Reliability of a Multisensor Armband in Estimating Energy Expenditure According to Degree of Obesity

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Abstract

Resting energy expenditure (REE) represents the amount of calories required by the body to maintain vital body functions. One of the most commonly used methods for estimating REE is indirect calorimetry. Recent studies on different populations have validated a highly innovative instrument, the SenseWear® Armband (SWA), which evaluates total energy expenditure and, when used in resting conditions, could also evaluate REE. The purpose of this study was to determine the agreement of the SWA in assessing REE in obese subjects and, see how this agreement varies with different obesity degree.

89 obese subjects (59 women and 30 men), with an age range from 35-65 years and body mass index (BMI) 34.5 4.5 kg/m^2 were studied. REE was measured by IC Sensor Medics Vmax (SM-29N) and by SWA. Fat mass (FM) and fat-free mass (FFM) was determined by anthropometry and bio-impedance measurements. No statistical difference was found between REE measured by SWA (1693±276) and REE measured by SM-29N (1627±293). The two methods showed similar assessments (r=0.8, p<0.0001). When the BMI range is limited to 30 to 35 kg/m^2, this agreement increases (r = 0.85, p<0.0001). However, at higher BMIs (BMI> 35 kg/m^2), the agreement decreases (r = 0.6 p <0.0001). FFM, measured using different methods, and REE measured using SWA and SM-29N are very closely correlated.

The accuracy of the SWA is affected by BMI, in fact it appears to be good in obese subjects with a BMI range of 30 to 35, but this accuracy decreases with higher BMIs (BMI> 35).

Introduction

There is a critical need to control the current obesity epidemic in the light of the increasing prevalence of overweight and obese individuals around the world [1-4], since one and 1, 5 billion of the world's population are overweight or obese [5,6]. The largest component of total daily energy expenditure is resting energy expenditure (REE), accounting for 60-70% of total expenditure [7]. The factor that determines energy balance, at a given level of energy intake and physical activity, varies from person to person and is influenced and largely determined by body size and composition. Total energy expenditure (TEE) consists of resting energy expenditure (REE), the thermal effect of food (TEF) and activity thermo-genesis (AT). AT can be further split in to two components, exercise-related AT and non-exercise AT (NEAT). According to Levine [8], NEAT is reported to be the most variable component of TEE and is thought to play an important role in the pathogenesis of obesity. An imbalance in energy intake and energy expenditure leads to obesity, which is associated with increased morbidity and mortality [9-11] and with a higher incidence of type 2 diabetes, risk factors for cardiovascular disease (CVD) and chronic diseases in general [12,13]. Body mass index (BMI: m/kg^2), is positively correlated with dyslipidaemia and cardiovascular diseases (CVD), and negatively correlated with poor physical fitness [12,13]. Weight-loss diets are associated with a reduction in resting energy expenditure (REE, kcal/day) [12] and in lean body mass (LBM), which is positively associated with REE [14]. On the other hand, increased physical activity also favours better weight maintenance [15], and weight regain is twice as high in those with sedentary life styles [16]. Regular physical activity reduces abdominal fat, risk of mortality [17] and calorie intake and weight loss is also associated with a reduction in metabolic risk factors [18].

Metabolic carts are the standard method used in research based on REE measurements [19]. However Indirect Calorimetry (IC) and metabolic carts are the standard techniques for measuring REE in research settings, the equipment required to measure respiratory exchange makes this procedure time-consuming, costly and often impossible to perform. This calls for the need to find more manageable devices for measuring energy expenditure. As a substitute for this procedure and to overcome the problems related to the great variability between measurements, several prediction equations have been developed [20,21]. The Harris-Benedict equations [21] are widely used in clinical settings and nutritional assessment. Prediction equations are often used as alternatives to measuring energy expenditure, however, the accuracy of these equations has often been criticised [22,23]. To overcome the disadvantages of metabolic carts, more manageable energy expenditure measuring devices have been developed. In order to reduce costs and complexity, new technologies are needed to provide to clinicians with more accurate methods of measuring REE.

A new energy expenditure system called the SenseWear™ System Armband (SWA) was recently developed and marketed. The device is worn on the right upper arm over the triceps muscle and monitors various physiological and movement parameters (i.e. movement, heat flux, skin temperature, galvanic skin response) and estimates the wearer's calorie expenditure, number of steps, and duration of physical

activity. Previous studies have reported the SWA as being highly accurate when estimating the resting energy expenditure in relatively young, normal-weight and overweight adults [24-26], but less in obese subjects [27]. The purpose of our study was to assess the validity of the SWA to assess resting energy expenditure for different obesity ranges, and if this is in agreement with standard indirect calorimetry.

Subjects and Methods

Subjects

The study caseload consisted of 89 healthy obese subjects (F=59, M=30), with an age range from 35-65 years and body mass index (BMI) 34.5 ± 4.5 kg/m^2. Written informed consent was obtained from all subjects before collecting a general history and conducting a physical examination to rule out illness. None of the subjects had taken medication or followed a diet in the six months prior to the study. Subjects were asked to follow their usual diet during the week preceding the study. All subjects were studied in the early morning after overnight fasting and were instructed to void before measurements were taken. The protocol was approved by the institutional review boards of the University of Modena and Reggio Emilia.

Resting energy expenditure

REE measurements were taken between 8:00 a.m. and 10:00 a.m. after overnight fasting (at least 12 hours) by means of the gas dilution method using the Sensor Medics Vmax29 metabolic cart (SM-29N Metabolic Cart, Yorbe Linda CA, USA). Subjects were asked to stay awake and motionless for the duration of the simultaneous measurements, which were taken for 30 to 40 minutes. Since there is no reliable approach for assessing inter-day variability of REE, we consider a measurement valid when 15 minutes of steady state, determined as a coefficient of variation <5% in minute respiratory quotient and minute oxygen consumption, is obtained, according to Weir's formula [28]. The SWA (SenseWear™ Armband, BodyMedia, Roche Diagnostics, and Indianapolis, IN, USA) was worn on the right arm over the triceps muscle at the midpoint between the acromion and olecranon processes. The armband was placed on the subject's arm for 5-10 minutes before data collection to allow for acclimation to skin temperature. The SWA data was analysed using dedicated software (I*nnerView Research Software, version 6.0* BodyMedia, Inc., Pittsburgh, PA), which, to our knowledge, is the most recent version. The SWA also provided a number of measured parameters (accelerometry, heat flux, galvanic skin response, skin temperature, near body temperature) and demographic characteristics (gender, age, height, weight) in proprietary algorithms to estimate energy expenditure. Accelerometry was measured using a two-axis micro electro mechanical sensor. Heat flux was measured using a proprietary sensor that incorporates low thermal resistant materials and thermocouple arrays. Galvanic skin response was used as an indicator of evaporative heat loss and was measured using two hypoallergenic stainless steel electrodes. Skin temperature was used to reflect the body's core temperature activity and was measured using a thermistor-based sensor.

Anthropometry

All anthropometric measurements (TH) were performed by the same operator according to the *Anthropometric Standardisation Reference Manual* [29]. Weight (Wt) was measured to the nearest 100 g and height (Ht) to the nearest 0.1 cm using an electronic scale with built-in stadiometer (Tanita, Tokyo, Japan). BMI was calculated as Wt (Kg)/Ht (m^2). Skinfolds and circumference were measured using a caliper and an anthropometric tape, respectively (Holtain, Crymich,

UK). Skinfold thickness (biceps, triceps, subscapular, suprailiac, calf and mid-thigh) were measured to the nearest millimetre using calipers on the right side of the body [29]. Circumferences (arm, waist, hip, calf, and mid-thigh) were measured to the nearest millimeter using a plastic tape measure. All skinfold and circumference measurements were taken three times and the values were averaged.

Bioimpedance analysis

Bioimpedance (BIA) was measured using an octopolar tactile-electrode impedance-meter (Tanita MC-180, Japan). Resistance (R) of arms, trunk and legs was measured in fasting conditions (≥ 8 h) at frequencies of five, 50, 250 and 500 kHz with an 8-polar tactile-electrode impedance-meter. This instrument makes use of 8 tactile electrodes: two are in contact with the palm and thumb of each hand and two with the anterior and posterior aspects of the sole of each foot. An alternating current (a.c.) of 250 A of intensity (I) is applied. No caution was taken to standardize the subject's posture before BIA, as suggested by the manufacturer. Whole-body resistance was calculated as the sum of segmental resistance (right arm + left arm + trunk + right leg + left leg). The whole-body resistance index was calculated as Ht (cm) ^{2} / whole body resistance. Measurements were taken in the morning at room temperature (21°), after at least 12 hours of rest, following overnight fasting.

Statistical analysis

Data was analysed using a PC version of Intercooler Stata 10 (Stata Statistical Software: Release 10.0 Collage Station, Texas). Pearson's product-moment correlation analyses were performed to determine associations between REE estimated by SWA and SM-29N measurements.

Bland – Altman bias plots [30] were created to assess the agreement/difference between the indirect calorimetry measurement and SWA estimation of REE as well as the reliability of the SWA estimate. Pearson correlation was used to evaluate the relationship between FFM (kg) measured by IC and SWA and FFM (kg) measured using different body composition methods. Statistical significance was set at P < 0.001. Data is presented as M ± SD.

Results

Physical characteristics, FM and FFM in kg of the study population are given in Table 1. Un-paired *t-tests* were computed to examine differences between age and gender for the parameters measured and we did not find any statistical difference (in all cases p = n.s.) and analysed as one group. REE measurements estimated by SWA (1693 ± 276 kcal*min^{-1}) were very similar to the mean indirect calorimetry measurement (1627 ± 293 kcal*min^{-1}). We also calculated REE with Harris-Benedict predicted equation (Table 1) and find that the best correlation was between REE estimated by SWA and REE estimated by Harris Benedict (r = 0.85). This correlation is higher than the correlation of REE measured by Vmax and REE measured by Harris Benedict (r = 0.75) and even higher than the correlation between REE measured by gold standard Vmax and REE measured by SenseWear (r = 0.8). Dividing the subjects in 2 categories: one group with 30 < BMI > 35 kg/m^2 and the other with BMI > 35 kg/m^2 the correlation between REE measured by SWA and REE measured by HB, though decreasing with increasing BMI, is always the best (r > 0.8).

The mean measurements for each subject provided by the two devices were significantly correlated (r = 0.80, p < 0.0001). Is very

interesting to analyse this correlation when patients are divided in two groups according to BMI class: one group with $30 < BMI > 35$ kg/m^2 and the other with $BMI > 35$ kg/m^2.

Indeed, as expected, the correlation increases to r = 0.85 for $30 < BMI > 35$ kg/m^2 but for greater BMIs this correlation decreases (r = 0.6 p < 0.0001). The same thing happens in the correlation between HB and REE measured by the other two methods, increasing BMI decrease the correlation. This emphasized that in presence of important BMI ($BMI > 35$ kg/m^2) the reliability of unknown algorithms (like SWA algorithms) and predicted equation for body composition assessment is still limited.
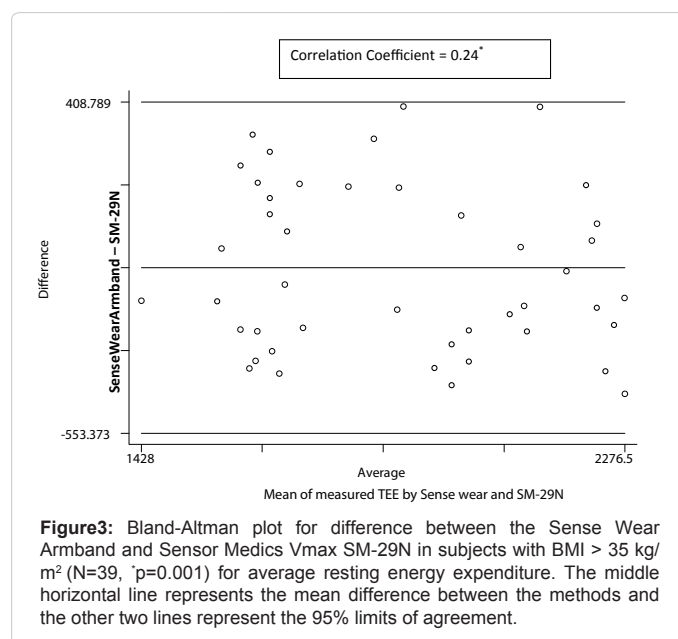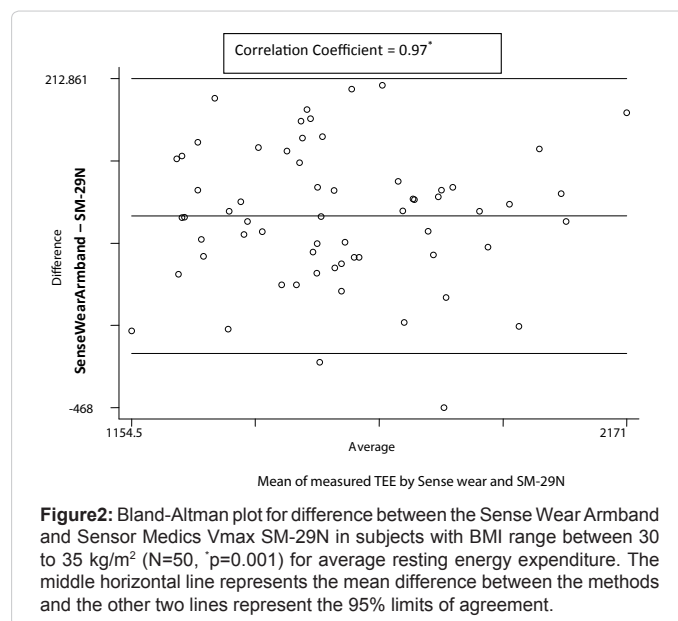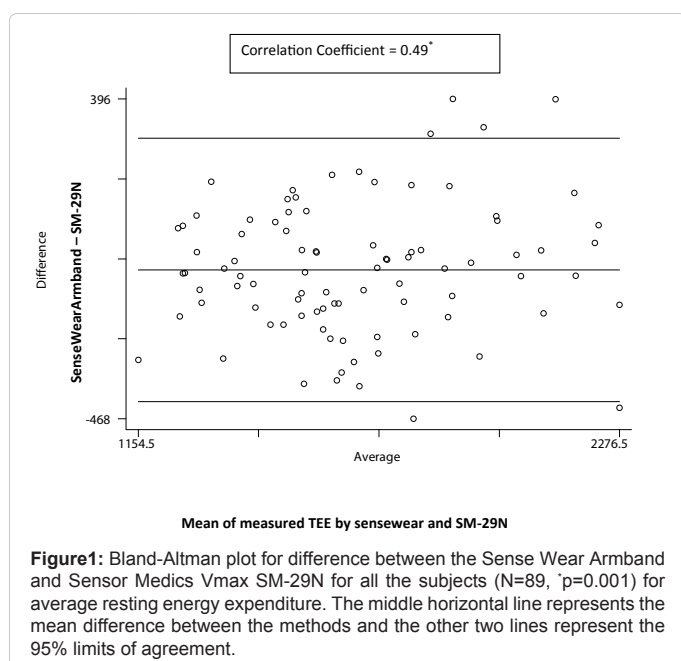
The Bland – Altman plot (Figure 1) also shows the good agreement (N = 89, p = 0.49) between the two measurements as we considered the entire subject one big group and no bias toward over- or underestimation. This agreement changed if we divided the subjects according to the BMI range: one with $30 < BMI > 35$ kg/m^2 and one with $BMI > 35$ kg/m^2. With $30 < BMI > 35$ kg/m^2 (Figure 2) the agreement increase (N = 50; p = 0.97), while $BMI > 35$ kg/m^2 (Figure 3) the agreement decrease (N = 39; p = 0.24).

We found a high correlation between FFM in kg estimated using different methods and REE measured by SWA and by indirect calorimetry.

In our sample, FFM was estimated by TH and BIA (manufactured given the equations) (Table 1) and no significant difference was established between them. The correlation coefficients between FFM, measured using different techniques, and REE estimated by SWA and indirect calorimetry are summarised in Table 2.

The best association is between REE measured by SWA and FFM measured by BIA (r = 0.82; p < 0.0001). The correlation between REE measured by SM-29N and by SWA and BMI class of the study population is better if $30 < BMI > 35$ kg/m^2 (r = 0.85 p < 0.0001) but this correlation decreases (r = 0.69 p < 0.0001) with BMI >35 kg/m^2.

Body composition measurements, including REE are greatly affected by the patient's obesity status, indeed we found that when BMI

Figure2: Bland-Altman plot for difference between the Sense Wear Armband and Sensor Medics Vmax SM-29N in subjects with BMI range between 30 to 35 kg/m^2 (N=50, *p=0.001) for average resting energy expenditure. The middle horizontal line represents the mean difference between the methods and the other two lines represent the 95% limits of agreement.

Figure3: Bland-Altman plot for difference between the Sense Wear Armband and Sensor Medics Vmax SM-29N in subjects with BMI > 35 kg/m^2 (N=39, *p=0.001) for average resting energy expenditure. The middle horizontal line represents the mean difference between the methods and the other two lines represent the 95% limits of agreement.

increases, the correlation between REE measured using SWA and REE measured using Vmax is reduced.

Discussion

The SWA was seen to be highly reliable at estimating resting energy expenditure in lean and overweight individuals, but less so in obese subjects. Papazoglou et al. [27] suggest that specific algorithms should be used for the obese (more strictly speaking according to their findings for individuals with high REE) to provide more accurate energy expenditure estimates. To our knowledge, this study is the first to examine the validity of this instrument for estimating resting energy expenditure in comparison with indirect calorimetry in different BMI class of obese people. We examined the SWA's agreement in estimating REE compared with Harris Benedict equation in two groups: one with BMI's range from 30 to 35 kg/m^2 and the second with BMI > 35 kg/

Figure1: Bland-Altman plot for difference between the Sense Wear Armband and Sensor Medics Vmax SM-29N for all the subjects (N=89, *p=0.001) for average resting energy expenditure. The middle horizontal line represents the mean difference between the methods and the other two lines represent the 95% limits of agreement.

	N	Age(y)	Weight kg	Height m	BMI kg/m²	FM_1	FFM_1	FM_2	FFM_2	REE_1	REE_2	REE_3
Male	30	44±12	104±14	1.75±7	34±5	33±9	71±9	32±9	71±7	1824±269	1931±258	2047±156
Female	59	51±11	89±13	1.60±5	34±4	36±6	52±7.6	36±8	53±6	1528±254	1573±196	1558±156
Total	89	50±12	94±15	1.65±9	34.5±4.5	35±8	59±12	35±9	59±11	1627±293	1693±196	1729±306

BMI=body mass index; FM_1= fat mass kg by TH; FFM_1= fat-free mass kg by TH; FM_2 = fat mass kg by BIA; FFM_2= fat-free mass kg by BIA; REE_1= REE by Vmax; REE_2= REE by Sense Wear; REE_3= REE by Harris Benedict equation

Table 1: Subject characteristics.

	N	Weight kg	Height m	FM_1	FFM_1	FM_2	FFM_2	REE_1	REE_2
30<BMI>35	62	88±10	1.65±9	31.7±5	56±12	30.6 ±5	57±10	1540±240	1613±241
35<BMI>40	27	109±13	1.65±8	43.8±6	66±11	46±6.5	64±10	1830±308	1900±255

BMI=body mass index; FM_1= fat mass kg by TH; FFM_1= fat-free mass kg by TH; FM_2 = fat mass kg by BIA; FFM_2= fat-free mass kg by BIA; REE_1= REE by Vmax; REE_2= REE by SenseWear

Table 2: Subject characteristics in two groups with different BMI ranges.

m². No significant differences were found, however we found that if we limited the BMI range to 30 to 35 kg/m² these correlations increase. In addition, good correlation and very good agreement were found in the measurement of REE between two methods in this population. The best correlation was found between REE measured by SWA and REE measured by HB equation (r = 0.84). These results indicate not only that the SWA could provide reliable estimates of REE, but also that the manufactured equation of SWA could be similar to HB equation. However, a high degree of correlation does not imply agreement between the two methods. It is widely agreed that the standard statistical method for the comparison of a new and established measurement technique is that described by Bland and Altman. Using the Bland-Altman technique for this comparison, we found a significant positive correlation and no meaningful difference between SWA and indirect calorimetry. The agreement increases if we limit the BMI range to 30-35 kg/m². Above the 35 kg/m² mark, the agreement decreased and the two methods cannot be used interchangeably in obese subjects with BMI > 35 kg/m². We used SM-29N as the criterion measurement for evaluating the SWA. It is important, however, to point out that this is not a gold standard, since an element of skill is involved in its calibration and usage. Nonetheless, this metabolic cart, when used by skilled technicians, is generally considered to provide an accurate measurement of the resting metabolic rate. Our results suggested that trained technicians are likely to obtain similar values for REE when using the metabolic cart and the SWA.

The SWA appears to have a similar accuracy to and some practical advantages over traditional metabolic carts. For instance, the cost is significantly lower and the SWA is portable and self-calibrating, whereas calibration of metabolic carts must be performed by a skilled technician. According to our results, the SWA should increase the accessibility of REE measurements. Indeed, unlike metabolic carts, SWA can be easily used in doctors' and dieticians' practices and many other healthcare settings, whereas metabolic carts are used primarily in research laboratories and hospitals, due partly to the fact that metabolic cart measurements require standardised conditions that can only be obtained in these facilities. We conclude that the Sense wear System Armband method is able to provide a good estimate of basal metabolic rate, however in populations with a higher BMI (BMI >35 kg/m²), its accuracy decreases, probably as a consequence of fat mass increase, so a larger population study could be decisive to improve Armband precision and accuracy.

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