	1983.8	543.9	0.64*	0.57***	41.1	448.1	879.5**	0.68***	649.0
Developed equations									
Equation 1 (weight)	2490.8	565.9	0.72***	0.64***	51.3	407.4	409.6	0.73***	640.8
Equation 2 (weight and age)	2491.9	591.3	0.77***	0.69***	59.2	372.8	357.5	0.75***	633.2
Equation 3 (weight x PAL)	2480.3	526.4	0.68***	0.60***	46.5	427.1	375.1	0.75***	644.9
Equation 4 (FFM)	2479.1	527.4	0.68***	0.60***	46.4	427.6	381.8	0.74***	645.0

Measured TEE considered as a dependent variable and the estimated TEE by prediction equations as independent variables. [(a)] Physical activity level values of FAO/WHO; [(b)] Physical activity levels of Johansson & Westerterp; [(c)] Physical activity level values proposed by the Academy of Nutrition and Dietetics. Abbreviations: $\bar{X}$, mean; S, standard deviation; r_p; Pearson's correlation coefficient; r_{ic}; intraclass correlation coefficient; IC, Akaike's information criterion; PAL, physical activity level; FFM, fat-free mass. * p<0.050; ** p<0.010; *** p<0.001.

DISCUSSION

In this study, we developed a TEE prediction equation that requires the following information: sex, body weight, age and assessment of PAL based on two questions. In addition, we observed that factorial methods, Mifflin's equations, and empirical equiations had low accuracy in estimating TEE.

In the Mexican adults of our sample, it was observed that the three factorial methods underestimated TEE because the intercept was positive, although in two cases there were no differences with the origin (FAO/WHO and IOM); with the Ainsworth's MET, there was clearly systematic underestimation of the TEE. In adults, the FAO/WHO factorial method tends to both underestimate[26] and overestimate[27] TEE. The differences between measured TEE and estimated TEE may be due to the evaluation methods used, difficulties of participants in reporting the time allocated to each activity or its intensity, and misclassification of the level of physical activity.

Methods based on PAL values (FAO/WHO and Mifflin) and empirical equations are simple and frequently used in the clinical practice; however, there is scarce data about their accuracy. Our results show that they had modest agreement and accuracy. In addition, practitioners should be aware that these tools tend to systematically over- or underestimate TEE.

The main limitation of this study is that the best methods to evaluate TEE (i.e., doubly labelled water or direct calorimetry) were not used. Rather, we used the HRFLEX method. Minute-to-minute heart rate monitoring (using the HRFLEX method) is a feasible technique to assess TEE in field studies that allows activity patterns and the intensity of the physical exertion that is carried out to be captured[28]. When comparing the TEE estimated by the HRFLEX with that measured using double-labelled water, an average difference of 2.0% was observed, with correlations between both methods >0.95[19]. When compared with the TEE measured by calorimetry, HRFLEX exhibited a high to excellent correlation (r from 0.87 to 0.94[29]) and slightly underestimated TEE (1.2%)[29]. Another limitation is that we used a small sample size, which could produce imprecise estimations.

Figure 1. Bland Altman plots to evaluate agreement between measured and estimated total energy expenditure

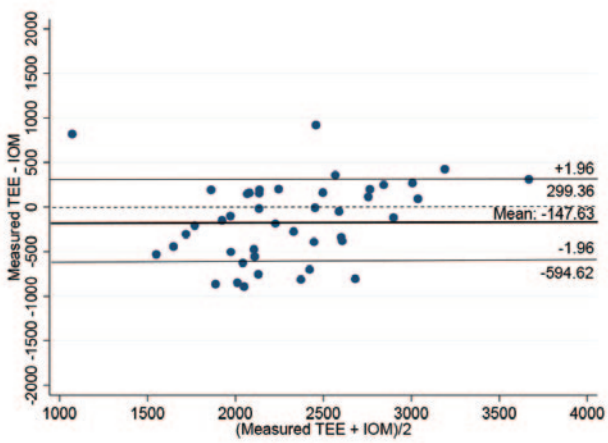

Figure 1A. Institute of Medicine

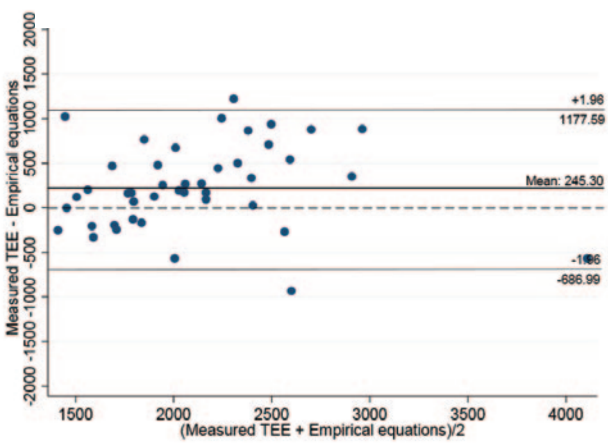

Figure 1B. Empirical equations

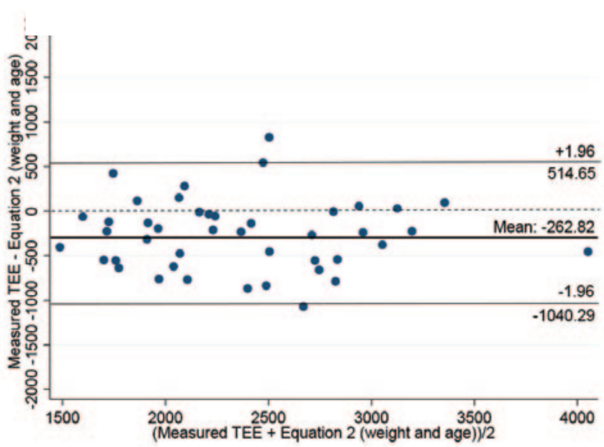

Figure 1C. Equation 2 (weight and age)

Limits of agreement ±1.96 standard deviations (solid lines) of the mean of the differences (solid bold line) between measured and estimated total energy expenditure. Dotted line on the 0 represents zero or null differences between methods.

CONCLUSIONS

Considering that the previous methods used to estimate TEE do not provide the best results and are time consuming, the objective of the present study was to propose a TEE prediction equation based on anthropometric measurements and two simple questions related to physical activity. In comparison with the factorial methods and empirical equations, the developed equation is simpler and more practical to estimate the TEE of Mexican adults. Although the developed equation is not perfect, it had the highest predictive capacity. We suggest that our equation can be used for clinical practice with caution since we did not obtain exact results applied to specific individuals; rather, it is a general orientation that professionals can use to provide nutrition counselling.

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