Influence of Changes in Body Composition and Adaptive Thermogenesis on the Difference between Measured and Predicted Weight Loss in Obese Women

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Key Words

Dietary treatment · Body composition · Adaptive thermogenesis

Summary

Background: There is a difference between measured and predicted weight loss in obese patients. This might be explained by the composition of weight loss, adaptive thermogenesis, or poor compliance. **Patients and Methods:** 48 overweight and obese female patients (31.5 ± 6.1 years; BMI 35.4 ± 4.4 kg/m²) were investigated before and 13.9 ± 2.4 weeks after dietary treatment (1,000 kcal/day). Body composition was measured by air-displacement plethysmography and resting energy expenditure (REE) by indirect calorimetry. Physical activity was assessed using electronic pedometers in order to calculate total energy expenditure from REE and physical activity level (PAL). Fat mass (FM) and fat-free mass (FFM) were converted into caloric equivalents using 9.45 kcal/g FM and 1.13 kcal/g FFM. Predicted weight loss was calculated by Wishnofsky's '7,700 kcal/kg rule'. **Results:** Weight (-8.4 ± 3.9 kg; $p < 0.001$), FM (-7.8 ± 3.6 kg; $p < 0.001$), and FFM (-0.6 ± 2.0 kg; $p < 0.05$) decreased with caloric restriction. Measured weight loss was only 44% of the predicted value. Since FM contributed to 87% of weight loss, the energy deficit/kg weight loss was considerably higher ($9,098 \pm 2,349$ kcal/kg) than the assumed 7,700 kcal/kg. Adaptive thermogenesis after weight loss was significant in 26 of 48 women (-3.2 ± 1.2 kcal per kg FFM; $p < 0.001$). **Conclusion:** 14% of the difference between measured and predicted weight loss was explained by the higher proportion of FM in weight loss and 38% by adaptive thermogenesis (in 54% of the women). Thus, poor compliance was responsible for about 50% of the difference between measured and predicted weight loss only.

Introduction

Low-calorie diets (LCD) are frequently used in the treatment of obesity. In order to predict weight loss at a given energy deficit or to calculate the required energy deficit for a certain aim of weight loss, the most pervasive rule of Wishnofsky from 1952 is used [1]. Wishnofsky's rule is based on the assumption of a cumulative energy deficit of 7,700 kcal (32.2 MJ) per kg body weight loss that requires a fixed composition of weight loss, i.e. 79% fat mass (FM) and 21% fat-free mass (FFM). However, in clinical practice, the actual composition of weight loss is highly variable and the proportion of %FFM of weight loss may reach up to 53% [2]. The rate of weight loss and the effect of variations in protein intake on losses in FFM have been discussed [2, 3]. In a meta-analysis, Krieger et al. [3] had combined the results of 87 dietary intervention trials (≥ 4 weeks, $\geq 1,000$ kcal/day) and observed that protein intake was a significant predictor of FFM retention.

Measured weight loss with LCD is often less than the predicted value [4–6]. This is most frequently explained by a poor compliance of the patients, particularly because of an increase in hunger and the desire to eat during energy restriction [4, 7–9]. In addition, adaptive thermogenesis defined as reduced resting energy expenditure (REE) per kg FFM may add to the low success of weight loss interventions [5, 10]. Over the last 80 years, the presence of adaptive thermogenesis has been discussed controversially but did not attract interest in the clinical context [5]. Ravussin et al. [11] disproved the existence of adaptive thermogenesis associated with LCD, whereas other studies found an adaptive reduction in REE in response to caloric restriction in obese subjects [5, 12, 13]. However, the exact contributions of the variance in body composition, specific energy expenditure, and non-compliance to diet-induced weight loss have not been calculated.

The aim of this study was to examine the contribution of i) the composition of weight loss and ii) adaptive thermogenesis to the difference between measured and predicted weight loss. In addition, we analyzed the effect of the rate of weight loss and protein content of the diet on the composition of weight loss.

Patients and Methods

Study Design and Population

A group of 59 healthy overweight and obese women (age 32.0 ± 6.2 years; BMI 35.1 ± 4.2 kg/m²) was recruited by notice board posting and advertisement in the local newspaper for a diet-induced weight loss program. Exclusion criteria were smoking, pregnancy or breastfeeding, cardiovascular diseases, diabetes mellitus, or regularly used medications with influence on body composition or REE. Seven women (12%) dropped out because of personal reasons (3 cases) and unsuccessful weight loss (<2 kg in 6 weeks; 4 cases). Data from 4 women were excluded because the achieved weight loss was <4 kg. The remaining 48 women (22–41 years; BMI 28.6–46.5 kg/m²) were included in this study. The study protocol was approved by the local ethical committee of the Christian-Albrechts-University Kiel. Each participant provided written informed consent before participation.

During the 13.9 ± 2.4 weeks of weight loss intervention, the women consumed a low-calorie, nutritionally balanced diet (1,000 kcal/day) consisting of two meals of a formula diet (BCM®-Diät, PreCon, Darmstadt, Germany) and a low-fat meal per day. One meal of the formula diet contained 205 kcal, including 18.7 g protein, 17.4 g carbohydrates, and 6.7 g fat. The low-fat meal contained a maximum of 450 kcal and consisted mainly of vegetables and a portion size of either 100 g meat or 150 g fish. In addition, 7 'bonus' portions of 100 kcal/day each were allowed during the week. All women obtained individual counselling in the principles of the hypocaloric diet by a registered dietitian. They were also instructed to keep a daily food record to monitor the dietary composition of the low-fat meal.

Anthropometric Measurements and Body Composition Analysis

Body height was measured to the nearest 1.0 cm with a stadiometer (Seca, Vogel and Halke GmbH and Co, Hamburg, Germany). Body weight was assessed to the nearest gram by an electronic scale coupled to the BOD POD® system (Body Composition System; Life Measurement Instruments, Concord, CA, USA). Body composition (FM and FFM) was assessed by air displacement plethysmography (BOD POD®) as described elsewhere [14].

Calculation of the Energy Deficit of Weight Loss

In order to calculate the energy deficit of weight loss, losses in FM and FFM were converted into kilocalories using the caloric equivalents: 1 g FM = 9.45 kcal and 1 g FFM = 1.13 kcal, with an assumed protein content of 20% in FFM [1, 15].

Assessment of Resting and Total Energy Expenditure

Indirect calorimetry was performed using a ventilated hood system (Vmax Spectra 29n; SensorMedics; Viasys Healthcare, Bithoven, The Netherlands; software Vmax, version 12-1A) which was described elsewhere [16]. REE was adjusted for FFM (REE_{adjFFM}) according to Ravussin and Bogardus [17]. Physical activity was measured using electronic pedometers (Walking Style pro; OMRON Healthcare, Mannheim, Germany) for 25–50 days to reach a reliable estimate of daily step counts. For each woman, a physical activity level (PAL) was calculated from the mean step counts per day. Less than 5,000 steps/day were attributed to a PAL of 1.2 (sedentary activity), 5,000–7,499 steps/day to 1.5 (low activity), and 7,500–9,999 steps/day to 1.6 (slightly active) [18]. As the step counts of 10

women were missing, a PAL of 1.5 was assumed for these participants. Total energy expenditure (TEE) was calculated as the product of PAL and REE. Energy deficit was calculated from the difference between TEE and energy intake (1,000 kcal/day).

Statistical Analysis

Graphical and statistical analyses were performed using Microsoft Excel 2003 (Redmond, WA, USA) and SPSS 13.0 (Chicago, IL, USA) for Windows. All data are given as means $\pm$ standard deviation (SD). Differences were tested by paired samples t-test. Pearson's correlation was used to demonstrate the relationship between two variables. To explain the variance in losses of FFM, multiple step-wise regression analysis was performed with the following independent variables: rate of weight loss, initial body weight, and protein intake/day. $p < 0.05$ (two-sided) was considered as statistically significant.

Results

Characterization of the Study Population

Weight ($-8.4 \pm 3.6\%$), BMI ($-8.5 \pm 3.5\%$), FM ($-4.4 \pm 2.8\%$), and FFM ($-0.9 \pm 3.7\%$) significantly decreased after 13.9 ± 2.4 weeks of weight loss (table 1). Decreases in weight loss and BMI ranged from -4.0 to -16.0 kg and from -1.5 to -6.1 kg/m², respectively. FM and FFM were reduced by -1.3 to -17.6 kg and -4.0 to 2.8 kg, respectively.

Changes in Body Composition and Difference between Measured and Predicted Weight Loss

A comparison between measured weight loss and weight loss predicted by the '7,700 kcal/kg rule' [1] showed that weight loss was overestimated by the prediction (fig. 1). Measured weight loss was only 44% of the predicted value (table 2). The composition of weight loss differed from estimated values. Weight loss of 1 kg consisted of 87% FM (51–98%) and 13% FFM (2–49%) instead of estimated 79% FM and 21% FFM. The decrease in FFM correlated with the rate of weight loss (0.43 ; $p < 0.01$) and initial body weight (0.31 ; $p < 0.05$) and was inversely associated with protein intake/kg body weight (-0.30 ; $p < 0.05$). There were no associations between the decrease in FFM, initial FM at baseline, and duration of weight loss. In a multiple step-wise regression analysis, 18% of the variance in loss of FFM was explained by the rate of weight loss, whereas initial body weight and protein intake/day did

Table 1. Age and nutritional status of the study population before (T0) and after 13.9 ± 2.4 weeks of weight loss (T1) (n = 48)

	T0	T1	$\Delta T1-T0$
Age, years	31.5 ± 6.1	–	–
Height, cm	168.7 ± 8.0	–	–
Weight, kg	100.6 ± 17.6	92.2 ± 16.9	$-8.4 \pm 3.9^{***}$
BMI, kg/m ²	35.4 ± 4.4	32.2 ± 4.2	$-3.0 \pm 1.3^{***}$
FM, kg	47.6 ± 12.6	39.8 ± 15.5	$-7.8 \pm 3.6^{***}$
FFM, kg	52.9 ± 7.1	52.3 ± 6.5	$-0.6 \pm 2.0^*$

*** $p < 0.001$; * $p < 0.05$ (paired t-test).

Table 2. Daily energy deficit during weight loss as well as the comparison between predicted weight loss according to '7,700 kcal/kg rule' and measured weight loss (n = 48)

	Daily energy deficit, kcal ^a	Predicted weight loss, kg ^b	Measured weight loss, kg	Δ predicted to measured weight loss, kg
Mean ± SD	1,536 ± 399	19.27 ± 5.14	8.44 ± 3.94	10.83 ± 6.00***
Range	700–2,550	7.69–29.83	1.56–19.34	–0.62–27.43

^aEnergy deficit was calculated as the difference between total energy expenditure and daily energy intake (1,000 kcal).

^bPrediction based on '7,700 kcal/kg rule' [2].

***p < 0.001 (paired t-test).

Table 3. Comparison between weight loss according to measured energy deficit and energy deficit estimated by '7,700 kcal/kg rule' (n = 48)

	Measured energy deficit, kcal/kg	Predicted weight loss according to, kg		Δ weight loss ^b , kg
		measured energy deficit	estimated energy deficit ^a	
Mean ± SD	9,098 ± 2,349	18.3 ± 8.8	19.8 ± 6.4	–1.5 ± 6.5*
Range	3,097–16,401	7.2–30.1	7.7–29.8	–10.4 to 32.3

^aBased on the assumption that the caloric equivalent of 1 g FM is 9.45 kcal and 1 g FFM is 1.13 kcal.

^bMeasured energy deficit minus estimated energy deficit.

*p < 0.05 (paired t-test).

not significantly contribute to the model. Measured energy deficit/kg weight loss calculated from the composition of lost weight (87% FM / 13% FFM) as well as a comparison between weight loss according to measured energy deficit and energy deficit estimated by the 7,700 kcal/kg rule are shown in table 3. Measured energy deficit/kg weight loss (9,098 ± 2,349 kcal/kg) was considerably higher than the estimated value of 7,700 kcal/kg. The deviation between measured and estimated energy deficit explained 14% (1.5 ± 6.5 kg) of the difference between measured and predicted weight loss.

Adaptive Thermogenesis and Difference between Measured and Predicted Weight Loss

After weight loss, REE and REE_{adjFFM} decreased by 5.6% and TEE decreased by 5.7% (table 4). Mean step count was 6,520 ± 2,084 (2,250–10,600) steps per day corresponding to a low activity level (PAL = 1.5). After caloric restriction, a decrease in REE per kg FFM (less than –1.5 kcal/kg) was observed in 26 women (–3.2 ± 1.2 kcal/kg FFM; p < 0.001) (fig. 2). By contrast, REE per kg FFM did not change with weight loss in the other 22 women (–0.6 ± 1.4 kcal/kg; p = 0.074). Rate and composition of weight loss in the 26 women who showed an adaptive thermogenesis did not differ from those without adaptive thermogenesis (weight loss –0.60 ± 0.27 vs. –0.62 ± 0.38 kg/week; FM –7.0 ± 3.5 kg vs. –8.5 ± 3.5 kg; FFM –1.1 ± 1.8 kg vs. –0.2 ± 2.1 kg FFM). Adjusting the weight loss prediction according to Wishnofsky [1] for adaptive thermogenesis in 26 women, a significant difference between predicted and measured weight loss remained (6.4 ± 6.0 kg; p < 0.001). Thus, adaptive thermogenesis explained 38% (–4.3 ± 2.9 kg) of the difference between measured and predicted weight loss in this group of women.

Fig. 1. Comparison between measured weight loss and weight loss predicted by the '7,700 kcal/kg rule' [2] after 13.9 ± 2.4 weeks of caloric restriction (n = 48).

Discussion

The results show that body composition changes add to weight loss in response to dieting. FM was lost at a higher proportion of weight than was hypothesized in Wishnofsky's '7,700 kcal/kg rule' [1]. In the whole study population, body composition explained 14% of the difference between measured and predicted weight loss, and in 54% of the subjects adaptive thermogenesis further explained 38% of this difference. Thus, in these women, poor compliance explained 50% of the discrepancy between measured and predicted weight loss only.

Changes in Body Composition and Difference between Measured and Predicted Weight Loss

LCD are a cornerstone in the treatment of obese persons but the low efficacy of LCD limits its acceptance [1, 4]. In the present study, the composition of lost weight and adaptive

Table 4. REE, TEE, and physical activity before (T0) and after weight loss (T1) (n = 48)

	T0	T1	ΔT1-T0
REE, kcal/day	1,726 ± 220	1,635 ± 218	-92 ± 134***
REE _{adjFFM} , kcal/day	1,702 ± 198	1,623 ± 152	-79 ± 135***
Step counts, steps/day	6,520 ± 2,084	–	–
PAL	1.5 ± 0.2	–	–
TEE, kcal/day	2,537 ± 399	2,400 ± 372	-137 ± 204***

***p < 0.001 (paired t-test).

thermogenesis were analyzed since they might relate to poor success during LCD treatments. Our obese patients reached only 44% of their predicted weight loss (table 2). Similar results were reported in the review published by Heymsfield et al. [4]. These authors systematically reviewed LCD studies of non-diabetic overweight and obese subjects published in the *New England Journal of Medicine* and *JAMA* over the past 5 years. In 16 intervention studies with a duration ≥26 weeks, the average weight loss ranged from 1.7 to 8.1 kg, representing 11–45% of the predicted value. Interindividual variability in weight loss was high and ranged from 7.1 to 103.5% of the predicted value.

The weight loss rule by Wishnofsky was based on a fixed composition of weight loss (79% FM / 21% FFM) [1]. In our study, the average proportion of FM in weight loss (87%) was considerably higher than the estimated value of 79%, but the interindividual variability of the composition of weight loss was high (FM 51–98%; FFM 2–49%). The loss in FFM increased with higher initial body weight and rate of weight loss. Since a higher initial body weight reflects a higher energy requirement and thus a higher energy deficit during LCD, it was associated with the rate of weight loss as well as the loss in FFM. In agreement with these findings, Chaston et al. [2] demonstrated that dietary-induced losses in FFM increased with energy deficit and thus with the rate of weight loss. In addition, losses in FFM decreased with a higher protein intake/day (see results) because protein has been shown to be a significant predictor of FFM retention [3]. Krieger et al. [3] determined that a high protein intake of >1.05 g/kg body mass during energy restriction was associated with a greater FFM retention when compared with protein intake closer to the Recommended Dietary Allowance (RDA) (0.8 g/kg body mass). As the RDA for protein has been calculated for weight-stable conditions and isocaloric nutrition, this value is not sufficient for FFM retention during energy restriction. However, during a prolonged period of dieting, energy restriction could decrease the nitrogen balance and therefore the amount of protein and FFM retained by the body. In the present study, daily protein intake was calculated from daily food records and varied from 0.5–0.9 g protein/kg body mass which was i) below or close to the RDA for protein as well as

Fig. 2. Relationship between REE per kg FFM at baseline (T0) and during follow-up (T1); Group 1: subjects who did not show an adaptive thermogenesis (n = 22); Group 2: subjects who showed an adaptive thermogenesis (n = 26).

ii) in the range of the recommendation that was determined for FFM retention during energy restriction (>1.05 g protein/kg) [3]. Thus, during energy restriction, daily protein intake should be adjusted to achieve a high FFM retention.

Energy deficits of lost weight were significantly higher than the hypothesized 7,700 kcal due to a higher proportion of FM in weight loss (87%) (table 3). Several studies have already attempted to validate the energy content of the weight change ‘constant’ in different dietary interventions. Pietrobelli et al. [19] showed that estimated energy contents of weight change in women (7,188–7,700 kcal/kg) were close to the estimated value of 7,700 kcal/kg. By contrast, Dole et al. [25] observed a low value for the energy content of weight change (2,627 kcal) in women during 4-day over- and underfeeding. We may deduce from these results and our own data that Wishnofsky’s rule [1] is not universally applicable and should be considered cautiously. It is likely that other factors play a role in the composition of weight loss, e.g. exercise or sustained energy restriction may modify the composition of lost weight [20]. However, the difference between measured and assumed composition of weight loss explained 14% of the difference between measured and predicted weight loss only.

Adaptive Thermogenesis and Difference between Measured and Predicted Weight Loss

The significant reduction in REE_{adjFFM} after caloric restriction (table 4) supports an adaptive thermogenesis in response to decreased energy intake which has been discussed controversially in the literature for many years [5]. Astrup et al. [21] conducted a meta-analysis based on 17 studies comparing REE in formerly obese subjects and matched control persons

who had never been obese. In 13 studies, there were no significant differences between REE in formerly obese and control subjects. Only 4 studies reported a significant reduction in REE in formerly obese subjects. In another review, Major et al. [5] confirmed the existence of an adaptive thermogenesis in response to caloric restriction in obese patients. These authors also concluded that metabolic adaptations varied substantially among individuals. Individual differences in metabolic responses to weight change were also reported by Weyer et al. [12] and were in agreement with the results from the present study. Adaptive thermogenesis was found in 26 of 48 women (54%) only (-3.2 ± 1.2 kcal/kg FFM) (fig. 2). Adaptive thermogenesis is explained by neuroendocrine adaptation to caloric restriction [5], including a reduced activity of the sympathetic nervous system as well as decreased plasma concentrations of leptin and thyroid hormones [22].

Study Limitations

Body composition (FM/FFM) was measured by air-displacement plethysmography that has been shown to be a reliable technique providing precise measurements of changes in body composition in obese subjects [23]. However, increased hydration of FFM in obesity might lead to an overestimation of FM. If hydration of FFM decreases with weight loss, this would

lead to an overestimation of losses in FM [24]. A second limitation of the study was the assumption of a low activity level (PAL 1.5) for 10 patients with missing step count data. As the mean activity level of our study population was generally low (table 4), we assumed the same low PAL for the missing data.

Conclusion

In obese patients, changes in body composition and adaptive thermogenesis significantly add to the outcome of diet-induced weight loss. Since 50% of the difference between measured and predicted weight loss was not explained by the composition of weight loss or adaptive thermogenesis, poor compliance significantly contributes to the variance in weight loss.

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Disclosure

The authors declared no conflict of interest.

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