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# Validation of ActiReg® to measure physical activity and energy expenditure against doubly labelled water in obese persons

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ActiReg® is an instrument that uses combined recordings of body position and motion to calculate energy expenditure (EE) and physical activity (PA). The aim of the study was to compare mean total energy expenditure (TEE) measured by ActiReg® and doubly labelled water (DLW) in obese subjects. TEE was measured by the DLW method during a period of 14 d in fifty obese men and women with metabolic risk factors. During the same period ActiReg® recordings were obtained for 7 d. RMR was measured by indirect calorimetry and also estimated by standardized equations. Because EE may be disproportionately increased in obese subjects during weight-bearing activities, we established a new set of physical activity ratios (PAR). These ratios were based on oxygen uptake measurements during treadmill walking. The mean TEE according to the DLW was 13·94 (SD 2·47) MJ/d. Mean TEE calculated from the ActiReg® data and measured RMR was 13·39 (SD 2·26) MJ/d, an underestimation of 0·55 MJ (95 % CI 0·13, 0·98; $P=0·012$) or 3·9 %. RMR derived from standard equations based on weight, age and sex were overestimated while the RMR based on fat-free mass values in addition was underestimated. Despite slight underestimation ActiReg® may be used to measure TEE in obese subjects on two premises: RMR should be measured, and the increased EE during weight-bearing activities in obese subjects should be considered.

**Energy expenditure: Physical activity: Activity pattern**

Obesity (BMI > 30 kg/m$^2$) is associated with type 2 diabetes, CHD, stroke, increased morbidity and early mortality. In order to plan optimal treatment for subjects at risk, validated methods to measure total energy expenditure (TEE) and physical activity (PA) are essential.

Although the doubly labelled water (DLW) method is clearly the most accurate measure of TEE, its widespread use is limited by the high cost of the labelled water and the requirement of highly specialized and expensive equipment for analysis. The need for precise quantification of TEE and PA during usual living conditions has led to the development of several measurement methods[1]. We have recently described a novel instrument called ActiReg®, a validated position-and-movement monitor[2]. The ActiReg® system uses RMR combined with calculated physical activity ratio (PAR) values as the basis for energy and activity calculations. RMR may be measured or estimated from predictive equations. These equations are usually based on body weight, body height, age and sex and/or fat-free mass (FFM)[3–6]. However, the most widely used predictive equations may not be well suited in obese populations, because the source materials on which they are based include very few if any obese individuals[6–9]. Choice of prediction method for the estimation of RMR may therefore be important. To date the PAR values used by the ActiCalc32® program to calculate EE are published reference values for people with normal body weight[2,6]. Due to the relative increase of adipose tissue mass in obese individuals, predictive equations for RMR based on body weight and developed mainly for a normal-weight population may lead to overestimation of RMR. Likewise the energy cost of weight-bearing activities such as walking and standing is related to body weight, and is therefore increased in obesity[10–14]. Therefore PAR values developed for weight-bearing activities in lean individuals may not be appropriate for obese subjects[15]. As both these factors are the main contributors to the calculation model, it is important to establish reliable and validated values for obese individuals.

The aim of the present study was to calculate TEE from the ActiReg® recordings and compare this to TEE measured by DLW. In order to achieve this aim we established a set of mean PAR values for obese subjects during weight-bearing activity. Finally, we asked whether RMR could be estimated using predictive equations rather than directly measured by indirect calorimetry to simplify the procedure.

**Abbreviations:** DEXA, dual-energy X-ray absorptiometry; DLW, doubly labelled water; EE, energy expenditure; FFM, fat-free mass; LPA, Low Physical Activity; MHPA, Moderate-High Physical Activity; PA, physical activity; PAR, physical activity ratio; TEE, total energy expenditure; VLPA, Very Low Physical Activity.

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## Subjects and methods

### *Subjects*

Fifty non-smoking, obese men and women (BMI ≥ 30·0 kg/m$^2$) with two or more risk factors for the metabolic syndrome were recruited by newspaper advertisement and referral to the Department of Preventive Cardiology at Ullevål University Hospital. The characteristics of the group are shown in Table 1. As this was part of a broader study of subjects with two or more risk factors for metabolic syndrome subjects were screened via blood chemistry and a medical examination done by a physician to assess risk factors and eligibility to the study[16]. Exclusion criteria were body weight > 135 kg, current dieting, cigarette smoking, history of eating disorder or chronic disease, suspected non-compliance due to abuse of drugs or alcohol, drug- or insulin-treated diabetes mellitus, migraine requiring intermittent medication, use of thyroxin, diuretics or weight-reducing agents, and use of inhaled or oral β-agonists or corticosteroids. The educational level of each subject was determined according to the number of years of education and categorized as completed primary school, high school or a university degree. The Ethical Committee (region 1 in Norway) approved the protocol and all participants gave their written informed consent. The study was conducted between October 2001 and October 2003.

### *Experimental schedule*

The total duration of the experiment was 4 weeks. At baseline (week 1) the participant underwent physical examination including measurement of height, body weight, waist–hip ratio, sitting blood pressure, and collection of plasma and serum samples for different blood parameters[16]. During this week lean body mass was determined by dual-energy X-ray absorptiometry (DEXA). At week 2, RMR and energy expenditure (EE) during weight-bearing activities were measured. Later in the same week the DLW measurement, which lasted for 14 d, was initiated. At the same time the subjects attached the ActiReg® instrument for recording for 7 consecutive days, i.e. the first 7 d of the 14 d DLW period. At week 4, the DLW measurement was terminated and the final urine spot samples were delivered. A dietary assessment using a FFQ was administered.

### *Methods*

Height was measured with a standardized wall measuring stick scale to the nearest 0·5 cm. Subjects were weighed (in underwear) with a digital weight (Seca, Germany) to the nearest 0·1 kg. Weight was measured at the screening and baseline visits and on day 1 and day 15 of the DLW measurement period. Weight changes during the DLW period were calculated as the difference between day 15 and day 1. Body composition was determined by DEXA (Lunar Expert 1116). The measurement was done in the course of 15 min. The CV for the DEXA measurements was 3–4 %. RMR was measured with a standard portable ventilated hood system (Deltatrac® Metabolic Monitor; Datex Instrumentarium Corp., Helsinki, Finland). The Deltatrac® was calibrated by automatic standard gas calibration at the start of each measurement. The subjects slept at home the night before the measurement. On the day of the measurement the subjects took a taxi to the site. The subjects fasted during the last 12 h before the measurement and were instructed not to eat or drink anything but water on the day of the measurement. After changing clothes and mounting the equipment, the subjects relaxed for 30 min in the recumbent position before the head was covered with the canopy. Measurements were done at 1 min intervals for 20–25 min. A mean value of at least a 10 min period at a stable level of EE was defined to be the RMR. After completion of the RMR measurements the subjects were offered a sugar-containing drink prior to the start of a standardized treadmill test. This was done because they all had fasted for more than 12 h. The treadmill test consisted of walking at increasing speeds (1, 2, 3, 4, 5 and 6 km/h) at an inclination of 1 % for periods of 5 min at each velocity, while their $O_2$ uptake and $CO_2$ output were measured with spirometry (Jaeger Oxicon®). The treadmill test was performed in order to obtain calibration values for the EE related to different weight-bearing PA.

### *The doubly labelled water method*

EE by the DLW method was measured over a period of 14 d and used as a gold measure of habitual EE. Sample analyses and calculation procedures have been described in detail elsewhere[17]. First a baseline urine sample was collected for the determination of the background isotope enrichment (day 1). Then a weighted mixture of deuteriated and oxygenated water, corresponding to 0·05 g $^2H_2O$ and 0·10 g $H_2^{18}O$ per kg body weight, was ingested. The percentage enrichment of the waters was 99·9 % for $^2H$ and 10·0 % for $^{18}O$. The dose was planned to enrich body water with approximately 350 δ (delta per mill) for $^2H$ and 60 δ (delta per mill) for $^{18}O$. Urine samples were collected from the second voiding during days 2, 3, 4, 8, 13, 14 and 15. The mean time interval between drinking dose and the first post-dose urine sample was 22 (SD 3) h (range 12–30 h). The participants were instructed to collect the urine spot, register exact voiding

**Table 1.** Physical characteristics of the participants

| | Males (*n* 23) | | | Females (*n* 27) | | | |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Range | Mean | SD | Range | *P** |
| Age (years) | 44·5 | 10·0 | 27·7 | 42·6 | 10·7 | 41·0 | 0·5322 |
| Height (m) | 1·82 | 0·07 | 0·30 | 1·69 | 0·06 | 0·24 | 0·0000 |
| Weight (kg) | 116·2 | 14·8 | 52·6 | 105·0 | 12·2 | 48·1 | 0·0053 |
| BMI (kg/m$^2$) | 34·9 | 3·1 | 11·5 | 36·6 | 3·3 | 12·8 | 0·0645 |

* Two-sample *t* test assuming equal variances.

**Table 2.** Mean RMR measured by indirect calorimetry and calculated by different prediction equations

| | RMR (MJ/d) | | | | | |
|---|---|---|---|---|---|---|
| Type of measurement/estimation | Mean | SD | Difference | Range | 95 % CI | *P** |
| Measured by indirect calorimetry | 7·75 | 1·05 | | 4·53 | | |
| Mifflin *et al.* [4]† | 7·94 | 1·06 | −0·19 | 4·61 | −0·33, −0·05 | <0·007 |
| FAO/WHO/UN University[6]‡ | 8·20 | 1·19 | −0·45 | 4·44 | −0·62, −0·29 | <0·000 |
| Müller *et al.* [3]§ | 8·25 | 1·09 | −0·50 | 4·53 | −0·63, −0·36 | <0·000 |
| Cunningham[5], fat-free mass from DEXA¶ | 6·65 | 0·97 | 1·11 | 4·17 | 0·90, 1·32 | <0·000 |

DEXA, dual-energy X-ray absorptiometry.
* Paired samples test on the mean difference between the measured value and predicted values. Significance level $P<0·05$.
† Calculation formula: RMR (kcal/d) = 9·99 × weight (kg) + 6·25 × height (cm) − 4·92 × age + 166 × sex (males = 1; females = 0) − 161 (result converted to MJ/d by multiplication by 4·184).
‡ Calculation formula: Males (age 30–60): RMR (MJ/d) = 0·0485 × weight (kg) + 3·67; females (age 30–60): RMR (MJ/d) = 0·0364 × weight (kg) + 3·64.
§ Calculation formula (BMI ≥ 30): RMR (MJ/d) = 0·05 × weight (kg) + 1·103 × sex (males = 1; females = 0) − 0·01 586 × age + 2·924.
¶ Calculation formula: RMR (kcal/d) = 370 + 21·6 × fat-free mass (kg) (result converted to MJ/d by multiplication by 4·184).

time and freeze the samples at home. Participants were called every voiding day to ensure compliance with the procedure. When the samplings were completed, the urine samples were stored at −75°C until transportation to laboratory on dry ice.

Analysis of the isotopic enrichment was determined in triplicates with a Thermoquest Finnigan MAT Delta plus isotope-ratio mass spectrometer with water/$H_2$–$CO_2$ equilibrating device (Thermoquest Finnigan MAT, Bremen, Germany). The precision defined as standard error in triplicate samples is 0·26 δ for $^2$H and 0·10 δ for $^{18}$O. Tap water was collected and analysed for background measurements and all TEE calculations were corrected for the content of isotopes in the drinking water. TEE was calculated by the multi-point method using linear regression as suggested by the International Dietary Energy Consultancy Group[18]. All elimination curves were checked for major or diverging residuals. The CV for the elimination constants was on average 3·2 % for hydrogen and 2·7 % for oxygen. We used the relationship between pool size of $^2$H ($N_d$) and pool size of $^{18}$O ($N_o$) derived from the antilog intercept on the *y*-axis of the elimination curves as a quality measurement for the DLW as suggested by the International Dietary Energy Consultancy Group[18]. The mean food quotient determined from the FFQ was 0·85 (SD 0·016; range 0·81–0·89). The individual $N_o/N_d$ ratio and food quotient of the participants were used in the calculation of the energy

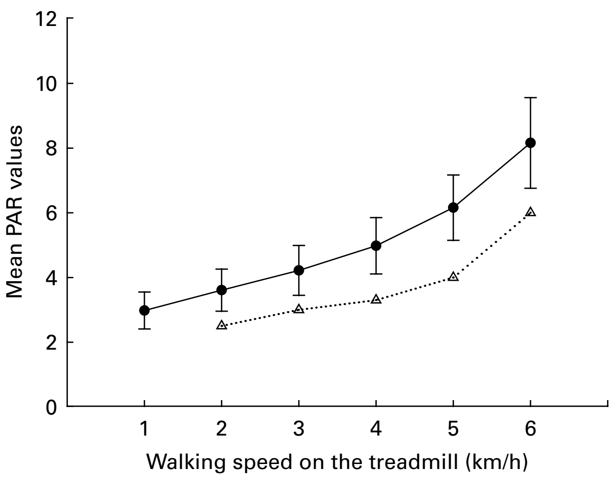


**Fig. 1.** Treadmill walking test for the combined group of obese subjects (both sexes, *n* 50). The physical activity ratio (PAR) is the measured energy expenditure divided by RMR at each speed. Values are means with their standard errors depicted by vertical bars. (●), Mean PAR for the combined obese group (both sexes); (△), for comparison, table values of PAR for normal-weight subjects[6,23,24].

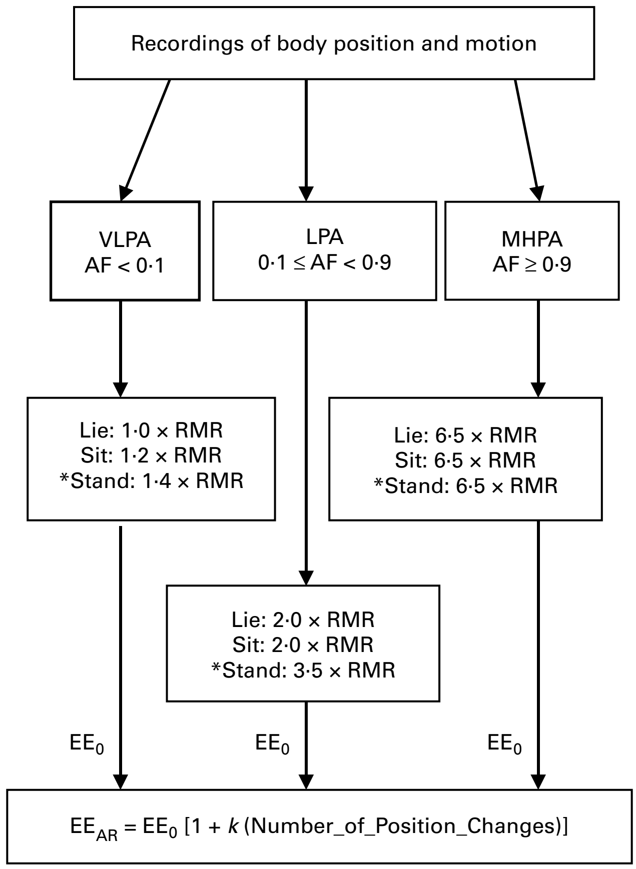


**Fig. 2.** The calculation procedure for energy expenditure based on ActiReg® data ($EE_{AR}$). In the first step the data are distributed into the three activity levels: Very Low Physical Activity (VLPA), Low Physical Activity (LPA) and Moderate-High Physical Activity (MHPA)[2]. The calculation within each level is based on the estimated energy cost for the actual body position, expressed as the RMR-factors. The result of this first calculation step is denoted $EE_0$. The second step takes the number of body position changes into account by applying the algorithm shown, where $EE_{AR}$ is the final result for the actual minute. The constant $k = 0·025$ determines the weight given to the number of body position changes, here designated as 'Number_of_Position_Changes'. AF, activity factor; * Stand, standing position including the bent forward position.

equivalence of the produced carbon dioxide as suggested by the International Dietary Energy Consultancy Group[18]. The mean $N_o/N_d$ ratio was 1·033 (SD 0·008; range 1·007–1·049).

### *ActiReg®*

ActiReg® is an electromechanical device which records the main body positions (stand, sit, bent forward and lie) together with motion of the trunk and/or one leg each second[2]. The position (tilt switches) and motion sensors are fixed to plastic brackets. During registration the subjects attached the ActiReg® (actual size of the box is 8·5 cm × 4·5 cm × 1·5 cm) to a belt while the sensors were connected to the box with thin lines. The brackets were attached by medical tape to the subject's chest (on sternum) and on the front of the right thigh approximately midway between the knee and the hip. The tilt switches were oriented so that they would be in the vertical position when the subject was standing. A specially developed computer program (ActiCalc32®) calculated EE and activity pattern from the collected information and calibration data[2].

The ActiReg® system uses a combined second-to-second recording of body position and motion to calculate EE and PA. The apparatus has two pairs of position and motion sensors connected by cables to a battery-operated storage unit fixed to a waist belt. Each pair of sensors is attached by medical tape to the chest and the front of the right thigh, respectively. The collected data are transferred to a PC and processed by a dedicated program ActiCalc32®. More details about the method are published elsewhere[2]. The calculation model used by ActiCalc32® is based on the estimated cost of the actual body position and activity expressed as PAR values (i.e. EE/RMR) combined with the number of position changes within each minute.

As described by Hustvedt *et al.* [2] the data from the ActiReg® was categorized into three levels of physical activity defined as Very Low Physical Activity (VLPA), Low Physical Activity (LPA) and Moderate-High Physical Activity (MHPA). The calculation within each level was based on the estimated energy cost for the actual body position, expressed as RMR-factors (PAR values) for subjects with normal body weight and taken from published reference values (Annex 5 of FAO/UN University/WHO[6]). In the VLPA range, the following factors were selected: lie still: 1·0 × RMR; sit still: 1·2 × RMR; stand still/bent forward: 1·4 × RMR. The LPA range extended from moving very slowly to walking at about 3 km/h and 2·5 × RMR is chosen as the average energy cost of standing activities. This is the energy cost given for 'walking around or strolling'. The factor for sitting and lying activities, which are non-weight-bearing activities, was set somewhat lower, at 2·0 × RMR. The dominant activity in the MHPA range during the daily life of most people is walking. The reported energy cost of 'walking: at normal pace' is 3·2 × RMR. In addition, a variable amount of more energy-requiring activities is expected, such as walking on stairs or uphill, walking while carrying loads, and performing exercise. The factor 5·0 × RMR was therefore chosen as the average energy cost of all MHPA activities. It was applied for all body positions. The treadmill experiments performed by Hustvedt *et al.* [2] showed that walking will fall in the MHPA range and that no body position changes were recorded until the walking speed exceeded 5 km/h. At ≥ 7 km/h, where the number of position changes increased, some minutes with the body positions 'sit' or 'lie' were also recorded. These recordings show that the state of the position sensors as well as the movement sensors is influenced by acceleration forces during rapid movement, such as running, in addition to the effect of the position angle. When walking/running speed increases a rising number of body position changes is recorded which is used to discriminate between higher levels of PA. The calculation procedure for $EE_{AR}$ (EE based on ActiReg® data) utilizes the combined information about PA level, body position and the number of position changes. The $EE_{AR}$ of all MHPA are therefore not calculated according to a PAR value of 5·0 but by an increased value proportional to the number of position changes as described by Hustvedt *et al.* [2].

However, for obese subjects we expected that the PAR values (RMR-factors) for weight-bearing activities would be

**Table 3.** Mean total energy expenditure (TEE) from the doubly labelled water (DLW) measurements and those calculated from the ActiReg® data based on the different RMR values and the difference between results calculated by ActiReg® and DLW values

| | TEE (MJ/d) | | Difference (MJ) | | | |
|---|---|---|---|---|---|---|
| Calculation method* | Mean | SD | Mean | SD | 95 % CI | *P*† |
| DLW | 13·94 | 2·47 | | | | |
| AR-RMR-measured | 13·39 | 2·26 | −0·55 | 1·49 | −0·98, −0·13 | 0·012 |
| AR-RMR-Mifflin | 13·73 | 2·32 | −0·21 | 1·65 | −0·68, 0·25 | 0·358 |
| AR-RMR-FAO/WHO/UNU | 14·18 | 2·59 | 0·24 | 1·78 | −0·26, 0·75 | 0·341 |
| AR-RMR-Müller | 14·26 | 2·42 | 0·32 | 1·71 | −0·17, 0·80 | 0·199 |
| AR-RMR-Cunningham-FFM-DEXA | 11·48 | 2·05 | −2·46 | 2·00 | −3·03, −1·90 | 0·000 |
| AR-RMR-measured-normal-PAR | 11·81 | 1·87 | −2·13 | 1·36 | −2·52, −1·74 | 0·000 |

DEXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; PAR, physical activity ratio.

* AR-RMR-measured: calculated by ActiReg® with measured RMR. AR-RMR-Mifflin: calculated by ActiReg® with RMR predicted from the equation of Mifflin *et al.* [4]. AR-RMR-FAO/WHO/UNU: calculated by ActiReg® with RMR predicted from FAO/WHO/UN University equation[6]. AR-RMR-Müller: calculated by ActiReg® with RMR predicted from the equation of Müller *et al.* [3]. AR-RMR-Cunningham-FFM-DEXA: calculated by ActiReg® with RMR predicted from the equation of Cunningham, with FFM from DEXA[5]. AR-RMR-measured-normal-PAR: calculated by ActiReg® with measured RMR combined with calculation parameters for normal-weight subjects. For comparison, the last row gives the result obtained by using the measured RMR values combined with PAR values for normal-weight subjects, i.e. no correction made for increased energy expenditure during weight-bearing activities.

† Paired samples test on the mean difference between the TEE calculated from ActiReg® data and those measured by DLW.

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somewhat increased. In this investigation these PAR values were based on mean values obtained during the treadmill experiments.

### Statistics

The agreement between the results obtained by two different methods was tested by the method of Bland and Altman[19]. Paired two-sample $t$ tests were used to evaluate the difference between the groups (SPSS for Windows version 13.0.0; SPSS Inc., Chicago, IL, USA). The significance level was set at $P < 0.05$. The correlation of linear regression is given as $r^2$.

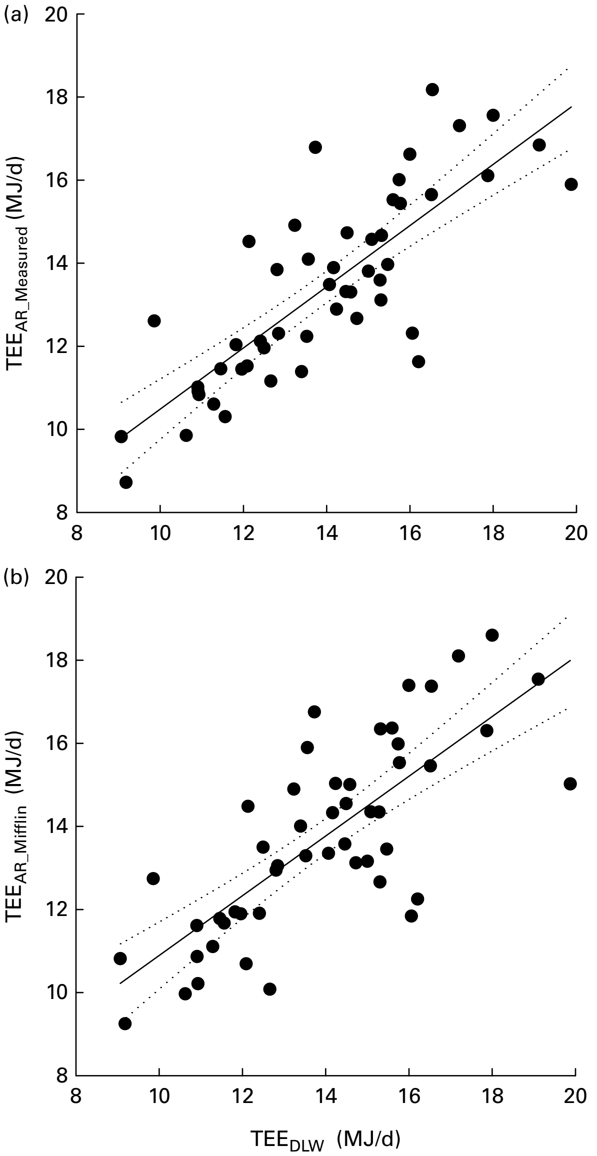


**Fig. 3.** (a), Linear correlation between the mean total energy expenditure measured by ActiReg® based on measured RMR ($TEE_{AR\_Measured}$) and the mean total energy expenditure from doubly labelled water measurements ($TEE_{DLW}$). The linear regression line shows a positive correlation ($y = 0{\cdot}736 + 3{\cdot}122$, $r^2$ 0·64, $P$=0·000). (b), Correlation between by $TEE_{DLW}$ and the mean total energy expenditure from the same ActiReg® data but here the calculations are based on predicted RMR from equations developed by Mifflin *et al.*[4] ($TEE_{AR\_Mifflin}$). The linear regression line shows a positive correlation ($y = 0{\cdot}718 + 3{\cdot}704$, $r^2$ 0·585, $P$=0·000). —, Linear regression line; ·····, 95 % confidence limits.

## Results

Subject characteristics according to sex are shown in Table 1. There was no significant difference in mean age between males and females.

TEE from DLW measured over 14 d was not significantly different from the value extracted from 7 d, and the mean value during 14 d was chosen as a more reliable measurement based on more data points.

Table 2 shows the mean RMR combined for both sexes obtained by indirect calorimetry and corresponding results using different predictive equations for RMR. The results of all predictive methods differed significantly from the measured RMR value. The equation proposed by Cunningham based on FFM significantly underestimated RMR[5]. The equations proposed by Müller *et al.*[3], Mifflin *et al.*[4] and the FAO/WHO/UN University[6] all led to overestimation of RMR.

Figure 1 show the results of the treadmill experiments. It will be seen that the mean PAR value for the total group (both sexes) is increased compared to the table values of PAR for normal-weight subjects at all walking speeds between 2 and 6 km/h. This implies that the basic PAR values used during calculation of $EE_{AR}$ should be increased accordingly during weight-bearing conditions in order to follow the same logic as used for normal-weight subjects. The logic of the calculation model is described earlier[2].

The calculation procedure established for the obese group is shown in Fig. 2. This implies that the PAR value for the weight-bearing body positions, i.e. standing and bent forward at LPA (which corresponds to a walking speed of about 3 km/h) is increased from 2·5 to 3·5, while it is increased from 5·0 to 6·5 at MHPA (corresponding to a PA of walking 4·0–5·0 km/h) for all body positions.

The mean TEE from the DLW measurements as well as those calculated from the ActiReg® data based on different RMR values are presented in Table 3. There was no significant difference between the mean $TEE_{DLW}$ and those calculated from ActiReg® data based on RMR values from the FAO/WHO/UN University, Mifflin and Müller predictive equations (Table 3). However, the difference between the mean $TEE_{DLW}$ and the mean $TEE_{AR}$ based on RMR values measured by indirect calorimetry was statistically significant. The $TEE_{AR}$ value calculated from RMR values based on the predictive equation using FFM instead of body weight significantly underestimated the mean TEE. Also the mean $TEE_{AR}$ based on measured RMR but using PAR values for 'normal-weight' subjects grossly underestimated mean TEE.

Fig. 3 shows the linear correlation between $TEE_{AR\_Measured\_RMR}$ and $TEE_{DLW}$ (Fig. 3 (a)) and $TEE_{AR\_Mifflin\_RMR}$ and $TEE_{DLW}$ (Fig. 3 (b)) with $r^2$ 0·64 ($P$=0·00) and $r^2$ 0·585 ($P$=0·00), respectively.

In Figs. 4 and 5 the results are compared with Bland–Altman plots. The difference between the calculated $TEE_{AR}$ and the $TEE_{DLW}$ are plotted against their average values. The limits of agreement of the mean difference (i.e. ± 2 SD) are indicated by the dotted lines. Fig. 4 includes results calculated from measured RMR, and predicted from

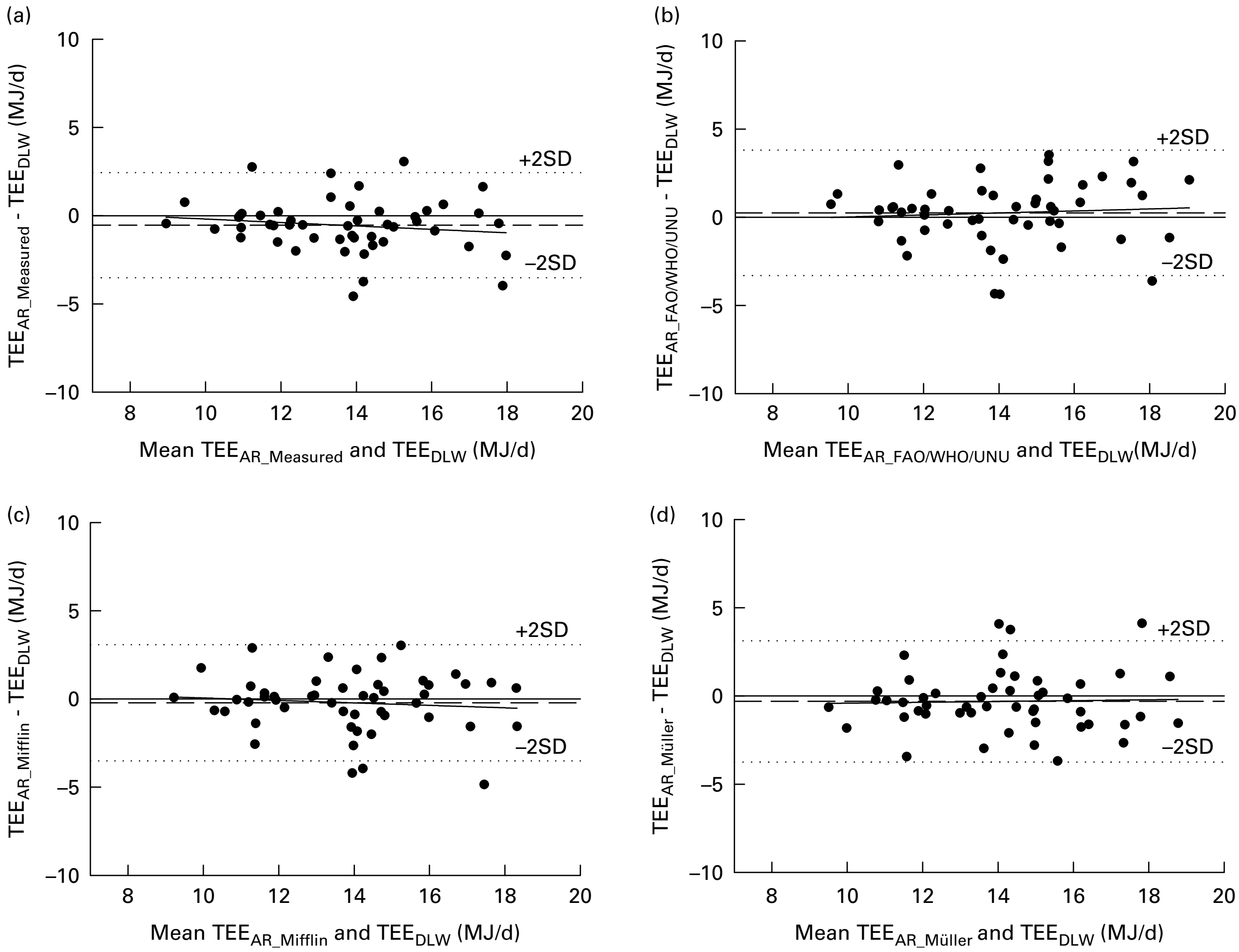


**Fig. 4.** The results are compared in Bland–Altman plots. The difference between the calculated total energy expenditure measured by ActiReg® ($TEE_{AR}$) and the total energy expenditure from doubly labelled water measurements ($TEE_{DLW}$) are plotted against the average value of them. The results are based on measured RMR (a), and RMR predicted from the equations of the FAO/WHO/UN University[6] (b), Mifflin *et al.*[4] (c) and Müller *et al.*[3] (d). – – –, Mean difference; ·····, limits of agreement of the mean difference (±2SD); —, zero difference and the linear regression lines.

FAO/WHO/UN University[6], Mifflin[4] and Müller[3] equations. For all four graphs in this figure the differences are evenly distributed throughout the range of the measurements and the linear regression lines are almost parallel to the *x*-axis. Fig. 5 presents the corresponding results based on RMR values calculated from FFM by the Cunningham equation[5] and measured RMR using PAR values for normal-weight people. The graphs in Fig. 5 show serious underestimation of mean TEE, but also a tendency to increased underestimation at higher levels of TEE. This is shown by the negative trend of the linear regression line and is most pronounced when PAR values for normal-weight people are employed.

## Discussion

The present study compared measurements of TEE by ActiReg® and DLW in a group of obese subjects. The results show that with the use of increased PAR values for weight-bearing activities, mean TEE calculated from the ActiReg® data was underestimated by less than 4 % compared to DLW, a statistically significant but minor difference for most purposes. Despite this underestimation we propose that ActiReg® may be used to measure TEE in obese subjects on two premises: RMR should be measured, and the increased EE during weight-bearing activities in obese subjects should be considered.

The calculation model used by the ActiReg® system is based on the product of RMR (kJ/min) and the PAR value for each minute of the registration period, i.e. the factorial principle. The PAR values for each specific minute is estimated from the combined information of body position, motion and number of position changes. Reliable values of RMR and PAR values in different body positions and activity levels are therefore a prerequisite for an optimal estimate of EE. The results of using the prediction equations based solely on anthropometric data, age and sex led to significant overestimation for this group of obese subjects (Table 2). This is in accordance with previous reports[3,9,11,20–22]. The Schofield[8] equations which have been adopted by WHO for general use in predicting RMR are linear in weight (Table 2)[6]. The overestimation between measured and predicted RMR may be explained in part by composition of the database and biological factors. These equations are based on analysis of data collected from 114 previous studies made

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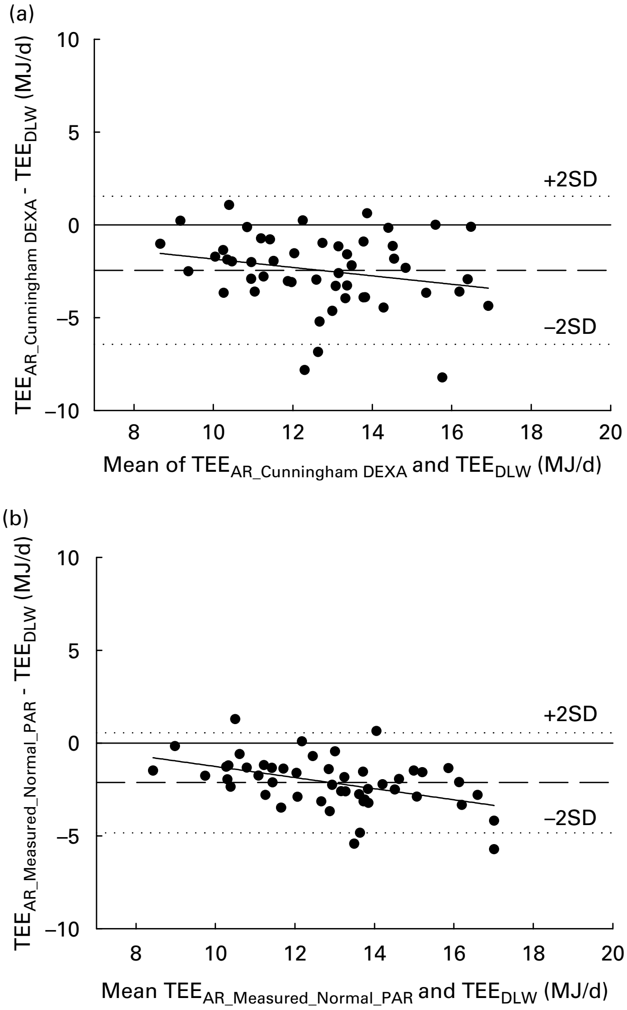


**Fig. 5.** Bland–Altman plots comparing the calculated total energy expenditure measured by ActiReg® ($TEE_{AR}$) results based on RMR values calculated from fat-free mass obtained from dual-energy X-ray absorptiometry (DEXA) by the Cunningham[5] equation (a) and measured RMR values using physical activity ratio (PAR) values for normal-weight people (b) with total energy expenditure from doubly labelled water measurements ($TEE_{DLW}$). – – –, Mean difference; ·····, limits of agreement of the mean difference (±2SD); —, zero difference and the linear regression lines.

in persons belonging to different races. In addition, one-third of the reference population had BMI $< 20\,kg/m^2$, but very few were obese. Also the total distribution of body weights within this population is quite different from the normal distribution for subjects living in modern affluent societies[3,9]. It is well documented that RMR increases with increased body weight and with increasing BMI, but the increase is not linear or directly proportional to body weight. RMR increases more slowly at heavier weights, and to ignore this will lead to overestimation of RMR in the obese. When the body gets fatter, a greater ratio of fat to lean tissue is deposited and as the metabolic rate of adipose tissue is low compared to that of lean tissue, RMR will not increase linearly by weight[9].

Mifflin *et al.*[4] derived new prediction equations based on a data set of 498 men and women that also incorporated a significant number of obese subjects (Table 2). More recently Müller *et al.*[3] developed equations based on an actual German database for different BMI groups of which the equation for BMI $\geq 30$ has been used in this paper (Table 2). Because most of the values included in the development of these prediction equations fell within the normal weight range, it is reasonable that they will overestimate RMR in the obese because they all are linear with respect to body weight. The RMR values calculated by the general prediction equation proposed by Cunningham[5] are based solely on the amount of FFM (Table 2). When we apply this equation to calculate RMR in our obese subjects this will underestimate RMR compared to measured values.

In the present study, reliable PAR values for obese subjects during weight-bearing activities were obtained by treadmill walking and indirect calorimetry (Fig. 1). Based on the mean PAR values for the whole group (both sexes) at LPA and MHPA the PAR values in the calculation model were set to 3·5 and 6·5, respectively, compared to 2·5 and 5·0 for normal-weight people. The LPA level extends from moving very slowly to walking at about 3 km/h which is equivalent to 'walking around or strolling'. A reasonable value for this activity for the obese is therefore set to 3·5, a value that we chose empirically.

Walking is the dominant activity in the MHPA range during the daily life of most people. The reported PAR value of 'walking at normal pace' (4–5 km/h) is 3·2 for normal-weight people.

In addition, there will be a variable amount of more energy-requiring activities, such as walking on stairs or uphill, walking while carrying loads, and performing exercise. Based on the treadmill measurements a PAR value of 6·5 is therefore chosen as the average energy cost of all MHPA activities. The same PAR value is applied for all body positions, since the body position recording may be erroneous during high activity[2].

Comparison of the results of mean TEE from the ActiReg® recordings based on different RMR values (measured and estimated) and the DLW measurements shows that results based on the anthropometric data age and sex are not significantly different from the DLW values. This is likely to be due to overestimation of RMR and underestimation of PA by ActiReg® while the results based on measured RMR underestimate TEE by − 0·55 MJ on average (Table 3). The reason for the underestimation based on the measured RMR may be due to variation in variables other than pure anthropometrical data.

The mean TEE values obtained by using RMR based on FFM calculated by the Cunningham equation seriously underestimate TEE compared to $TEE_{DLW}$.

The correlation between $TEE_{AR\_Measured\_RMR}$ and $TEE_{DLW}$ (Fig. 3 (a)) and $TEE_{AR\_Mifflin\_RMR}$ and $TEE_{DLW}$ (Fig. 3 (b)) are of the same magnitude, i.e. $r^2$ 0·645 and $r^2$ 0·585, respectively. The difference between them is small also when the results based upon RMR values from the anthropometrical data and measurements are compared in Bland–Altman plots (Fig. 4). However, the limits of agreement for the measurement based upon measured RMR are narrower than for those based upon predicted RMR values. This is the most likely reason why this value is different compared to DLW. It will be seen that the mean and the standard deviation of the differences are constant throughout the range of measurements and normality tests show that the differences are evenly distributed and the linear regression line is almost parallel to the $x$-axis. A close look at the frequency distribution plot of the difference values based upon the RMR value from FFM shows that these are less evenly distributed and exhibit an increased tendency to underestimation as TEE increases (Fig. 5 (a)). This is also demonstrated by the negative trend of the linear regression. The reason for underestimation of TEE in this plot is solely due to underestimated RMR because all other calculation parameters are equal. (Measured RMR is closely correlated to body weight also in this group ($r$ 0·82) while the corresponding values for $RMR_{Cunningham\_DEXA}$ is 0·50.)

In Fig. 5 (b) the calculation has been performed using the measured RMR values but employing the calculation parameters (PAR values) for normal-weight subjects. The underestimation can be seen clearly, and in addition this underestimation increases with higher TEE. This clearly demonstrates the significant impact on TEE of the increased EE due to body weight during weight-bearing activities which are not compensated for when using the PAR values for normal-weight subjects. The only difference in this calculation compared to that in Fig. 4 (a) is the application of lower PAR values.

In conclusion, ActiReg® is a simple and cheap method to estimate TEE compared to DLW. The present study shows ActiReg® to give good estimates of mean TEE in obese subjects as validated by DLW with a mean underestimation of only 0·55 MJ. The performance of ActiReg® in obese subjects is comparable to that previously shown in normal-weight subjects[2].


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