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Accuracy of SenseWear Pro2 Armband to predict resting energy expenditure in childhood obesity

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Abstract

Objective: We evaluate the accuracy of the SenseWear Pro2 Armband (SWA) in estimating resting energy expenditure (REE) in children and adolescents with obesity, using indirect calorimetry (IC) as a reference.

Design and Methods: REE was assessed using both the SWA and IC in 40 obese subjects (26 M/14 F, age 11.5±2.57 years, z-score BMI 3.14±0.53). The agreement between methods was assessed by the Bland-Altman procedure. The relationship between REE assessments and patients' characteristics was also analyzed.

Results: SWA- and IC-derived estimates of REE showed a significant correlation (r=0.614; P<0.001), but the SWA overestimated mean REE by 13% (P<0.001). Age and kg of fat-free mass (kgFFM) were significantly correlated with both REE estimation by SWA (r=0.434 and r=0.564; respectively) and IC (r=0.401 and r=0.518; respectively). Only kgFFM was demonstrated to be the main predictor factor of REE variability (r^2 79% SWA; 75% IC).

Conclusions: The SWA overestimated mean REE in childhood obesity, suggesting that the SWA and IC are not yet interchangeable methods. This would require improving the SWA by developing better algorithms for predicting REE and, probably, bias in each individual REE could be reduced by an adjustment for subjects' kgFFM.

Introduction

Prevalence of childhood obesity has increased worldwide over the last few decades; although it appears to be stabilizing in different countries, it remains high, representing a significant public health issue [1,2]. Three metabolic factors have been reported to be predictive of weight gain: low adjusted sedentary energy expenditure (EE), high respiratory quotient, and a low level of spontaneous physical activity [3].

A change of lifestyle targeted towards increasing daily EE is one of the cornerstones of obesity treatment. Therefore, the accurate estimation of daily EE and resting EE (REE – the major component of daily EE) could be important for weight management and for the prevention of lifestyle-related health problems in overweight/obese patients [4].

However, their measurement remains difficult [5]. Some studies reported that obese children and adolescents exhibit an increased daily EE due to a higher REE compared to non-obese subjects [6] and similar or higher physical activity EE because of the more elevated energy cost of weight-bearing activities [7]. The increased REE in obese subjects is mostly related to their higher fat-free mass (FFM) and fat mass (FM) [6], the main significant determinants of REE [8].

Indirect calorimetry (IC) is the method of choice for estimation of REE in overweight and obese adolescents [9] but, due to its complex nature and the high cost of the equipment involved, it cannot be systematically assessed [10].

Innovative technologies such as the SenseWear Armband, providing lifestyle self-monitoring and consequent weight loss tools in sedentary, overweight or obese adults, may contribute to improving the current obesity epidemic [11].

The SenseWear Pro2 Armband (SWA) is a developed, portable device that, worn on the right upper arm over the triceps muscle, monitors various parameters (heat flux, skin temperature, galvanic skin response, near-body temperature, and accelerometer) that are used to estimate EE through specific equations, also taking into account the auxological characteristics (gender, age, height and weight) [12-14]. Although it was developed to measure EE during exercise [7,12,13], the SWA has also been reported to have great potential for the assessment of REE [12,15]. Most of the published studies that report the determination of REE by SWA in relatively young [5], normal-weight [16], and overweight adults [14] often show contrasting results; so, it is unclear whether similar results could be observed in obese children and adolescents.

The aim of the present study was to assess the accuracy of the SWA in measuring REE compared to IC in severely obese children and adolescents.

Methods and Procedures

Study population

The study included a total of 40 Caucasian obese children and adolescents (26 boys and 14 girls, aged 11.5±2.57 years, BMI 30.7±4.23 kg/m^2, z-score BMI 3.14±0.53) referred to our Pediatric Department for further assessment and management by their primary health care physicians.

Eligibility criteria were: 1) the presence of primary obesity and 2) the absence of acute and chronic diseases, any drug treatment and total parenteral nutrition. Subjects were asked to follow their usual diet during the week preceding the study.

All measurements were performed in each included patient between 07.00 and 10.00 am, after a 12-hour overnight fast.

Informed consent was obtained from all the subjects and/or their parents before data collection.

Anthropometric measurements

All patients underwent a complete clinical history and physical examination including anthropometric measurements that were performed by fully-trained examiners according to the Anthropometric Standardization Reference Manual [17]. Height was measured to the nearest 0.1-cm with a calibrated wall-mounted stadiometer (Harpenden, Crymych; UK) and weight was measured to the nearest 0.1-kg with a calibrated scale. Body mass index (BMI) was calculated by dividing weight in kg by height squared (m^2); z-score of BMI (z-BMI) was calculated using the appropriate Italian growth reference (ISPED Growth Calculator).

Circumferences (C - arm, waist, and hip) were measured using an inelastic cloth measuring tape.

Skinfold (SF - biceps, triceps, subscapular, and supra-iliac region) were measured using Harpenden SF calipers on the right side of the body [17]. Each C and SF was measured by the same technician (PB) and all SF measurements were taken three times and reported as the average of the three values. We also estimated FM (%FM and kgFM) and FFM (%FFM and kgFFM) using the SF formula [18].

Pubertal development was determined using the grading system defined by Tanner for pubic hair and breast [19].

Systolic (S) and diastolic (D) blood pressure (BP) were measured following standard procedures [20].

Resting energy expenditure

REE was measured using the Sensor Medics Vmax with an open-circuit ventilated-hood system [Sensor Medics 29 N, Metabolic Cart, Yorbe Linda, Ca, USA] after a 12-h fast and at least 24-h free of structured physical activity [21]. The use of metabolic charts is the standard procedure by which REE is measured in a research setting, but the equipment required to measure respiratory exchange makes this procedure time consuming, costly and often impossible. To avoid this procedure and the problems related to the great variability between measurements, several predictive equations were developed [9]. However, these equations, applied to a wide range of ages, and body types, often overestimate the measured REE by at least 5%.

In our study REE was also simultaneously estimated with the SWA (Sense Wear Pro2 Armband, Bodymedia Inc, Pittsburgh, PA, USA), in order to avoid errors derived from the predictive equations. Data were recorded in the morning for at least 30 minutes by trained persons.

Before commencement of measurements, subjects rested for 30 minutes, during which time the traditional IC was calibrated. Subjects were asked to remain awake and motionless for the duration of the simultaneous measurements performed in a thermoneutral environment (24-26°C) and in the absence of external stimuli.

The SWA was positioned on the right arm over the triceps muscle, at the midpoint between the acromion and olecranon processes. The armband was placed on the subjects' arm for a period of 30 minutes before data collection to allow for acclimation of skin temperature.

Because there is no reliable approach to assess inter-day variability of the REE assessment, we considered a measurement valid when 15 minutes of steady state, defined as a coefficient of variation <5% in respiratory quotient/minute and oxygen consumption/minute, were obtained.

Oxygen consumption (V_{O2}) and carbon dioxide production (V_{CO2}) were used to calculate REE in accordance with the Weir formula [22].

Subjects' gender, age, height and weight were programmed into the SWA before each trial.

REE was estimated by applying a generalized proprietary algorithm (*InnerView Research Software, version 6.0* BodyMedia, Inc., Pittsburgh, PA) developed by the manufacturer.

Statistical analysis

The REE by IC was established as the criterion measure. All results are reported as the mean± SD. Data were checked for normal distribution using the Kolmogorov-Smirnov test, so non-parametric statistical analysis (STATISTICA™ software, StatSoft Inc., Tulsa, OK, USA) was performed. Between-gender comparisons were evaluated using Mann-Whitney's *U*-test.

Differences between REE values by IC and SWA were analyzed using Wilcoxon's paired test. The Bland-Altman bias plot [23] was generated for the comparison of the methods at an individual level, to assess the agreement between IC and the SWA in predicting REE by calculating bias and limits of agreement. Spearman's correlation analysis was performed to assess the relationship between various variables, including method difference. The association between potential predictors and REE (SWA and IC) difference values was evaluated using the 2 following multivariate logistic regression models:

- model 1 age, gender, BMI kg/m^2, kgFM, and kgFFM
- model 2 age, gender, BMI kg/m^2, arm-C, waist-C, waist-hip ratio (WHR), kgFM, and kgFFM.

Statistical significance was set at $P<0.05$.

Results

Anthropometric data

The physical characteristics of the study population are shown in table 1. Children were 7.39-17.9 years old. All subjects were obese since BMI ranged from 22.9 to 41.0 kg/m^2 and z-BMI ranged from 1.88 to 4.44.

Taking account of gender, chronological age was not significantly different. Biceps and subscapular SF were significantly higher in females than males. No other significant difference was found.

Resting Energy Expenditure

The SWA device significantly overestimated the mean REE compared to IC (1748.1±246.7 vs. 1550.8±246.6 kcal/day, respectively; $P<0.001$); the mean over-prediction for the recordings was 12.7%. Females showed significantly lower REE levels compared to males by IC (1414.0±184.5 vs. 1630.6±246.1 kcal/day, respectively; $P=0.008$), while this difference was not present in REE values measured by SWA (1677.3±228.4 vs. 1789.4±252.2, respectively; $P=0.231$). Adjusting for gender, the difference (Δ) between REE by IC and by SWA was not significantly different (-263.3±197.2 in females vs. -158.8±168.4 kcal/day in males; $P=0.130$).

The Bland-Altman plot for REE is shown in fig. 1: 97.5% of the values ($n=39$ of 40) were within 2 SD (±184.1 kcal/day) of the difference between methods (95% limits of agreement from -565.5 to 184.1 kcal/day). It must be noted that the methods can have a large difference in mean or variance and still have a perfect correlation. We have found a significant level of agreement between the SWA and IC measurements of REE (r=0.614; $P<0.001$).

The results for the correlation between residual values for REE and the values obtained from IC and SWA measurements are shown in Figure 2. The plot identifies a statistically significant overestimation of lower REE by SWA values (r=-0.416; $P=0.009$).

REE values measured by both IC and SWA were significantly correlated with kgFFM (r=0.518, $P<0.001$ and r=0.564, $P<0.001$, respectively). Moreover, we found a significant correlation between kgFM and REE by SWA (r=0.552, $P<0.001$), but not with REE by IC (r=0.240, $P=0.145$).

REE measurements obtained by SWA were also significantly correlated with age (r=0.434; $P=0.0063$), BMI (r=0.648; $P<0.001$), arm-C (r=0.524; $P<0.001$), waist-C (r=0.760; $P<0.001$), and hip-C (r=0.779; $P<0.001$). REE measured by IC was significantly correlated with age (r=0.401;

P=0.0125), arm-C (r=0.388; *P*=0.0160), waist-C (r=0.555; *P*<0.001), hip-C (r=0.432; *P*=0.0067), and WHR (r=0.334; *P*=0.0400). No correlation was demonstrated with laboratory data.

Logistic regression analysis (table 2) using model 1 showed that the main predictors of REE by IC were kgFFM (β=1.010, *P*<0.001), kgFM (β=0.546, *P*=0.001), sex (β=0.278, *P*=0.011), and age (β=-0.350, *P*=0.032). For REE by SWA the significant predictors were kgFFM (β=0.744, *P*<0.001) and kgFM (β=0.473, *P*=0.002). Model 2 demonstrated kgFFM (β=0.843, *P*<0.001), sex (β=0.300, *P*=0.015), and age (β=-0.478, *P*=0.013) as significant predictors of REE by IC, while kgFFM (β=0.614, *P*=0.002) and sex (β=0.226, *P*=0.041) were revealed to be the main predictors of REE by SWA. Finally, only kgFFM was demonstrated to be the main predicting factor for REE variability (r^2 79% SWA; 75% IC).

Neither model did found any significant predictors for the Δ between REE by IC and SWA.

Discussion

To our best knowledge, this is the first study to evaluate the accuracy of the SWA device in estimating REE in obese children and adolescents, compared with simultaneous IC.

Our findings suggest reasonable agreement between methods on the basis of the Bland-Altman plot. However, the SWA significantly overestimated the mean REE in resting obese children and adolescents by 13%, compared with IC. Although, in absolute values, the mean difference between SWA and IC was small (184.1 kcal/day), the agreement may not be sufficient for measurement of REE in all subjects. The individual variations were great, in some subjects ranging from - 42% to +12%. The residual values showed that the SWA, compared with IC, gave an overestimation of the REE for the subjects with low REE values and an underestimation of REE for the subjects with high REE values. These results show that SWA could not provide accurate estimates of REE in childhood obesity, despite the significant correlation with REE by IC.

Previous studies have been conducted in adults to examine the validity of the SWA in assessing EE during rest and exercise compared with IC. The SWA was demonstrated to provide valid and reliable estimates of EE at rest while, during exercise, it provided an accurate estimation of EE compared to IC only if using exercise-specific algorithms [12,13]. More recently, the SWA was demonstrated to provide a reliable estimate of REE in healthy, older subjects. However, the authors showed that it overestimated REE, suggesting that better algorithms for predicting REE in older people were needed [24]. Other authors also observed that the SWA overestimates EE in middle-aged, normal subjects [25]. By contrast, some authors considered SWA an acceptable device to accurately measure REE, attributing a non-significant underestimation of REE by SWA in adults and younger subjects [5,16], while others showed a significant underestimation (9%) in obese adults, suggesting that the two methods were not interchangeable [14].

SWA underestimated energy cost of most activities in healthy children and this underestimation rose with increased physical activity intensity [26]. Dorminy *et al.* [27] studied 21 healthy African American children and demonstrated that SWA significantly overestimates REE by 16% to 43% compared with IC. Recently, it was demonstrated that the average error with the newly developed algorithms was only 1.7%, suggesting improved accuracy in assessing EE for typical activities in children [28].

We showed that BMI was correlated positively and significantly with REE by SWA but not with IC, suggesting that it may play a role in the accuracy of the measurements. Moreover, with our study we demonstrated a significant positive correlation between FFM (kg) and both REE by IC and REE by SWA, while FM was significantly correlated only with REE by SWA. In our analysis kgFFM was shown to be the main variable predicting the most variability in REE, as suggested by resting metabolic rate of normal weight and obese patients [29].

FFM is one of the most highly metabolically active tissues [30] and is the major contributing factor of REE in adults and children [31]. Although FFM explains inter-individual variations in REE better than body weight does, body composition is rarely considered, particularly in children. In obese children FFM was demonstrated to be the most powerful predictor of REE, explaining 72.3% of the variability, while no significant contribution of FM was found [32]. In particular, when the FM and FFM variables were entered in the multivariate analysis model, REE was revealed as being mainly explained by FFM [33]. More recently body weight and FFM were demonstrated to be the major determinants of REE, explaining 56% and 44% of the variance, respectively, in a simple linear regression [34].

Age and anthropometry may contribute substantially to the prediction of REE in obese children [14]. Our data confirm this hypothesis since, when arm-C, waist-C, and WHR variables were also considered in our multivariate logistic regression models (model 2), REE was mainly explained by FFM (r^2 was 75% for IC and 79% for SWA). Interestingly, anthropometric data predict only 32% of the difference in values between methods, suggesting that other parameters are probably involved in the determination of bias methods. In our study the subjects' number may be consider a bias because it could influence the results per se and our subjects are not enough for having strong influence on the parameters included. However, body composition measurement results are definitely fundamental in the REE prediction even in pediatric age.

REE is the largest component of total daily energy expenditure; therefore, the ability to accurately estimate REE is of the utmost importance for adequate dietary therapy. The use of metabolic charts is the standard procedure for measuring REE in a research setting, but the equipment required to measure respiratory exchange makes this procedure time consuming, costly and often impossible. Our study suggests that the SWA method is not precise and does not give accurate estimates of REE in childhood obesity. Algorithms developed for estimating REE by portable monitors in adult populations cannot be applied to obese children and adolescents and should be adapted to them as has been done for other children groups [28]. Bias in individual REE measurements estimated by SWA could be reduced by an adjustment for the body composition. However, we believe that the features of the SWA have the potential to reduce measurement time, making it useful for epidemiological studies, as other authors also suggested [24].

The present study investigated the applicability of the SWA device to determining REE in childhood obesity for the first time. Although the SWA is an easy to handle, practical and new portable device for measuring EE, our data suggest that further research is needed before SWA can be considered as a good replacement of IC in clinical practice. Moreover, taking into consideration that the use of the portable armband is mainly for the evaluation of total energy expenditure and daily physical activity in normal-weight subjects, our results strongly support the need to develop new pediatric- and obesity-specific algorithms for REE based on body-composition formulas.

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TABLES

Table 1. Anthropometric measurements of the study population.

	Total (n=40)		Males (n=26)	Females (n=14)	*P*
Age (years±SD)	11.5±2.57		11.9±2.77	10.9±2.10	0.244
Height (cm±SD)	150.1±12.6		153.0±13.8	144.7±8.23	0.078
Height z-score (SDS±SD)	0.81±1.44		0.96±1.27	0.55±1.76	0.244
Weight (kg±SD)	69.9±16.2		71.1±17.6	67.7±13.7	0.680
BMI (kg/m^2±SD)	30.7±4.23		30.0±3.35	32.2±5.38	0.156
z-BMI (SDS±SD)	3.14±0.53		3.07±0.53	3.26±0.53	0.244
Puberty (no/yes)	17/23		13/13	4/10	-
SBP (mmHg±SD)	112.3±9.05		112.8±9.40	111.4±8.64	0.660
DBP (mmHg±SD)	69.5±7.40		69.0±7.35	70.4±7.71	0.755
Arm-C (cm±SD)	31.3±3.58		31.1±3.70	31.6±3.32	0.736
Waist-C (cm±SD)	89.6±11.2		90.2±12.0	88.7±10.1	0.849
Hip-C (cm±SD)	99.6±9.73		98.1±8.48	102.4±11.5	0.253
WHR (mean±SD)	0.89±0.07		0.92±0.08	0.87±0.05	0.051
Triceps SF (mm±SD)	29.1±6.60		27.8±5.49	31.4±7.85	0.220
Biceps SF (mm±SD)	21.1±8.59		17.9±4.37	26.8±11.1	0.019
Subscapular SF (mm±SD)	29.7±7.24		27.7±6.17	33.3±7.77	0.031
Supra-iliac SF (mm±SD)	31.9±7.78		31.0±7.84	33.7±7.68	0.296
FM (%±SD)	43.0±9.96		42.2±10.5	44.7±9.14	0.716
FM (kg±SD)	30.0±8.90		29.8±8.93	30.4±9.16	0.773
FFM (%±SD)	56.9±9.96		57.9±10.5	55.3±9.14	0.716
FFM (kg±SD)	40.3±13.2		42.2±15.1	37.2±8.96	0.555

BMI: body mass index; z-BMI: BMI z-score; SBP: systolic blood pressure; DBP: diastolic blood pressure; C: circumference; WHR: waist hip ratio; SF: skinfold; FM: fat mass; FFM: fat-free mass

Table 2. Stepwise multiple linear regression analysis of resting energy expenditure (kcal/day) in obese children and adolescents.

REE	**Sex**		**Age**		**BMI**		**FFM**		**FM**		**Intercept**				
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	SE	R^2	*P*
IC															
All	140.5	52.3	-33.6	15.0	-16.1	9.8	18.7	3.1	15.1	4.3	-13043.1	5374.3	138.9	0.73	0.000
M			-26.3	18.9	-24.1	15.1	18.5	3.9	16.9	5.1	1394.3	367.9	137.5	0.74	0.000
F			-76.7	31.5	12.3	20.5	19.7	6.9	3.71	10.7	1005.5	294.6	142.9	0.58	0.069
SWA															
All	77.3	47.7	-12.5	13.7	5.85	8.97	13.8	2.8	13.5	4.0	-7103.8	4895.8	126.5	0.77	0.000
M			-7.9	17.2	-1.18	13.7	14.9	3.6	12.5	4.7	914.4	333.9	124.8	0.79	0.000
F			-41.7	20.6	15.8	13.4	9.1	4.5	15.9	7.0	799.9	192.8	93.6	0.88	0.000
IC-SWA															
All	63.2	63.2	-21.1	18.2	-21.9	11.9	4.8	3.7	1.66	5.3	-5939.4	6493.5	167.8	0.28	0.050
M			-18.9	24.3	-22.9	19.4	3.61	5.0	4.39	6.6	479.8	473.5	176.9	0.08	0.764
F			-35.0	33.3	-3.50	21.7	10.6	7.3	-12.1	11.3	205.5	311.1	151.0	0.59	0.063

Model 2 - Regression coefficient

REE	**Sex**		**Age**		**BMI**		**FFM**		**FM**		**Arm-C**		**Waist-C**		**WHR**		**Intercept**				
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE	SE	R^2	*P*
IC																					
All	151.7	58.8	-45.9	17.4	-21.0	11.1	15.7	3.8	7.0	6.6	1.1	9.7	12.6	8.7	-460.6	724.8	-14280.6	5925.3	138.2	0.75	0.000
M			-42.0	23.5	-31.3	16.5	16.8	4.9	10.6	7.6	3.6	11.5	9.5	10.7	-170.4	935.0	1241.8	548.7	140.3	0.77	0.000
F			-71.7	38.2	31.8	38.3	20.2	13.6	-2.9	25.7	-8.4	27.0	-3.6	31.0	1617.1	2476.6	-314.0	1563.6	161.8	0.64	0.302
SWA																					
All	114.4	53.5	-26.4	15.8	-3.1	10.1	11.4	3.5	8.3	6.0	-0.2	8.8	13.8	7.9	-1162.8	658.8	-10375.9	5386.1	125.6	0.79	0.000
M			-16.3	22.0	-3.8	15.4	14.2	4.6	10.5	7.1	-5.0	10.8	7.9	10.8	-736.6	874.6	1299.5	513.2	131.3	0.81	0.000
F			-45.7	25.4	3.1	25.5	3.9	9.0	8.0	17.1	12.2	18.0	13.6	20.6	-1275.8	1648.1	1196.3	1040.5	107.7	0.89	0.012
IC-SWA																					
All	37.3	72.9	-19.5	21.5	-17.9	13.8	4.23	4.7	-1.37	8.2	1.26	12.0	-1.17	10.8	702.3	897.6	-3904.7	7337.4	171.2	0.32	0.134
M			-25.7	30.6	-27.5	21.5	2.61	6.4	0.11	9.9	8.64	15.0	1.48	13.9	566.1	1216.9	-57.7	714.0	182.6	0.18	0.814
F			-25.8	37.3	28.7	37.4	16.3	13.3	-10.9	25.1	-20.6	26.4	-17.2	30.3	2892.9	2418.7	-1510.3	1527.1	158.0	0.70	0.202

REE: resting energy expenditure; IC: indirect calorimetry; SWA: SenseWear Pro2 Armband; M: males; F: females, Coeff.: coefficient; SE: standard error; BMI: body mass index (kg/m^2), FFM: fat-free mass (kg), FM: fat mass (kg); C: circumference; WHR: waist-hip ratio

FIGURE LEGENDS

Figure 1. Bland-Altman plot between the indirect calorimetry (IC) and armband (SWA) methods for measuring resting energy expenditure (REE) (n=40). Broken horizontal line: mean difference between methods. Solid lines: 95% limit of agreement

Figure 2. Residual values for resting energy expenditure (REE) plotted against the indirect calorimetry (IC) and armband (SWA) REE.

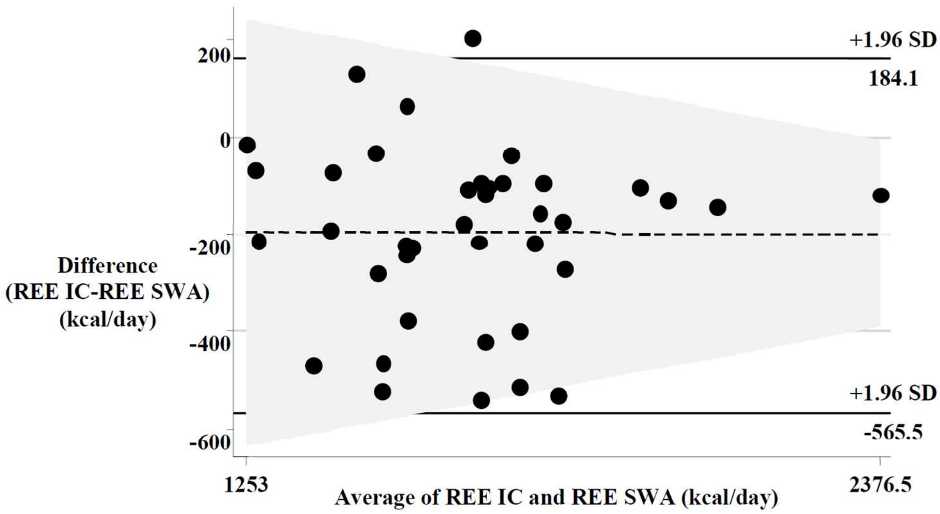

Figure 1
426x245mm (96 x 96 DPI)

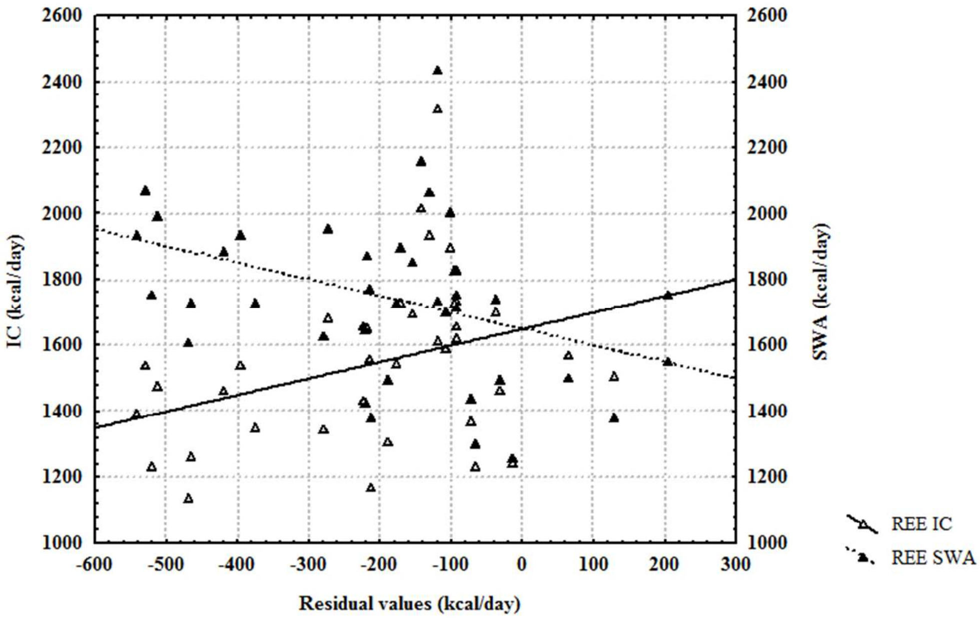

Figure 2
210x135mm (96 x 96 DPI)