CHAPTER 17

ENERGY NEEDS AND WEIGHT MAINTENANCE IN CONTROLLED FEEDING STUDIES

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Abbreviations

AF	Activity factor
BEE	Basal energy expenditure
BMI	Body mass index
BMR	Basal metabolic rate
EE	Energy expenditure
FFM	Fat-free mass
LBM	Lean body mass
PA	Physical activity
REE	Resting energy expenditure
RMR	Resting metabolic rate
TEE	Total energy expenditure
TEF	Thermic effect of food
WHO	World Health Organization

Weight maintenance is of paramount importance in a controlled diet study, unless weight change is part of the experimental design. Because significant changes in body weight may be accompanied by changes in metabolism and/or nutritional status that alter study outcomes, care should be taken to preserve energy equilibrium throughout the study. Stability of body weight and body composition within a finite range requires energy intake and expenditure to be carefully controlled. In addition, participants must be clearly and frequently informed that the study design requires constant weight so they do not perceive the study as an opportunity to lose weight.

Typically diets are developed to be ''isocaloric'' and caloric levels are adjusted when a weight gain or loss is observed over a 4-day period (1). There is debate, however, regarding what constitutes significant weight change and whether adjustments in the overall caloric level might directly affect important factors such as body composition and/or metabolism of macronutrients, mainly fat (2, 3). This chapter discusses energy prescriptions for controlled diets; evaluation of weight changes; adjusting energy intake; and recommendations for maintenance of energy balance. (Also see Chapter 16, ''Compartmental Modeling, Stable Isotopes, and Balance Studies,'' for a discussion of laboratory-based techniques for assessing energy balance, such as doubly labeled water and calorimetry. Energy requirements for children are discussed in Chapter 9, ''Children as Participants in Feeding Studies.'')

ENERGY PRESCRIPTIONS

The concept common to metabolic studies that ''the diet must be adequate in all nutrients except those under investigation'' is especially true for energy. Fortunately, because energy is eventually reflected in body weight changes, adequacy of energy intake is more easily monitored than most nutrients. However, efforts should accurately predict energy needs initially so that adjustments in energy intake will not be necessary once the controlled diet study has begun.

There is no well-established protocol for determining when weight changes become large enough to require adjustment in calories. The literature also is not specific regarding exactly how methods are implemented. For example, a recent article reported only that ''the energy intake was adjusted so that each subject maintained his weight constant throughout the study'' (4). In a survey of persons attending a series of research methodology workshops sponsored by the American Dietetic Association (ADA) and the National Heart, Lung, and Blood Institute (NHLBI) in 1991 (''Workshop Survey''), respondents suggested a variety of approaches as summarized in this chapter. Most respondents employ predictive equations and/or food diaries along with activity factors to estimate energy needs. (See *J Am Diet Assoc,* 1992;92:156–157 for a brief summary of this workshop.)

Energy Balance Equations

$$\text{Dietary intake} = \text{Total energy expenditure (TEE)}$$

Usual dietary intake is frequently estimated by 24-hour recalls, food records, and/or food frequencies (5). Assessment of usual dietary intake can provide important information regarding food preferences, dietary patterns, and usual levels of nutrients consumed. This information can be used in the formulation of menus to increase adherence to diets that may be monotonous because of restricted food choices and frequent repetition of standard menus. Food records (generally 7 days in length) have been used to establish an individual's usual pattern of energy intake because weekly patterns in energy intake as well as other nutrients have been shown to recur (6, 7). However, food records are generally not suitable for estimating the specific caloric need for individuals because the precision of the estimate is low and because energy requirements may change under study conditions. For example, the participant's usual level of physical activity may decrease during the study. Thus, the level of energy intake for each participant is based on estimates of total energy expenditure as described next.

Total energy expenditure (TEE) measured per 24 hours consists primarily of 65% to 70% resting energy expenditure (REE), which is approximately 10% above the basal metabolic rate (BMR) or basal energy expenditure (BEE); plus 20% to 30% physical activity (PA); plus 10% to 15% thermic effect of food (TEF) (8, 9):

$$\text{TEE} = \text{REE (BEE} + 10\%) + \text{PA} + \text{TEF}$$

$$\text{REE} = 1.1 \times \text{(BEE)}$$

Predictive Equations

The basal metabolic rate (BMR) represents energy use during the inactive, stress-free, fasting state. It is measured in a thermally neutral environment, upon awakening and before eating in the morning, in subjects who are at or near energy intake for weight maintenance. Because it is difficult to meet all of these conditions, the resulting measured energy expenditure is usually referred to as the resting metabolic rate (RMR). Metabolic rates can be calculated directly from respiration chamber measurements of either heat exchange or oxygen and carbon dioxide exchange. However, less cumbersome methods are preferable; the most convenient of these use predictive equations that take advantage of readily obtained information such as age, gender, and body size.

The method most widely used to calculate basal energy needs employs the predictive equation for BEE developed by Harris and Benedict in 1919 in a population of 136 males (64 ± 10.3 kg, 27 ± 9 years) and 103 females (56.5 + 11.5 kg, 31 ± 14 years) (10).

Harris-Benedict Equations for Basal Energy Expenditure (BEE):

$$\text{Females:} = 655 + 9.46 \text{ weight (kg)} + 1.86 \text{ height (cm)} - 4.68 \text{ age (yr)}$$

$$\text{Males:} = 66.47 + 13.75 \text{ weight (kg)} + 5 \text{ height (cm)} - 6.76 \text{ age (yr)}$$

Although the Harris-Benedict equation is still used for estimating energy requirements, it reportedly overestimates REE by approximately 5% to 15% in recently studied populations (11–16). Efforts have been made to develop predictive equations that update these original Harris-Benedict equations for current populations of typical body size, composition, and levels of physical activity, while applying improved technology and equipment (indirect calorimetry). Consistently, lean body mass (LBM) has been the best predictor of REE and simplified equations have evolved predicting REE from LBM alone. However, LBM or fat-free mass (FFM) are not routinely or easily measured, which limits their use for estimating REE. Recent observations also indicate that the relative metabolic activity of the various components of FFM (ie, skeletal muscle vs organs) is not constant throughout the life span and that age-adjusted FFM should be incorporated into equations for more accurate prediction of REE (17).

The Mifflin-St Jeor equations were more recently developed on a population of 498 healthy participants, including females (n = 247) and males (n = 251) aged 19 to 78 years (45 ± 14 years), and provide a useful alternative method for calculating REE (16). The sample also included normal weight (n = 264) and obese (n = 234) individuals. Thus weight, age, and sex-specific differences were better addressed (16). Furthermore, the equations have been simplified and the inclusion of weight, height, and age account for approximately 71% of the observed variability in REE. However, the limitations of predictive equations for REE must be considered, and indirect calorimetry is recommended when it is available and affordable.

Mifflin-St Jeor Equations for
Resting Energy Expenditure (REE):

$$\text{Females: REE} = 10 \text{ weight (kg)} + 6.25 \text{ height (cm)} - 5 \text{ age (yr)} - 161$$

$$\text{Males: REE} = 10 \text{ weight (kg)} + 6.25 \text{ height (cm)} - 5 \text{ age (yr)} + 5$$

REE values for a wide range of age, height, and weight groups have been calculated using the Mifflin-St Jeor equations and are shown in Table 17-1. REE estimates obtained from this table, multiplied by a factor for activity levels, can be used to approximate TEE. Thermogenesis is not included as a separate factor in the approximation of TEE because values for REE are approximately 10% higher than values for BMR.

Source: "Well-Controlled Diet Studies in Humans, A Practical Guide to Design and Management", American Dietetic Association, © 1999.

TABLE 17-1

Predicted Resting Energy Expenditure (REE) (kcal/24 hr) by Age and Weight[1]

	Age		
Weight (lb)	**18–29 Yr**	**30–59 Yr**	**60+ Yr**
Women[2,3]			
100–109.9	1,228	1,032	1,016
110–119.9	1,274	1,078	1,062
120–129.9	1,319	1,123	1,107
130–139.9	1,365	1,168	1,153
140–149.9	1,410	1,214	1,198
150–159.9	1,455	1,259	1,243
160–169.9	1,501	1,305	1,289
170–179.9	1,546	1,350	1,334
180–189.9	1,592	1,396	1,380
190–199.9	1,637	1,441	1,425
200–209.9	1,683	1,487	1,471
210–219.9	1,728	1,532	1,516
220–229.9	1,774	1,578	1,562
230–239.9	1,819	1,623	1,607
240–249.9	1,865	1,668	1,653
250–259.9	1,910	1,714	1,698
Men[4,5]			
120–129.9	1,565	1,459	1,352
130–139.9	1,610	1,505	1,398
140–149.9	1,655	1,550	1,443
150–159.9	1,701	1,596	1,498
160–169.9	1,746	1,641	1,534
170–179.9	1,792	1,686	1,580
180–189.9	1,837	1,732	1,625
190–199.9	1,883	1,778	1,671
200–209.9	1,928	1,823	1,716
210–219.9	1,974	1,869	1,762
220–229.9	2,019	1,914	1,807
230–239.9	2,064	1,959	1,852
240–249.9	2,110	2,005	1,898
250–259.9	2,155	2,050	1,943
260–269.9	2,201	2,096	2,034
270–279.9	2,246	2,141	2,080
280–289.9	2,292	2,187	2,125
290–299.9	2,337	2,232	
300–309.9	2,383	2,278	2,171
310–319.9	2,428	2,323	2,216
320–329.9	2,474	2,369	2,262
330–339.9	2,519	2,414	2,307
340–349.9	2,564	2,459	2,352
350–359.9	2,610	2,505	2,398

[1]These values were generated using equations published in: Mifflin MD, St Jeor ST, Hill LA, et al (16).
[2]Women: Predicted REE (kcal/24 hr) = (10 × weight [kg]) + (6.25 × height [cm]) − (5 × age [yr]) − 161.
[3]Mean height values for age ranges listed here are: 65.5″ (18–29 yr); 64.5″ (30–59 yr); and 64″ (60+ yr). Mean height varies slightly in each weight range. Adjustments should be made for those taller or shorter than indicated. Values for mean height derived from data published in: St Jeor ST, ed. *Obesity Assessment: Tools, Methods, Interpretations; A Reference Case; The Reno Diet-Heart Study.* New York, NY: Chapman and Hall; 1997:629.
[4]Men: REE (kcal/24 hr) = (10 × weight [kg]) + (6.25 × height [cm]) − (5 × age [yr]) + 5.
[5]Mean height values for age ranges listed here are: 70.5″ (18–29 yr); 70.5″ (30–59 yr); and 69″ (60+ yr). Mean height varies slightly in each weight range. Adjustments should be made for those taller or shorter than indicated. Values for mean height derived from data published in: St Jeor ST, ed. *Obesity Assessment: Tools, Methods, Interpretations; A Reference Case; The Reno Diet-Heart Study.* New York, NY: Chapman and Hall; 1997:629.

Equations for predicting REE on the basis of body mass index (BMI; weight (kg) $\div$ height^2[m^2]) have also been developed using the same study population (18).

$$\text{Females: REE} = (\text{BMI} \times 28.15) - (\text{Age} \times 6.44) + 905$$

$$\text{Males: REE} = (\text{BMI} \times 28.15) - (\text{Age} \times 6.44) + 1{,}290$$

The predictive value for these BMI-based equations is favorable ($r^2 = 0.62$); they correctly classify 87% of individuals to within 300 kcal of their measured REE. Interpretation of the regression coefficients indicates an increase of +28 kcal per unit of BMI, a decrease of −6.44 kcal per year of age, and an increase of +385 kcal for males compared with females (18). REE values for a range of BMI and age groups are shown in Table 17-2.

Physical Activity (PA) and Activity Factors (AF)

Most methods for estimating total caloric need involve either increasing REE by a factor reflecting an individual's overall activity level or by assigning energy values for specific activities. For most individuals, REE is about two-thirds of total energy need, with physical activity accounting for about one-third of need. The World Health Organization (WHO) factorial method recommends dividing an individual's day into periods of sleep, light, moderate, or heavy activity and applying separate factors to BMR for number of hours spent at each activity level.

In practice, the method for allotting additional calories for activity depends on the availability of accurate information about time spent in various activities. Our survey mentioned earlier indicated that equations for predicting BEE or REE plus one overall activity factor (AF) to predict TEE or 24-hour energy expenditure were most frequently used.

The AF applied to the BEE or REE ranged from 1.3 to 1.7; some researchers also make additional adjustments in AF to account for age effects. The level of activity is generally assessed using interviews, questionnaires, and/or objective measures such as activity monitors or other tools for assessing leisure time activities. In controlled diet studies, the "usual" activity level is frequently characterized or prescribed and subjects are classified as having light, moderate, or heavy activity. Thus, the lower factor of 1.3 × REE is frequently used to reflect sedentary or light activity and is recommended for establishing the baseline TEE. Severity and duration of moderate and heavy activity can then be evaluated and expressed as additional energy expended (kcal/kg/hr) and added to the baseline TEE (l9, 20).

The commonly used WHO method for predicting energy expenditure utilizes 1.6 − 1.7 × REE for moderate activity, 1.5 − 1.6 × REE for light activity, and 1.3 × REE for a minimum level, which is defined as 10 hours a day at rest and 14 hours of light activity (such as sitting, standing, driving, typing, lab work, sewing, and cooking).

Doubly labeled water shows promise for improving predictions of energy requirements. It uses an indirect calorimetric method that measures CO_2 production by determining the difference in elimination rates of H-2 (deuterium) and O 18 from labeled body water (21, 22). (Also see Chapter 16, "Compartmental Modeling, Stable Isotopes, and Balance Studies.") Although the doubly labeled water method has received favorable attention, particularly for the assessment of free-living participants, its practical application is limited by the high cost and complex procedure involved. Reassuringly, the validity of prediction equations was reaffirmed by a recent evaluation of the WHO method in confined and free-living subjects with BMR and TEE by continuous respirometry, 4-day records of intake and activities, body weight, and urine collections (23). Agreement between measured and predicted 24-hour EE was reported within ± 2% for group results and ± 10% for individuals and was improved by an additional ± 5% when the equations used measured rather than predicted BMR. No differences were found in the 24-hour EE quotients between males and females and overall maintenance requirements were below the 1.5 × BMR generally recommended. Thus, the mean value of 1.27 × BEE for subjects in whom no physical exercise was prescribed provided an acceptable estimate of TEE in the 13 subjects (7 male and 6 females). On the other hand, the cost of physical activity has been negatively correlated with body weight and with percent body fat (24) and is most strongly associated with lean body mass (25); the increase in EE in the obese can be reflected by an overall increase in BMR (26). The obese may not be less active than normal weight subjects (27) and the same (or a slightly higher) AF × REE has been recommended.

Thermic Effect of Food (TEF)

The thermic effect of food is approximately 10% of TEE and varies with the type of food component (carbohydrate, protein, or fat) eaten. Attention has focused on the role of macronutrient composition of the diet in energy requirements (28), differential substrate oxidation (3), and the role of fat intake in obesity (29). Of particular importance is the possibility that body weight can be lost by reducing dietary fat without restricting food intake (30), and that dietary fat may play an independent role in obesity beyond dietary energy intake and balance (31, 32). The high caloric density, lower thermogenic effect, and higher metabolic efficiency of fat compared to protein and carbohydrate are thought by some to facilitate energy storage as adipose tissue (29). Others, however, do not believe that the percentage of energy from fat has any significant influence on energy requirements to maintain weight (28, 32). Clearly, more research is needed in this area; but if a defined, eucaloric diet is used, with the macronutrients remaining stable as a

TABLE 17-2

Predicted Resting Energy Expenditure (REE) (kcal/24 hr) by Age and Body Mass Index (BMI)[1]

	Age					
BMI[2] (kg/m²)	**18–29 Yr**	**30–39 Yr**	**40–49 Yr**	**50–59 Yr**	**60–69 Yr**	**70+ Yr**
Women[3]						
18	1,260	1,190	1,125	1,061	996	932
19	1,289	1,218	1,153	1,089	1,024	960
20	1,317	1,246	1,181	1,117	1,053	988
21	1,345	1,274	1,210	1,145	1,081	1,016
22	1,373	1,302	1,238	1,173	1,109	1,045
23	1,401	1,330	1,266	1,201	1,137	1,073
24	1,429	1,358	1,294	1,230	1,165	1,101
25	1,457	1,387	1,322	1,258	1,193	1,129
26	1,486	1,415	1,350	1,286	1,222	1,157
27	1,514	1,443	1,378	1,314	1,250	1,185
28	1,542	1,471	1,407	1,342	1,278	1,213
29	1,570	1,499	1,435	1,370	1,306	1,242
30	1,598	1,527	1,463	1,399	1,334	1,270
31	1,626	1,555	1,491	1,427	1,362	1,298
32	1,654	1,584	1,519	1,455	1,390	1,326
33	1,683	1,612	1,547	1,483	1,419	1,354
34	1,711	1,640	1,576	1,511	1,447	1,382
35	1,739	1,668	1,604	1,539	1,475	1,410
36	1,767	1,696	1,632	1,567	1,503	1,439
Men[4]						
18	1,645	1,575	1,510	1,446	1,381	1,317
19	1,674	1,603	1,538	1,474	1,409	1,345
20	1,702	1,631	1,566	1,502	1,438	1,373
21	1,730	1,659	1,595	1,530	1,466	1,401
22	1,758	1,687	1,623	1,558	1,494	1,430
23	1,786	1,715	1,651	1,586	1,522	1,458
24	1,814	1,743	1,679	1,615	1,550	1,486
25	1,842	1,772	1,707	1,643	1,578	1,514
26	1,871	1,800	1,735	1,671	1,607	1,542
27	1,899	1,828	1,763	1,699	1,635	1,570
28	1,927	1,856	1,792	1,727	1,663	1,598
29	1,955	1,884	1,820	1,755	1,691	1,627
30	1,983	1,912	1,848	1,784	1,719	1,655
31	2,011	1,940	1,876	1,812	1,747	1,683
32	2,039	1,969	1,904	1,840	1,775	1,711
33	2,068	1,997	1,932	1,868	1,804	1,739
34	2,096	2,025	1,961	1,896	1,832	1,767
35	2,124	2,053	1,989	1,924	1,860	1,795
36	2,152	2,081	2,017	1,952	1,888	1,824

[1]These values were generated using equations published in: Harrington ME, St Jeor ST, Silverstein LJ. Predicting Resting Energy Expenditure from Body Mass Index: Practical Applications and Limitations. Proceedings of the Annual Conference of the North American Association for the Study of Obesity, Cancun, Mexico; 1997. *J Obesity Res.* 1997;5:175,A066(suppl).
[2]Body mass index (BMI) = weight (kg) ÷ height² (m²).
[3]Women: Predicted REE (kcal/24 hr) = (BMI × 28.15) − (Age × 6.44) + 905.
[4]Men: Predicted REE (kcal/24 hr) = (BMI × 28.15) − (Age × 6.44) + 1,290.

eat right. American Dietetic Association percent of calories throughout the study period, no adjustments are currently recommended to compensate for different substrate mixtures.

Evaluation of Weight Changes

The definition of what constitutes a *significant* weight change and how to determine the *energy equivalent* of a unit of body weight is approximate at best. Researchers vary in how frequently they monitor weights of subjects consuming constant diets with some evaluating weight daily, whereas others check weight biweekly or weekly. In the NHLBI-ADA workshop survey mentioned earlier, either initial body weight or a weight range constituted the baseline weight. Respondents considered weight change to be significant when it was ± 2% or 5 lb overall, when weekly variations were 3 lb, or when there was a change of 2 lb in 3 days. When weight changes exceed the critical level, recommendations were to "raise (or lower) to the next calorie level." Although these values are expressed in a variety of ways, they revolve around 1 kg per week as the "critical" weight change, with an absolute limit of 2.25-kg weight change overall before calorie adjustments are made. The "next calorie level" was ± 250 kcal/day to 300 kcal/day reflecting an approximate energy equivalent or net balance of ± 0.45 kg/wk.

Investigators must carefully assess fluid balance. Weight changes can be easily influenced by hydration (1 L of water weighs 1 kg), so changes in diet formulation, fluid retention, bowel irregularity, minor increases in activity, and hormonal fluctuations with the menstrual cycle can cause fluctuations in body weight. Daily fluctuations in weight should be evaluated before investigators increase or decrease calories. A history of weight ranges (including highest and lowest adult body weights), weight fluctuations, usual and desired weights, and dieting history should be documented and can provide valuable insight into weight management and facilitate timely intervention.

Small weight changes should be viewed with caution because interventions of even 250 kcal can cause abnormal and unwanted changes over the course of the study. It is useful to graph or track weights (daily, weekly, monthly) because small changes can be additive and reach significance if they are not monitored over time (33). It is important to consider that day-to-day fluctuations of 0.5 kg have been commonly observed in normal subjects for a variety of reasons, but a change of 1.0 kg has been quite rare. Body weight is apparently less stable in obese subjects (34).

Dietary Techniques for Management of Weight Maintenance

The method most frequently reported in the workshop survey described earlier to correct for weight gain or loss was to introduce a "unit food" that conforms to the overall macronutrient specifications of the diet and is used to provide additional energy when needed. Unit foods are generally in the form of cookies, muffins, puddings, or other palatable and easily administered supplements to the diet and are provided in "units" of 100 kcal to 300 kcal.

An alternative method is to increase the entire diet to provide an increase in all nutrients. In this case, the gram weights of all foods are increased by the factor required to achieve the desired calorie level.

The unit food system is advantageous because menus prepared ahead require minimal change. However, several sequential increases may produce a diet with excessive quantities of the supplemented food item.

Conclusion: Recommendations for Maintenance of Energy Balance

In summary, recommendations for maintenance of energy balance in metabolic studies are:

- Use a predictive equation for energy balance supplemented with a diet and activity record to assess typical food pattern and activity level. (The Mifflin-St Jeor equation is recommended starting with a baseline activity factor (AF) of 1.3 for light activity. The same AF can be used for men and women, obese and normal weight individuals.)
- Monitor weight changes over time with graphing techniques (see Figures 17-1 and 17-2). Consider usual weight fluctuations and history of highest and lowest adult body weight, weight ranges, and desired body weight. If weight fluctuates more than 1 kg per week, the energy level of the diet should be adjusted. Caloric adjustments should occur in as small as 100-kcal increments.
- Dietary management requires patience, close monitoring, and cooperation with the participant. Dietary increases may be absolute (by unit foods to provide kcal supplements) or proportional (increase of all foods) to meet the goals of the study.

Behavioral, psychological, and environmental as well as physiological and medical factors need to be considered because they influence the delicate energy balance equation and differ from individual to individual.

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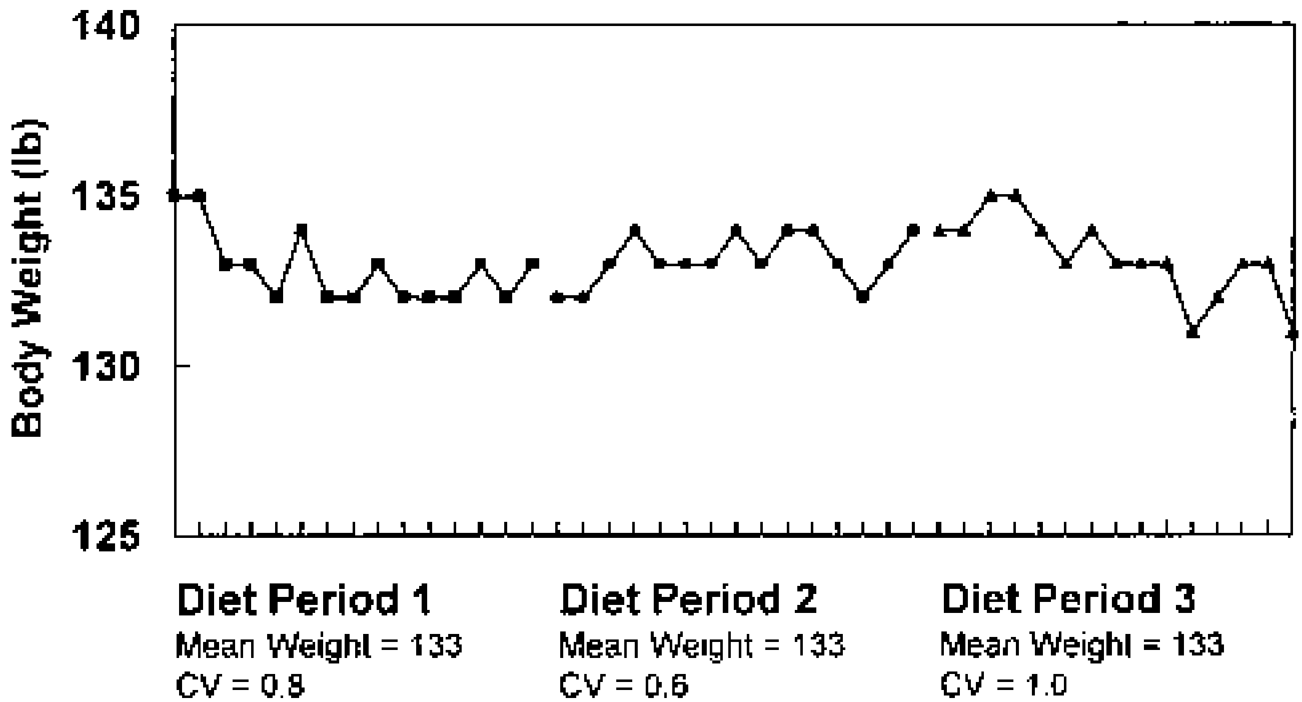

FIGURE 17-1. This controlled feeding study shows successful weight maintenance on three isocaloric diets in a 61-year-old female. Weight was measured twice weekly. Coefficient of variation (CV) = (SD ÷ Mean) × 100. All diet periods lasted 8 weeks. Break between diet periods 1 and 2 was 6 weeks. Break between diet periods 2 and 3 was 4 weeks.

Source: Courtesy of SS Jonnalagadda and PM Kris-Etherton, Nutrition Department, Pennsylvania State University, University Park, Pa.

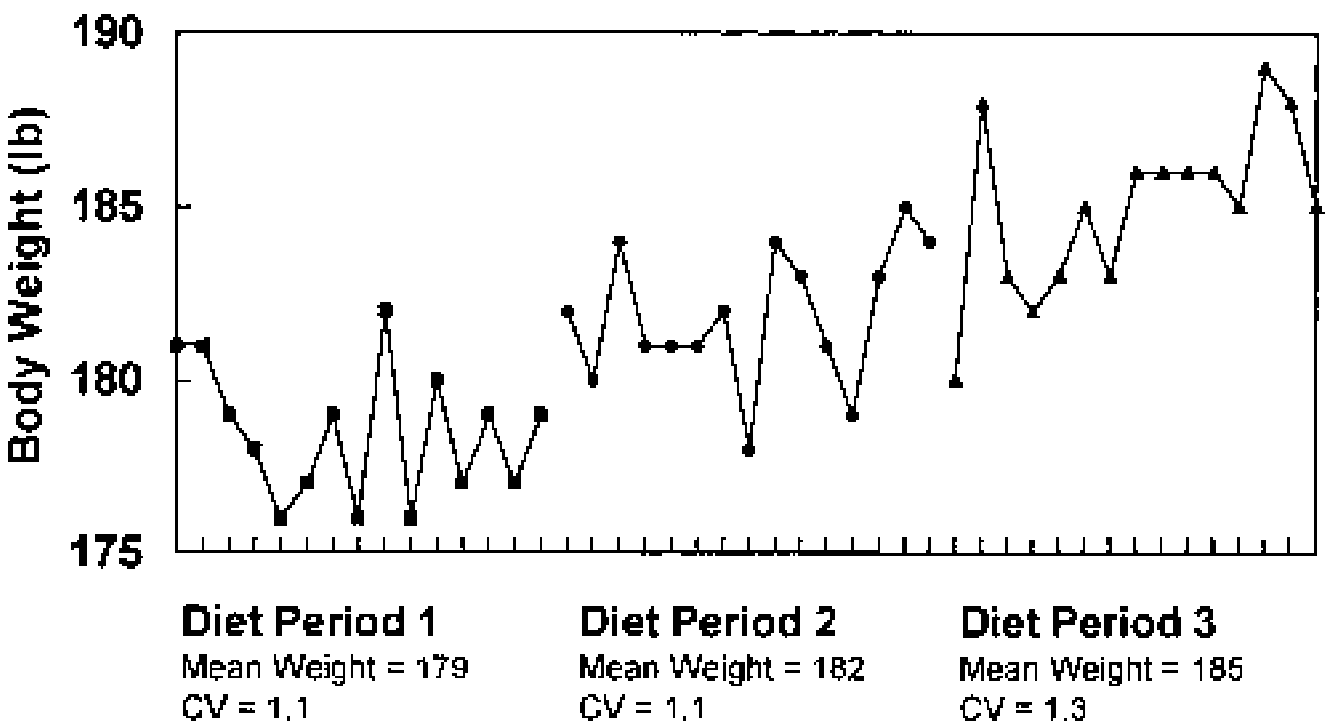

FIGURE 17-2. This controlled feeding study shows unsuccessful weight maintenance on three isocaloric diets in a 28-year-old male. Weight was measured twice weekly. Coefficient of variation (CV) = (SD ÷ Mean) × 100. All diet periods lasted 8 weeks. Break between diet periods 1 and 2 was 6 weeks. Break between diet periods 2 and 3 was 4 weeks.

Source: Courtesy of SS Jonnalagadda and PM Kris-Etherton, Nutrition Department, Pennsylvania State University, University Park, Pa.

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