Energy metabolism of overweight women before, during and after weight reduction, assessed by indirect calorimetry

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Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
in het openbaar te verdedigen
op dinsdag 12 april 1988
des namiddags te vier uur in de aula
van de Landbouwuniversiteit te Wageningen.

Aan mijn ouders

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STELLINGEN

1. Metingen van de lichamelijke activiteit zijn onmisbaar voor de interpretatie van uitkomsten van energiebalansproeven.

2. Een verlaging van de energieopname tijdens lijnperiodes lijkt samen te gaan met een verlaging van de lichamelijke activiteit.

Dit proefschrift.

3. In een studie naar 'metabolic adaptation to sustained alteration in energy intake' bij de mens, is een 3 maanden durende voedingsinterventieperiode naar alle waarschijnlijkheid te kort.

Report of a Consultative Group convened on behalf of the ACC subcommittee on Nutrition of the United Nations, 1986.

4. Gebrek aan uniformiteit in het gebruik van de energie-eenheid in voedingskundige publikaties, leidt tot het gebruik van beide eenheden (Joule / calorie) naast elkaar. De omvang van een publikatie neemt hierdoor onnodig toe en de leesbaarheid af.

5. Om af te vallen is naast minder eten, een begrijpende omgeving en een vaste wil, goede begeleiding nodig.

6. De bewering 'geen tijd' dient in vele situaties vervangen te worden door de bewering 'geen prioriteit'.

7. Uit het oogpunt van nauwkeurigheid en inzicht verdient het de voorkeur energiebehoefte te relateren aan lichaamsgewicht en vetgehalte boven aan vetvrije massa.

8. Aankondigingen over afslankvoedingen wekken te hoge verwachtingen ten aanzien van het wekelijks te bereiken gewichtsverlies, ook in het geval van de broodwisselvoeding.

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9. Met de 'Eigen Bijdragen' van de staatssecretaris van Volksgezondheid schiet de Nederlandse burger geen Deesimeter op.

10. Het is wrang dat de leertijd voor AIO's als niet produktieve arbeid wordt gezien, terwijl dezelfde leertijd voor andere categorieën van wetenschappelijk personeel als betaald werk geldt.

Volkskrant, 11 maart 1987.

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Energy metabolism of overweight women
before, during and after weight reduction,
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Wageningen, 12 april 1988.

Contents

Voorwoord

In dit proefschrift wordt een studie beschreven die deel uitmaakt van het onderzoek naar het energiemetabolisme van de mens, dat sinds 1980 op de vakgroep Dierfysiologie van de Landbouwuniversiteit te Wageningen, in nauwe samenwerking met de vakgroep Humane Voeding, wordt uitgevoerd. De beheerder van de vakgroep Dierfysiologie ben ik zeer erkentelijk voor de genoten gastvrijheid en voor het beschikbaar stellen van de outillage.

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Glossary of selected terms, abbrevations

adaptation of energy requirements: a process by which a new or different steady state is reached in response to a change or difference in the intake of energy (FAO/WHO/UNU, 1985)

basal metabolic rate: the rate of energy expenditure measured by indirect calorimetry in postabsorptive state under highly standardized conditions (at complete physical rest - immobile -,lying down, shortly after being awake; 12 h - 14 h after the last meal; awake, at sexual repose and emotionally undisturbed; without disease or fever) (Schutz, 1985)

cross-over comparison: comparison of the effects of two low-energy diets, prescribed in reverse order for each pair of women participating at the same time

digestible energy: the heat of combustion of the organic matter apparently digested, equal to energy intake minus energy in faeces

energy balance: metabolizable energy intake minus total energy expenditure

energy expenditure: heat production of a subject measured by indirect calorimetry

energy intake: energy intake representing metabolizable energy of food

gross energy: amount of heat released when a nutrient is completely oxidized in a bomb calorimeter under high O_2 pressure

maintenance energy expenditure: rate of energy expenditure measured in fed subjects with zero energy balance under conditions of daily life with little physical activity (measurements last 24h or multiples of 24h)

metabolizable energy: difference between the gross energy intake and the heat of combustion of faecal, urinary excretions and combustible gas

resting metabolic rate: rate of energy expenditure at rest measured under non-standardized conditions, i.e. not in postabsorptive state, lying down or comfortably sitting down, some hours after a meal, with possible previous activities (Schutz, 1985)

sleeping energy expenditure: the average rate of energy expenditure during normal undisturbed sleep

standardized metabolic rate: energy expenditure measured in resting conditions shortly after awakening (i.e. 14 h after the last meal) while lying down; awake; at comfortable ambient temperature

thermogenesis: increase in energy expenditure in response to various stimuli

A50/100	alternating slimming (low energy) diet: 50 % of energy need on one day, 100 % the other day
AB/100	alternating slimming (low energy) diet: bread, water, coffee, tea one day, the other day 100 % of energy need (normal diet)
AMrel	physical activity recorded by actometer, relative to the weight maintenance period
BMI	body mass index
BMR	basal metabolic rate
C50	continuous slimming (low energy)diet: every day 50 % of energy need
CO_2	carbon dioxide
d	day
DE	digestible energy
diff	difference
DIT	dietary induced thermogenesis
DMrel	physical activity recorded by Dopplermeters, relative to the weight maintenance period
EE	energy expenditure
24EE	energy expenditure over 24 h
EEca	energy expenditure during cycling above SEE and EEda
EEda	energy expenditure during daily activities, mainly sedentary, above SEE, with the exception of cycling periods
EEdiurnal	energy expenditure during daytime and evening, all activities (sitting, cycling, cooking, preparing for bed etc.) included
FFM	fat-free mass
GE	gross energy
h	hour
J	Joule
kJ	kilojoule
ME	metabolizable energy
min	minute
MJ	megajoule
mo	month
N_2	nitrogen
Nu	urinary nitrogen

O_2	oxygen
RMR	resting metabolic rate
RQ	respiratory quotient
S100	weight maintenance diet
sd (SD)	standard deviation
SE	standard error
SEE	sleeping energy expenditure
SMR	standardized metabolic rate
W	body weight
wk	week
yr	year

1. Introduction

1.1. General

In countries with a high standard of living the prevalence of overweight is considered to be high. The prevalence of moderate overweight ($25 \leq BMI < 30$ kg/m^2) and severe overweight ($BMI \geq 30$ kg/m^2) among Dutch adults was recently reported to be 34 and 4 % , respectively, in men and 24 and 6 %, respectively, in women (Seidell et al. 1986). The percentages of severe overweight in men and women in the U.S.A. are 12 % and 12 %, respectively, in the United Kingdom 6 % and 8 %, respectively, and in Australia 7 % for both sexes (Bray, 1985).

Such figures are a cause of concern because overweight is related to health hazards. Severe obesity is associated with hypertension in men and with hypertension, diabetes, varicose veins, asthma/bronchitis and haemorrhoids in women (Seidell et al. 1986).

The Body Mass Index (BMI, weight/height^2) is widely used as a measure of overweight (Garrow, 1981; Bray, 1985; Garrow, 1986;). BMI is often erroneously used to indicate body fatness. Bray (1985) distinguishes overweight from obesity as follows:

"overweight is an increase in body weight above some arbitrary standard, defined in relation to height"

"to be obese means to have an abnormally high proportion of body fat"

When health hazards are considered it is not only the total body fat but also the distribution of fat that is important (Vague, 1956; Larsson et al. 1984). Several investigators have found that abdominal fat causes a higher health risk than fat situated elsewhere (Björntorp, 1987; Seidell et al. 1985).

Whatever kind of obesity is involved, health complaints and risks tend to normalize when overweight people succeed in losing weight. Thus it is worth avoiding or reducing obesity, as this affects health positively, though it has to be recognised that retaining their good appearance is more important for many people.

There are many therapies available to reduce the amount of body fat or to prevent it increasing, including surgery, drugs, exercise, diets and behavioral treatment. Ensuring that energy expenditure exceeds energy intake is the most common and potent way. Either by increasing energy expenditure, decreasing energy intake or a combination of both, the energy balance becomes negative, which results in the utilisation of reserve tissue, mainly fat.

Unfortunately the human body reacts to a negative energy balance. The energy metabolism of individuals treated with a low-calorie diet declines and so reduces the negative energy balance. Moreover, once weight loss is achieved, it appears extremely difficult to maintain it (Bender & Bender, 1976; Saris, 1983). This might be because the reduction of energy metabolism continues after periods of low energy intake, an adaptation probably also responsible for an easy weight regain.

The reaction of people's energy metabolism to low energy intake and a way to prevent this reaction form the central theme of this thesis. If it is possible to prevent compensatory mechanisms - evoked to spare energy - becoming active, retardation of weight loss and rapid weight regain may be avoided. In this respect, alternating low and normal energy intakes from day to day was hypothesized to be a useful method.

In this study energy metabolism was examined before, during and after weight loss. To achieve weight loss alternating (low with normal) and continuous low-calorie diets were given for 4 weeks each, to test if an alternating diet was a promising therapy to fight obesity.

1.2. Adaptation of energy metabolism

Definitions, mechanisms

Keys et al. (1950) stated 38 years ago: "It might seem entirely reasonable that the energetic processes of the body diminish in intensity as the exogenous food supply is reduced .... it is reasonable in the sense that a wise man reduces his expenditures when his income is cut". In their work on the biology of starvation 'adaptation' was defined as 'a useful adjustment to altered circumstances'.

Waterlow (1985) restricts the term 'adaptation' to those physiologically-determined changes that maintain relative constancy within a definable range. Furthermore, in his opinion, physiological adaptation is characterized by four attributes: (1) every adaptation is an integration; (2) it maintains a steady state; (3) the steady state is within a 'preferred' range; (4) the adaptation is usually reversible if the environment changes. Changes in particular mechanisms of adaptation, such as enzyme activities or metabolic fluxes, can be described and analysed in terms of these attributes. However, the attributes are difficult to work with when it comes to some effects of long-term reduced energy intake, such as alteration of body height (stunting) and reduction of physical activity to essential activities. Value judgements then become involved and changes are called 'responses to environmental stress' rather than 'adaptations'.

A working definition of adaptation in the context of nutrition is given by the expert committee of the FAO/WHO/UNU in its 1985 report:

"a process by which a new or different steady state is reached in response to a change or difference in the intake of food and nutrients."

In this definition the words 'new' and 'different' are carefully chosen. The former includes short-term adaptations as occur in nutritional balance studies. The latter is appropriate only when long-term adaptations are involved, which might be the result of habitual exposure to a shortage of food supply. However, the borderline between the short term and the long term is not specified. The adaptations may be genetic, metabolic and socio-behavioral. To study genetic adaptations in humans would take many centuries. In nutritional balance studies only relatively short-term adaptations can be studied, and in the present study the 'short term' means periods of up to 2 months.

As for energy balance studies, a discrepancy in energy intake and energy expenditure may lead to three types of adaptation (fig. 1):

1. alteration of body size
2. behavioral adaptation
3. metabolic adaptation

As body size decreases the energy required for the activity of organs and tissues, for maintenance of body temperature and for the energy cost of physical activities fall concurrently. Moreover the Basal Metabolic Rate (BMR) tends to decrease more than would be expected from the weight loss (Keys et al. 1950).

According to Waterlow (1986) there are several possibilities, reflecting

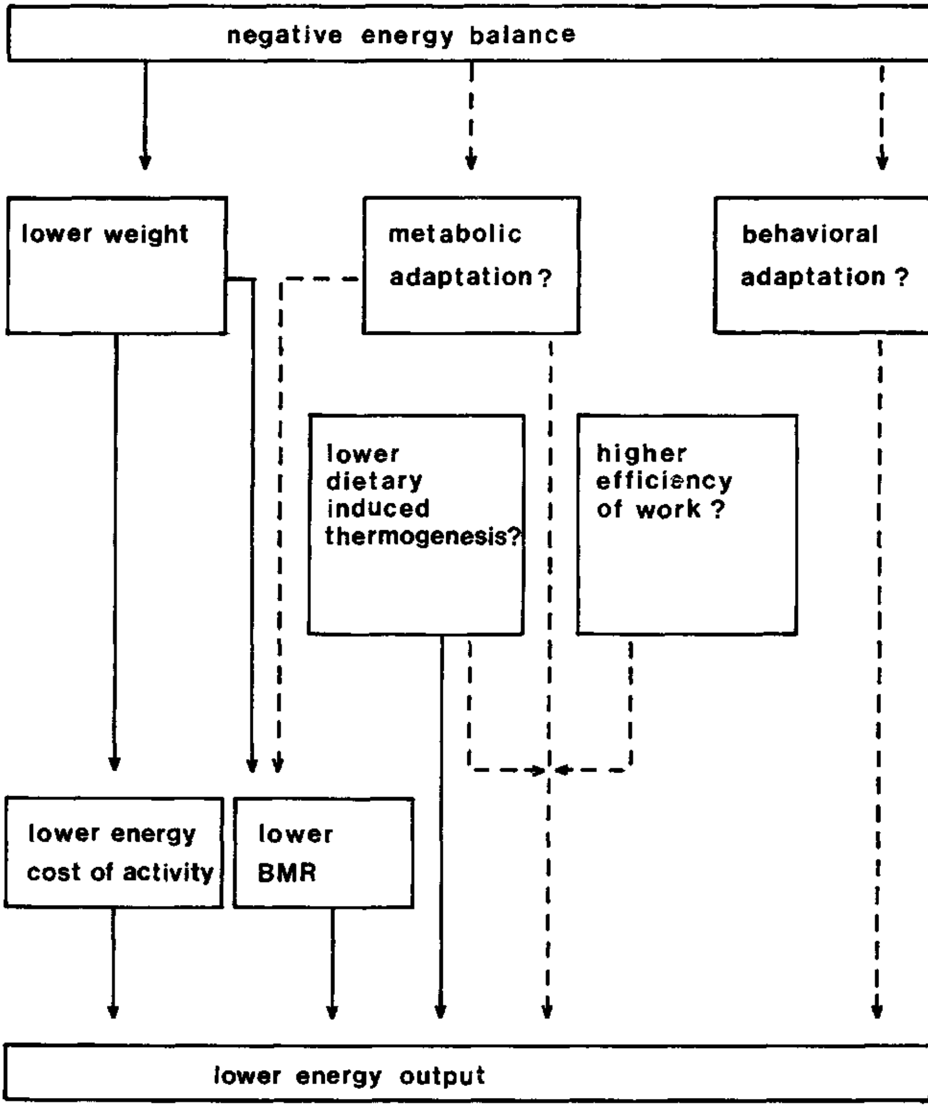


Fig. 1 Postulated factors contributing to a lowering of energy expenditure when energy balance is negative.
Thick lines indicate obvious contributions. Interrupted lines indicate contributions still in doubt.
(modified from: Ferro-Luzzi, 1985).

modification of metabolic efficiency, to account for this additional fall in BMR (though all are still hypothetical): (a) decreased work of the heart, (b) decreased rate of protein turnover, (c) decreased sodium pump activity, (d) alterations in metabolic pathways, (e) increased yield of ATP per unit oxygen used, (f) decreased substrate cycling, (g) increased efficiency in energy transduction.

It is obvious that the absolute energy cost of absorbing and processing nutrients decreases when energy intake is reduced. On average, dietary induced thermogenesis accounts for a daily energy expenditure of approximately 10 % of the caloric intake though this can vary from individual to individual (Garrow & Webster, 1985) and may be blunted for obese as compared to non-obese people (Schutz, Bessard & Jéquier, 1984). It is still unknown whether the thermogenic response to a meal decreases, stays the same or increases after weight reduction; results on this topic are contradictory (Shetty, Jung & James, 1979; Schwartz, Halter & Bierman, 1983; Bessard, Schutz & Jéquier, 1983). If a negative energy balance does result in a decrease of the thermogenic response to feeding, it is one of the mechanisms involved in increasing metabolic efficiency.

Since minor physical activities (fidgeting) are able to increase daily energy expenditure by approximately 10 % (Garrow & Webster, 1985), their reduction would make a substantial contribution to energy-sparing behavioral adaptations. Reductions in the total amount of physical activity as well as adjustments in the rate of doing work may be involved, and the metabolic efficiency could be increased by performing some physical activities in an energetically less costly way.

The mechanisms by which the metabolic rate is altered in response to a change in energy intake, may be mediated by changes in hormone metabolism. The available evidence indicates that suppression of T3-serum levels and sympathetic activity occurs in humans as well as in animals during periods of caloric restriction (Jung, Shetty & James, 1980; Landsberg & Young, 1982; Danforth, 1983; Danforth, 1985; Koppeschaar, Meinders & Schwarz, 1985). Moreover, starvation may alter tissue sensitivity to both catecholamines and thyroid hormones, and hormonal interactions are not unlikely to occur.

Measurements of adaptive changes in energy expenditure

At present no data are available on the effects of alternating low and normal energy intake on energy expenditure. In a study by van Es et al. (1984) energy metabolism was studied for 8 days at intakes below, near and above energy equilibrium. After each 8-day period the participants reverted to a normal diet for some weeks. Efficiency of metabolizable energy utilization appeared to be higher below equilibrium than above (1.0 vs 0.9). Thus there was some kind of adaptation within 7-8 days.

Alternating energy intake around the maintenance level did not affect energy requirement (de Boer, 1985). The hypothesis that alternating days of underfeeding (50 % of the energy required for weight maintenance) and overfeeding (150 %) would result in a higher energy expenditure was not supported by the results. Apparently the excess energy intake on days of overfeeding was not stored as fat to be mobilized on the subsequent day, but 'stored' in the gastro-intestinal tract or as glycogen.

Saris et al. (1986) studied an alternating diet, designed by a Dutch physician (de Vos, 1984). With this diet, called 'bread-diet', the energy intake is alternated from day to day (only bread, coffee, tea, water one day and unrestricted food intake on the other day). It was calculated that the weight losses achieved were no more than the expected weight losses would have been if based on energy intake alone. However, this study did not include any actual measurements of energy expenditure.

Whereas little or no data on intermittent energy restriction are available, numerous authors report a decline in the basal metabolic rate during fasting or permanent energy restriction (table 1). All but one report declines in the basal metabolic rate, resting metabolic rate, standardized metabolic rate or sleeping energy expenditure. The decline varied from about 6 to about 30 % according to the type of diet, the time span of energy restriction and the characteristics of studied subjects. After one day of undernutrition the standardized metabolic rate (SMR, measured from 8.30 till 9.30) was not affected (Dauncey, 1980). The slight decrease of 3 % that was observed late in the night (0.00 - 4.00 h), disappeared in the early morning (4.00 - 8.00 h). The effects of reduced energy intake on RMR probably must take several days to become established. The reduction in RMR after several days can be attributed mainly to a possible decrease in the metabolic

Table 1. Weight loss and decrease of energy expenditure

Authors	Year	Subjects		Restricted diet		Initial	Weight	Energy expenditure		
		Number	type	kJ(kcal)/d	time-span	weight	loss	basal or resting * energy expenditure	initial	% decrease
						(kg)	(kg)		(kJ(kcal) or ml/min)	%
Keys et al	1950	32	men	6570 (1570)	24 wk	69.4	16.8	basal oxygen cons.	22.8	39
Grande et al	1958	14	men	4184 (1000)	24 d	69.1	6.7	BMR	4.6 (1.1)	24
		12	men	4225 (1010)	16 d	71.6	6.2	BMR	5.1 (1.2)	20
Apfelbaum et al.	1971	18	?	920 (220)	15 d	?	?	Basal oxygen cons.	218	14
Drenick & Dennin	1973	10	men	fasting	1-2 mo	150.4	27.9	RMR	7.5 (1.8)	31
Garrow et al.	1978	15	women dieters	3347 (800)	3 wk	93.9	3.9	resting oxygen cons.	249	6
		17	women non-dieters	" "	"	94.1	5.2	" " "	265	12
Dauncey	1980	8	4 women 4 men	3703 (885)	1 d	60		SMR	4.1 (1.0)	0
Doré et al.	1982	19	women	3347 (800)	1 yr	105	30.8	resting oxygen cons.	290	19
Serog et al.	1982	14	men and women	2343 (560)	2 wk	63.5	4.5	resting oxygen cons.	227	25
Bessard et al.	1983	5	women	105(25)/kg	11 wk	85.2	12.1	BMR	5.0 (1.2)	17
Welle et al.	1984	6	women	1674 (400)	40 d	90.7	10.8	RMR	3.9 (0.9)	9
Ravussin et al.	1985	7	5 women 2 men	3360 (803)	10-16 wk	95.4	12.6	RMR	5.0 (1.2)	9
de Boer et al.	1986	12	women	4200 (1000)	8 wk	93.3	9.9	SEE	5.0 (1.2)	10
Welle & Campbell	1986	6	5 women 1 man	1757 (420)	2 wk	72-125	6.2	RMR	5.4 (1.3)	14
Barrows & Snook	1987b	15	women	2050 (490)	18 wk	85.8	19.9	RMR	4.9 (1.2)	21
Belko et al.	1987	5	women	4895 (1170)	6 wk	76.0	7.8	BMR	4.4 (1.0)	7
								24 h energy expenditure	initial	% decrease
									(kJ(kcal)/d	
Apfelbaum et al.	1971	41	?	-	-	90.9	7.3		?	15
Dauncey	1980	as above	-	-	-	-	-		7986 (1909)	6
Bessard et al.	1983	as above	-	-	-	-	-		9339 (2232)	10
Webb & Abrams	1983	11	5 men 6 women	4200 (1000)	42 d	81.9	5.9		8799 (2103)	12
Ravussin et al.	1985	as above		-	-	-	-		9819 (2347)	16
de Boer et al.	1986	as above							10520 (2514)	10

* terminology derived from original source

activity of the tissues, while in the long term the loss of the metabolically active tissue also becomes important.

When metabolic rates are expressed per unit of body weight or body fat-free mass, the results are inconclusive. Grande, Anderson & Keys (1958) found the BMR, expressed per kg body weight, to be significantly reduced by 8.7 - 14.2 %, Belko et al. (1987) did not find such a reduction. When basal metabolic rate was expressed in terms of body fat-free mass, a decline of about 11 % was found by Bessard et al. (1983) and by Barrows & Snook (1987b), not by Belko et al. (1987) nor by Ravussin et al. (1985). Unfortunately, attempts to relate changes in energy expenditure to changes in body composition are still prone to considerable error. Measurements of mean changes of fat-free mass for a group of subjects may be relatively valid, but individual values are defaced by wide standard deviations (Garrow, 1987).

The 24h energy expenditure also decreases when weight is lost. Apfelbaum, Bostsarron & Lacatis (1971) found a decrease of 15 % after a weight loss of 8 kg, and similar values were found by other investigators (Webb & Abrams, 1983; Ravussin et al. 1985). If after weight loss, a weight-maintenance diet is introduced before the final measurement of 24h energy expenditure is made, the decrease is only 10 % (Bessard et al. 1983; de Boer et al. 1986). Thus most studies have shown that there is a decrease in 24h energy expenditure after slimming. Three factors are bound to reduce energy expenditure during periods of negative energy balance: the loss of body weight and fat-free mass; the reduction in dietary induced thermogenesis when food intake diminishes; and the reduced energy cost of movement due to the decrease in weight. Some points of controversy remain: how much is the amount of spontaneous physical movement affected by weight loss and, is metabolic efficiency increased as a result of weight loss ?

If energy efficiency increases after slimming, it is likely to contribute to the often-reported easy regain in weight after slimming (Bender & Bender, 1976), but data on the persistence of metabolic adaptations are scarce. Studies from rats provide evidence that underweight rats, refed for a week, utilize food more efficiently than controls (Björntorp & Yang, 1982). For man, energy expenditure is still lowered after 1 week of refeeding (Bessard et al. 1983; de Boer et al. 1986). Metabolic adaptations may be possible in subjects exposed all their lives to low-energy intakes. In a comparison of chronically undernourished labourers with normal controls, the RMR appeared to be lowered, even when expressed per unit of body weight or lean body mass (Shetty, 1984). However it remains to be seen whether similar reductions also occur with massive weight loss and whether they persist afterwards. The results of studies that compared energy requirement of post-obese patients with those of people who had not slimmed are conflicting. Doré et al. (1982) studied 19 obese women before and after weight loss. After losing 30 kg in 1 year, the reduction in metabolic rate was no greater than could have been predicted from the weight loss. On the other hand, reduced obese patients studied by Leibel & Hirsch (1984) required lower energy intakes for weight-maintenance than control subjects, even though they still weighed 40 kg more. The observed low energy requirement in the reduced state might just as well reflect metabolic sequelae of the extreme weight loss as factors preceding obesity. Recently the latter assumption was strengtened by Geissler, Miller & Shah (1987): post-obese subjects had metabolic rates about 15 % lower than lean controls, matched by age, weight and height. However the post-obese were not studied in the pre-obese or obese state. Therefore it remains obscure whether reported differences in metabolic rates reflect intrinsic metabolic characteristics or long-lasting changes in metabolic efficiency.

1.3. Aims of the study

The aim of the study was to present a more detailed picture of energy metabolism before, during and after weight reduction, based on determinations of energy expenditure, energy intake, physical activity and changes in body composition. The study was intended to answer the following questions:

1. Does low-energy intake, continuous or alternating (low with normal), result in any alteration of body size or in any adaptations in energy metabolism or physical activity ?

2. (The main question:) does a low-energy diet, based on alternating energy intake, prevent any adaptation to low energy intake ?

3. Do any possible adaptations to low energy intake, in energy metabolism or in physical activity, persist for 1 month or 1 year after the slimming diet has ceased ?

2. Methodology

2.1. Introduction

The main aim of the study was to investigate the effects of low-energy diets, continuous or alternating daily, on energy-balance parameters. Three low-energy diets were compared in three separate studies.

- Study 1: comparison of an alternating diet, consisting of bread, water, coffee, tea only on one day, and 100 % of weight-maintenance diet on the next (diet AB/100), with a continuous diet of 50 % of the energy value of the maintenance diet (diet C50).
- Study 2: comparison of an alternating diet, consisting of 50 % of the maintenance diet on one day and 100 % of maintenance diet on the next (diet A50/100), with a continuous diet of 50 % of the energy value of the maintenance diet (diet C50).
- Study 3: comparison of the two alternating diets (diet AB/100 versus diet A50/100).

(For a detailed description of dietary regimes see section 2.4.)

Within each study ten subjects lived on each of both dietary regimes for 4 weeks. Diet comparisons were made 'within subjects' to exclude between-subject variations in energy-balance measurements. To avoid the possible effect of period of measurement, the diet order was reversed for each pair of subjects, participating at the same time. To compare energy balance data at low energy intake with analogous data at energy equilibrium, a control measurement was performed during the first week of each experiment. In follow-up studies, either approximately 1 month or 1 year after a slimming experiment, possible long-term changes in energy metabolism were studied in some of the subjects.

This chapter gives an outline of the methods used in this study. First it deals with the volunteers who participated and their selection. Next the techniques used for indirect calorimetry are described, including the assessment of physical activity. Finally, attention is paid to the various analytical and statistical procedures.

Table 2 gives an overview of the parameters measured during or after the energy balance experiments.

Table 2. Survey of parameters measured during or after the energy-balance experiments.

Energy balance	**Method**
gross energy intake (GE)	food intake for 8 days
faecal energy excretion (FE)	collection of faeces for 4 days
urinary energy excretion (UE)	collection of urine for 4 days
energy expenditure (EE)	stay in chamber for 2 or 3 days
energy retention (RE)	RE = GE - FE - UE - EE
Activity	
physical activity	actometer and Dopplermeter
Body characteristics	
body weight	
body height	
circumferences	
body composition	skinfold measurement, densitometry

2.2. Subjects

Female volunteers were selected on the basis of 4 criteria:

1. weight (overweight or obese),
2. general health (healthy),
3. age (20 to 45 years),
4. smoking habits (non-smokers preferred),

To define overweight, the body mass index (BMI) was used; which is the weight (kg) divided by the square of height (m). Subjects are considered to be overweight when this index exceeds 24.9 kg/m^2 and a body mass index above 30 kg/m^2 indicates obesity (Garrow, 1981; Bray, 1985). Despite being overweight or obese, all the participants had to be apparently healthy. Age boundaries were set at 20 and 45 to avoid adolescence as well as early menopause. Since smoking may increase energy expenditure (Dallosso & James, 1984; Hofstetter et al. 1986) 'non-smoking' was one of the selection criteria. Overweight women were recruited by means of an advertisement in local newspapers. Written information was sent to all responders about the nature and the aims of the study. Next, an introductory talk at the department and a visit to the respiration chambers was given. Responders were informed that withdrawal from participation was possible, even after a first stay of 30 hours in the respiration chamber.

In total 27 women were selected for participation. As subjects had to be available for the experiments for relatively long periods, it was not easy to find volunteers meeting all the selection criteria. All 27 women were medically reviewed by a physician, and all gave their informed consent before the start of the study. Their physical characteristics are shown in table 3. Each subject took part in at least three respiration experiments (for details see 2.3).

In the course of the study some deviations from the selection criteria appeared.

Health: One subject (subject 17) started to suffer from psychological stress (diagnosis of home physician), but she completed the experiment. Subject 2 was lightly asthmatic and therefore she used 'ventolin', a sympathicomimeticum. Some subjects suffered from other minor complaints. One woman (subject 7) had to use 'Lasix' a drug that affects water balance and induces diuresis, a few months after she stopped slimming. She still had to use the

Table 3. Initial physical characteristics of 27 women.

study		woman	age (yr)	height (m)	weight (kg)	body mass index (kg/m^2)	body fat‡ (%)
slimming study 1		1	21	1.69	71.8	25.1	33.7
		2	21	1.68	85.7	30.4	35.8
		3*†	35	1.70	79.0	27.3	38.9
		4*†	43	1.55	72.6	30.2	38.4
		5†	43	1.59	70.8	28.0	41.5
		6†	46	1.74	77.7	25.7	-
		7*†	36	1.65	73.0	26.8	32.5
		8*†	38	1.63	75.0	28.2	39.2
		26*	38	1.63	85.7	32.3	45.3
		27*	44	1.62	83.2	31.7	48.6
	Mean		36.5	1.65	77.4	28.6	39.3
	SD		8.9	0.06	5.7	2.5	5.2
slimming study 2		9*	34	1.56	67.5	27.7	35.4
		10*†	23	1.75	77.6	25.3	35.2
		11	34	1.68	95.6	33.9	39.5
		12	39	1.67	111.1	39.8	47.5
		13	39	1.69	77.0	27.0	38.5
		14	42	1.62	72.8	27.7	38.0
		15	23	1.80	99.8	30.8	39.5
		16†	44	1.74	76.8	25.4	28.2
		24*	45	1.62	79.7	30.4	42.4
		25*	36	1.64	70.8	26.3	42.8
	Mean		35.9	1.68	82.9	29.4	38.7
	SD		7.8	0.07	14.3	4.5	5.2
slimming study 3		11	35	1.68	82.7	29.3	35.4
		12	39	1.67	96.8	34.7	41.8
		15	24	1.80	87.5	27.0	36.5
		17	32	1.61	97.9	37.8	50.7
		18	38	1.63	83.5	31.4	-
		19	41	1.64	64.0	23.8	32.4
		20	41	1.64	70.4	26.2	37.2
		21	25	1.77	79.9	25.5	37.4
		22	28	1.68	107.1	37.9	54.7
		23	32	1.56	92.3	37.9	-
	Mean		33.5	1.67	86.2	31.2	40.8
	SD		6.3	0.07	13.0	5.6	7.9
All slimming studies	Mean		35.6	1.66	81.4	29.6	39.7
(n = 27)	SD		7.7	0.06	12.1	4.5	6.2
1 month follow-up	Mean		37.2	1.64	76.4	28.6	39.9
(n = 10)	SD		6.3	0.06	5.7	2.4	4.9
1 year follow-up	Mean		38.5	1.67	75.3	27.1	36.3
(n = 8)	SD		7.4	0.08	2.9	1.7	4.6

* women who participated in the 1-month follow-up study
† women who participated in the 1-year follow-up study
‡ assessed by densitometry

medicine at 3-day intervals, during a follow-up study a year later, but she did not use it during her stay in the respiration chamber. Three women were using oral contraceptives throughout the experiments.

Overweight: The BMI of subject 19 appeared to be 23.9 kg/m^2 rather than 25 kg/m^2 or more. This woman could not come to the laboratory before the start of the experiments. Calculation of BMI therefore had to be based on reported weight and height.

Non-smoking: Since one of the selected women withdrew just before the experiments started and had to be replaced quickly, a smoking woman was admitted. She was asked to smoke a fixed number of cigarettes, eight per day, before and during the months of participation.

Age: One of the women was 45 years old at the time of selection, so she was 46 in the first experiment and 47 in the last.

2.3. Design of the study

The slimming studies (fig. 2), lasted 9 weeks each. Each subject took at least part in one of the slimming studies, and three women participated in a second slimming study 3 to 4 months after their first study.

The follow-up studies (fig. 3) were performed 1 month (3 to 5 weeks) and 1 year (47 to 77 weeks) after the initial studies. Ten women participated in the 1-month follow-up study, and eight took part in the 1-year follow-up study, including five who had already participated in the 1-month study.

Energy expenditure (EE), being part of energy balance, was measured in one of the two whole-body indirect calorimeters in the Department of Animal Physiology of the Agricultural University Wageningen. Energy expenditure was measured during 72 hours at the first calorimetric session. In later measurements, when subjects were used to respiration chamber and experimental routines, the duration was reduced to 48 h. Between EE measurements the subjects lived at home on a prescribed diet; a dietician contacted them weekly.

As physical activity might vary among respiration experiments Doppler-meters and actometers were used to record movements of the subject inside the respiration chamber.

To assess the effects of slimming diets and to enable energy balance data

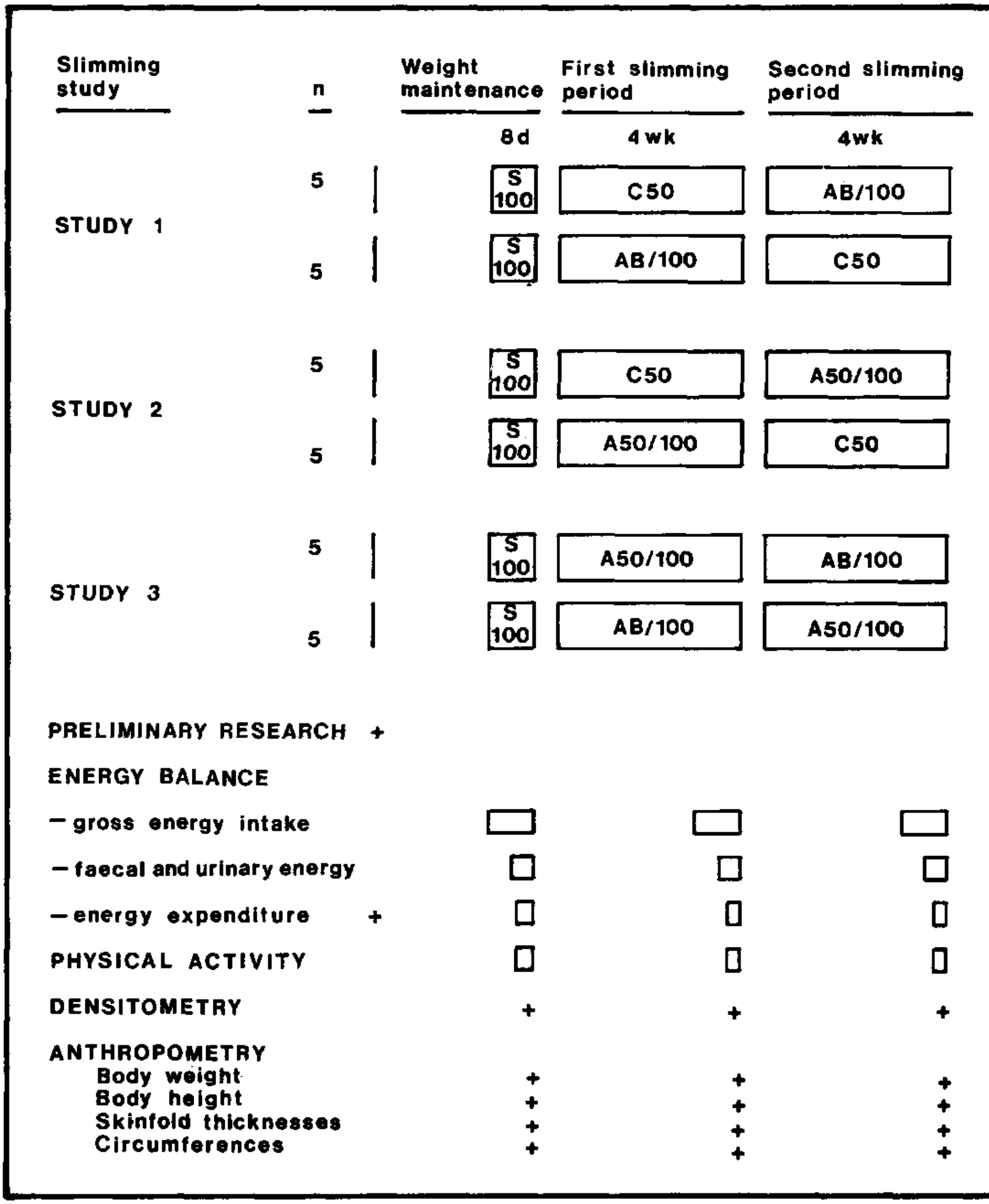


FIG. 2: DESIGN OF THE SLIMMING STUDIES

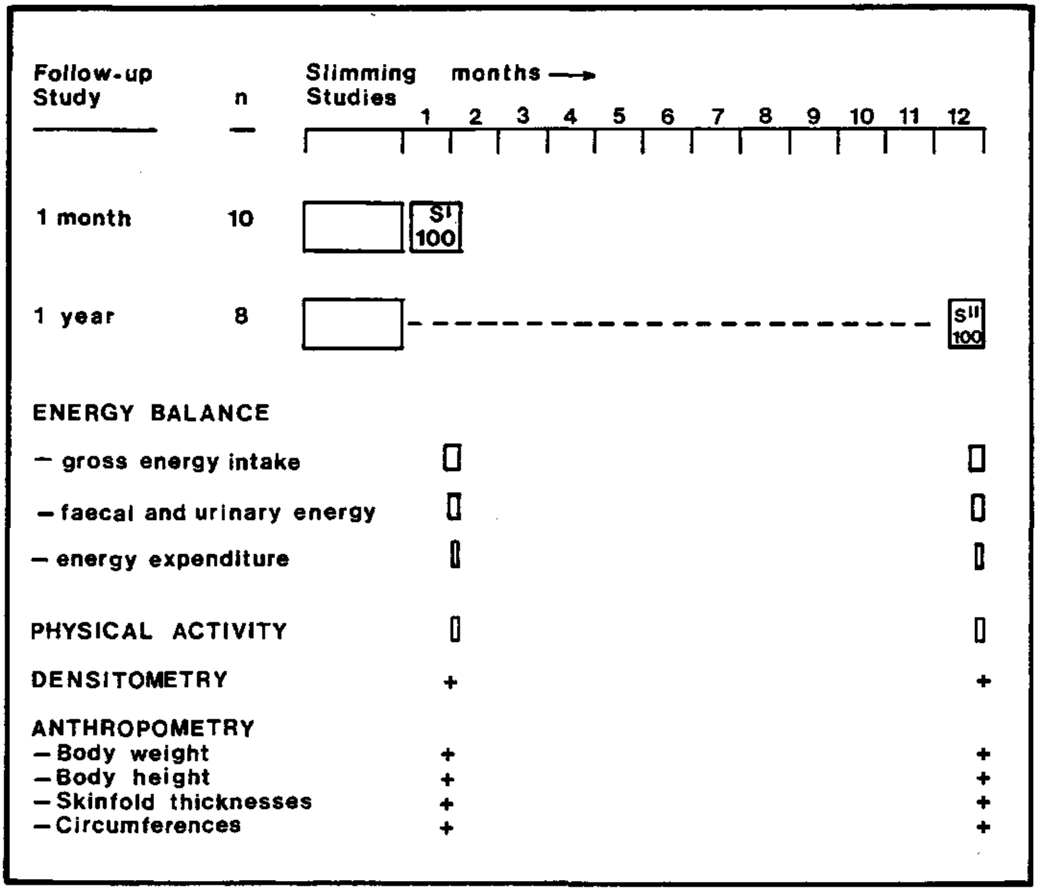


FIG. 3: DESIGN OF THE FOLLOW-UP STUDIES

to be expressed per unit weight, the height, skinfold thicknesses, circumferences and body density of each subject were measured immediately after she left the respiration chamber.

Since slimming and excessive activity may have a lasting effect on energy expenditure, subjects were asked not to indulge in either during the month preceding the study, nor to alter their normal activity pattern before and during the study. Strenuous exercise was to be avoided during the days before the energy expenditure measurements.

A few months before the slimming study, subjects spent 30 hours (the adaptation day) in the respiration chamber to familiarize themselves with the equipment. Energy expenditure was measured during 24 h (24EE, from 7.30 - 7.30). The data are not presented here but they were used to calculate energy requirements and the first weight-maintenance diet was based on the results. Shortly after the adaptation day, a dietician visited the volunteers at home. Questionnaires on dietary history, activity pattern and history of obesity were filled in. These data, together with those obtained on the adaptation day, were used to derive the slimming diets. The first energy balance was measured during 4 d on a supplied weight-maintenance diet (S100), that had also been eaten for 4 d beforehand. Faeces and urine were quantitatively collected and energy expenditure was measured for the last 72 hours. A period of 8 weeks on two different slimming diets followed immediately afterwards. Each dietary regimen was followed for 4 consecutive weeks. During the final 8 days of each diet period the slimming diet was supplied, faeces and urine were collected for the last 4 days and energy expenditure was measured for the last 48 hours. Three women, willing to continue weight reduction, were asked to take part in a second slimming experiment. Between the first and the second study they were allowed to diet for 4 weeks immediately after their first weight reduction program but for the consecutive 16 weeks their weight had to remain stable. With the exception of the diets prescribed, the second slimming experiment resembled the first.

The women willing to undergo a 1-month follow-up measurement of their energy balance, lived on a prescribed weight maintenance diet after the slimming study. This diet was designed using data on their energy expenditure that had been measured in previous experiments. For the final 8 days all food was supplied and energy losses with faeces and urine were determined during the last 4 days. Energy expenditure was measured over the last 48 h of the balance period. Some of the subjects continued to visit the laboratory regularly for advice. They wanted to keep an eye on their weight or lose some more weight. Eight of them entered a final energy-balance experiment 1 - 1.5 years after the slimming study. Previous energy-expenditure data as well as known body weight were used to calculate the diet for this follow-up study. During the months preceding the study, body weight had to remain stable.

2.4. Diets

A weight-maintenance diet (S100), 3 weight-reduction diets (C50, AB/100 and A50/100) and 2 weight-maintenance diets adjusted for weight loss (S'100, S"100) were prescribed or supplied. Prescriptions applied to the weeks of dieting at home. Diets were prepared at the department and supplied to the participants during each balance period of 8 d.

S100 (S'100, S"100): weight-maintenance diets

Experimental (supplied)

The dietary regimen for this control measurement was derived from the preliminary measurement of 24EE during the adaptation day and from the body weight. Each subject received a diet meeting her own requirement. The diet consisted of 26 foods common in Dutch diets (wholemeal bread, wholemeal biscuits, spiced cake, sugar, soy sauce, chocolate strands, coffee creamer, instant coffee, mashed potato flakes, white cabbage, cucumber, meatballs, cold sausage (four types), cheese, whole fat milk, whole fat yoghurt, custard, soft margarine, orange juice), chosen for their homogeneous composition, their ease of sampling and storage. These diets were almost the same as in earlier studies (van Es et al. 1984; van Es, de Groot & Vogt, 1986). Metabolizable energy (ME) content of the experimental diets was estimated using Dutch food composition tables (Nederlandse Voedingsmiddelen Tabel, 1981) and some earlier estimates. Of the total ME of the diets 46% was supplied by carbohydrate, 40% by fat and 14% by protein, in which respect the diets were close to the eating pattern in the Netherlands.

Coffee consumption was fixed throughout the experiment at either 3, 5 or 10 g instant coffee per day according to personal choice. Each food item was weighed out to the nearest 0.1 g using an electric scale (Sartorius, 1406 MP, Göttingen, West Germany). All food provided had to be eaten to the last bit and drop. Within the limits of the food provided, the subjects were free to plan their own breakfast, lunch and dinner. Apart from being adjusted for weight loss of the subjects, the diets S'100 and S"100 did not differ from diet S100.

C50: slimming diet, composed of normal food items, meeting half of one's energy need

Prescribed

This diet, which met 50% of the energy need as measured during the previous balance period, was prescribed for 20 days. Strict instructions were formulated by a dietician. Diet instructions, in terms of household measures of bread, fruit, meat etc., told the subjects what they should eat from day to day. A list of alternative food items was available. Thus the diet could be varied and tailored to individual preferences. Each subject received a diary in which to record any accidental departures from the prescribed diet. Subjects were taught how to weigh and record food intake. They were given modern scales, with a digital readout (Sartorius 1203 C MP 3 GMBH, Göttingen, West Germany) for use at home. During the first 3 days of each diet period they weighed and recorded all food items and drinks. This helped them to estimate the amounts of food and drinks prescribed in household measures. Though it was not asked for, subjects often weighed food after the compulsary 3 days as well. The dietician visited the subjects at home to discuss the 3-day weighed record. Later on she contacted the women weekly, either by phone or by visiting them, to check on adherence to the diets, to discuss weight losses and to keep them motivated. Weight was recorded daily on a calibrated scale (Seca optima 760, SECA, Hamburg, West Germany) and written in the diary. The diet prescribed for the first 2 slimming weeks differed somewhat from the experimental diet in the relative contributions of carbohydrate, fat and protein. To prevent substantial losses of body protein and a possible lack of micronutrients, the fractions were altered to 0.46 of total ME for carbohydrate, 0.31 for fat and 0.23 for protein. Average daily ME intake of this diet ranged from 3.6 MJ to 6.3 MJ. Six days before the experimental diet started, fractions of macronutrients were changed to 0.46, 0.40 and 0.14 of total ME for carbohydrates, fat and protein respectively; food consumption was recorded for 1 day to become familiar with the newly prescribed dietary regimen. A multivitamin preparation (Dagravit totaal 30, Dagra N.V. Diemen, Holland) was also supplied until the end of this slimming period.

Experimental (supplied)

The C50 and S100 diets were prepared from the same food items in the same proportions. Thus the relative contributions of carbohydrate, fat and protein to total metabolizable energy was also the same, so that the results would be comparable to those of van Es et al. (1984, 1986) and de Boer et al. (1986, 1987). All food provided during the experimental period was eaten to the last bit and drop. To prevent any deficiency of micronutrients, one vitamin capsule (Dagravit totaal 30, Dagra N.V. Diemen, Holland) a day (0.59 g; 7.7 kJ gross energy per g) was supplied.

AB/100: slimming diet based on alternating energy intake, providing 100% of the energy need one day and only bread, coffee, water and tea the other day

Prescribed

This diet is a modification of the so-called 'bread diet' popular in the Netherlands, especially in the years 1984 and 1985 (de Vos, 1984). This diet alternates intake daily. One day (bread day) only wholemeal wheat bread, water, coffee and tea are allowed. The other day (the free day) dietary intake is ad libitum. Anything may be consumed freely. In our study a modification was necessary to prevent a positive energy balance during the free day. Therefore energy intake on this day was limited to energy needs. Diet instructions, designed by a dietician, stipulated on the quantity and the nature of permitted food items. In this way a strict regimen for the 'free day' was prescribed; 0.46 of the ME was derived from carbohydrate 0.40 from fat and 0.14 from protein. In the beginning of the diet period bread consumption was free. Later on, once they were accustomed to a certain amount of bread, subjects were asked to stick to their own fixed number of slices of bread a day. Neither vitamins nor mineral supplements were given.

Adherence to the diet was checked by a dietician.

Experimental (supplied)

The diet on the 'free days' was in fact not free at all; it consisted of the same food items as the maintenance diet (S100) and was identical in every respect. For the 'bread days', bread was supplied according to the reported bread consumption. One of the participating women appeared to be unable to consume wholemeal wheat bread. In her case wheat bread was replaced by black (rye) bread. Average daily ME intake of the diet amounted from 5.1 to 6.9 MJ; on the bread day from 140 to 420 g of bread was eaten.

A50/100: alternating weight-reduction diet meeting 50% of the energy need one day and 100% of the energy need the other day

Prescribed

As with the C50 and AB/100 diets, the guidelines were designed to ensure that the subjects adhered to their diet as closely as possible. The guidelines for a 50% day were different from those for a 100% day. Metabolizable energy intake was twice as high on the 100% day, as on the 50% day. A dietician checked on adherence to the diet, and the body weight was recorded daily in the diary.

Experimental (supplied)

The experimental A50/100 diet resembled the prescribed diet. Diet composition was again limited to 26 ingredients. Protein, fat and carbohydrate contributed 0.14, 0.40 and 0.46 of the metabolizable energy, respectively. Daily ME intake of this diet varied from 5.5 MJ to 8.3 MJ.

2.5. Faecal and urinary energy

Urine and faeces were collected quantitatively over the last 4 days of each balance period. Urine was collected in 1 litre plastic bottles using mercury iodide as a preservative. Faeces were collected in bags of thin PVC and these were temporarily stored in buckets of hard PVC. Urine and faeces were stored at $5^{o}C$ during the collection period. From pooled 4-day specimens of urine and freeze-dried faeces, aliquots were taken for determination of nitrogen content. Urine samples, dried in vacuo at room temperature, and freeze-dried faeces samples were analysed for gross energy.

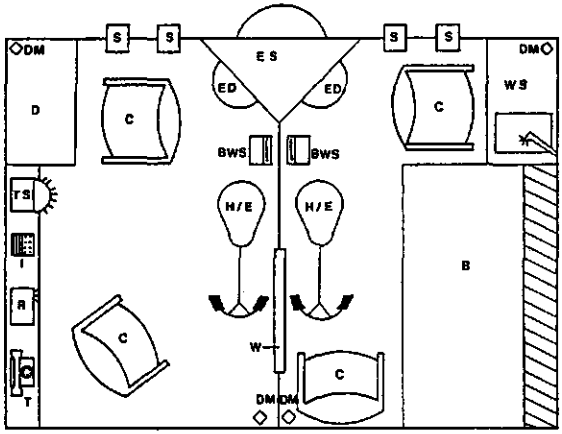
2.6. Indirect calorimetry and physical activity

General

Two open-circuit respiration chambers were used simultaneously (fig. 4). The chambers, formerly used for animal experiments, were converted into hotel-like rooms in 1980 and are now equipped with a bed, an easy chair, a cycle-ergometer (a bicycle home-trainer till August 1986), a washstand convertible into a writing desk, a desk-chair convertible into a toilet-chair, a telephone set, radio, television and an intercom. Two airlocks serve as an inlet for food and papers and as an outlet for faeces, urine and refuse. Subjects living in the adjoining rooms could see each other through a large window in the common wall. They could speak with each other, with 'outsiders' and with the caretaking staff by the intercom. Always during the experiments both chambers were occupied.

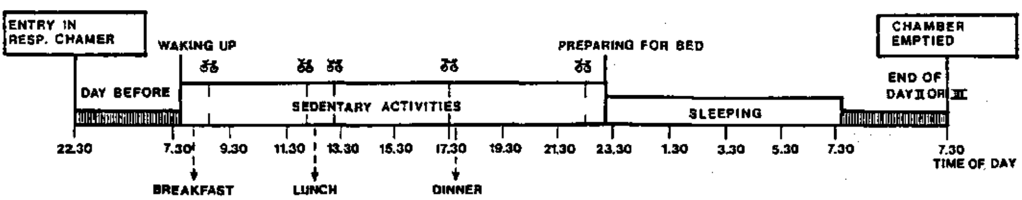
Fig. 5 gives the time-schedule of a respiration experiment. Participants came to the laboratory the evening preceding the energy expenditure measurement. They entered the calorimeter at approximately 22.30. After an overnight stay they were awakened at 7.45. Daily activity pattern was standardized. It was meant to simulate light housekeeping or work at an office. Each morning after awakening actometer counts (see later), body temperature and body weight - without clothes, after voiding (scale: SECA 708, SECA, Hamburg, West Germany) - were recorded in a diary. Meals for the whole day were supplied in the morning and stored in a cool box in the chamber. The three meals were consumed at fixed hours (8.15, 12.30 and 18.00). Subjects were free to take the hot meal either at lunch - or at dinner-time.

Five times a day the subject mounted the ergometer (Lode RH 32, Groningen, Holland) to cycle for 15 minutes at a load of 15 Watt (50 revolutions per minute). Before each cycling period the actometer was removed from the right ankle. Its hours and minutes were read and recorded in the diary. After cycling the actometer was reattached and again actometer



B — bed (folding bed)
BWS — body weight scale
C — chair
D — desk
DM — dopplermeter
ED — entrance door
ES — entrance sluice
H/E — hometrainer/ergometer
I — intercom
R — radio
S — sluices
T — telephone
TS — television set
W — window
WS — washstand

FIG. 4 INTERIOR OF THE CALORIMETERS (de BOER; 1985).



TIME :	ACTIVITIES :
7.45	RISE AFTER CALL (TROUGH INTERCOM)
	RECORDING OF ACTOMETER TIME, BODY WEIGHT, BODY TEMPERATURE
8.00 – 8.15	SUPPLY OF FOOD AND MORNING PAPER
8.15 – 8.45	BREAKFAST
8.45 – 9.00	CYCLING ON HOMETRAINER: VELOCITY 24 km/h OR ERGOMETER LOAD 15W, 50RPM
	RECORDING ACTOMETER TIME
9.00 – 12.15	SEDENTARY ACTIVITIES; BREAK FOR COFFEE, TEA, CAKE, COOKIES
12.15 – 12.30	CYCLING; RECORDING ACTOMETER TIME
12.30 – 13.15	LUNCH
13.15 – 13.30	CYCLING; RECORDING ACTOMETER TIME
13.30 – 17.30	SEDENTARY ACTIVITIES; BREAK FOR COFFEE, TEA, CAKE, COOKIES
17.30 – 17.45	CYCLING; RECORDING ACTOMETER TIME
17.45 – 19.00	DINNER PREPARATION, DINNER
19.00 – 22.30	SEDENTARY ACTIVITIES; BREAK WITH COFFEE, TEA
22.30 – 22.45	CYCLING; RECORDING ACTOMETER TIME
22.45	PREPARING FOR BED; RECORDING BODY WEIGHT, BODY TEMPERATURE, ACTOMETER TIME
23.15	IN BED

Fig. 5 Time and occupation schedule for each calorimetric session.

readings were recorded. During the rest of the day only limited activity, mainly sedentary, was allowed. Usually subjects were reading, knitting, sewing or writing and went occasionally to the desk, radio and telephone.

At 22.45 the subject had to prepare for bed, to ensure lying down at 23.15. Just before going to bed body weight, body temperature and actometer time had to be recorded. A diary was supplied to record body weight, body temperature, actometer time, occupations, possible disturbances during sleep, phase of menstrual cycle, state of well being and eating pattern in the chamber.

The chamber temperature was set at 21-23^{o}C from 07.30 till 22.30 and was lowered by 2 degrees during the night. The relative humidity was kept at about 70%. Subjects wore their own clothes. The room temperature was increased or decreased slightly if the subjects during their first session felt uncomfortable after adjustment of clothes, but no further changes were made.

For safety's sake, alarms for power-failure, fire, abnormal rise of chamber temperature and high carbon dioxide content of chamber air were installed. Alarms were connected with an alarm-peeper (Multimaster, 8550, Vellema telefoon efficiency BV, Haarlem, Holland) taken along by one of the employees. Apart from the fire alarm, alarm rings would only be heard outside the calorimeters. In case of fire subjects were instructed to flee; they could open the exit door, and there was also an emergency exit.

During the whole study a subject occupied the same respiration chamber.

Measurement of energy expenditure

Gas exchange measurements started at 07.30 in the morning and ended at 07.30 the next day. Immediately afterwards the next measurement over 24 hours started. Two air suction pumps drew air from each chamber, the volume of which was measured by a small dry gasmeter. The speed was set at a constant level for each session. The body weight of the chamber occupant determined speed selection; a speed resulting in a CO_2 content of 0.7% by volume, was aimed at. Air speed could vary from 40 to 60 liters per minute. The suction resulted in a slight underpressure within the chambers, preventing any loss of air in other ways than through the outlet pipe. Two systems analysed the composition of the in- and outgoing air independently (fig. 6). Composite samples, collected over 24 hours, as well as continuous air

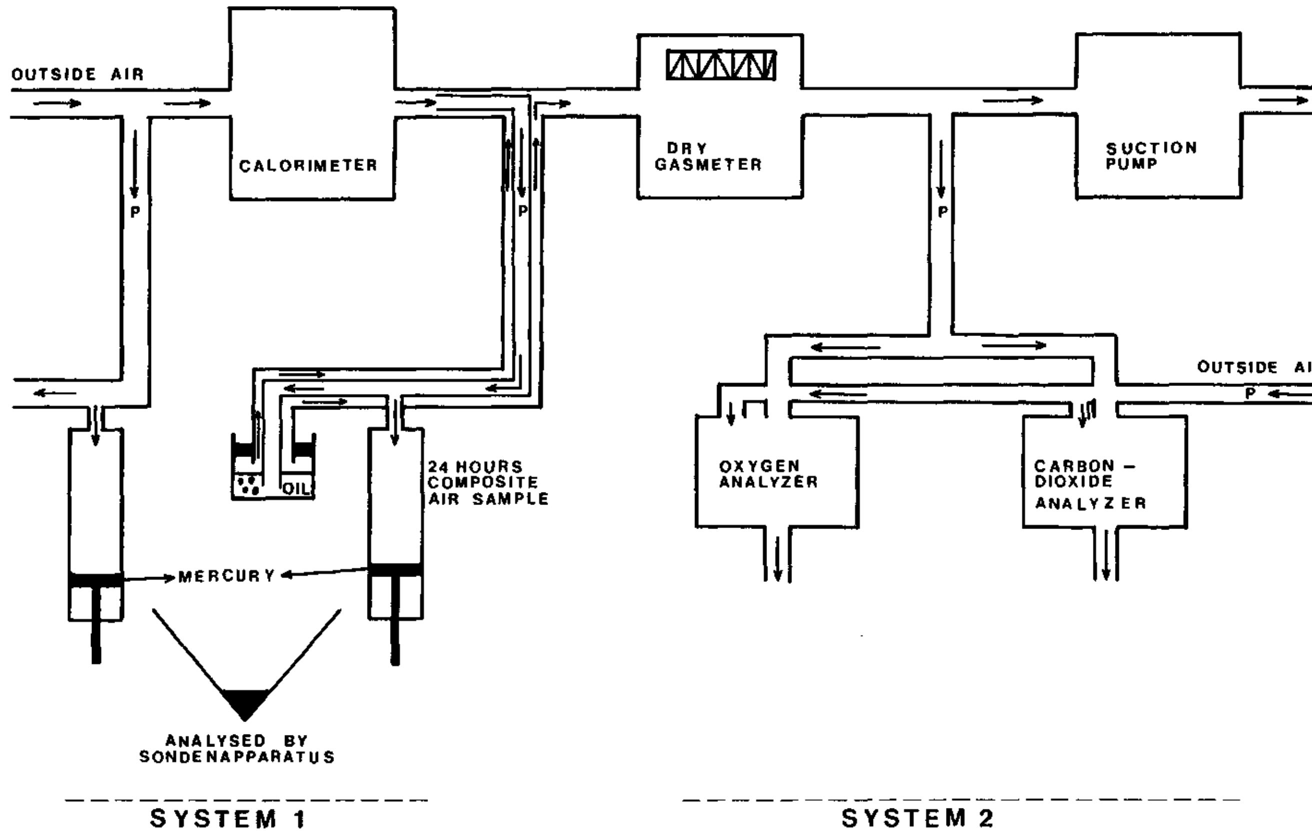


Fig. 6 Outline of gas flow and systems used in the analysis for oxygen and carbon dioxide. P indicates pumps that draw air samples from the main stream to the systems for analysis.

samples were analysed as follows:

Just before the outgoing air reached the gasmeter, small samples were withdrawn and collected in duplicate in glass tubes (of 1 m length and 2.5 liter content) over mercury. A composite sample of ingoing air was collected as well. The three composite samples were analysed volumetrically with a Sonden apparatus (van Es, 1958). The results were used to calculate mean oxygen consumption and mean carbondioxide production over 24 hours.

Samples of in- and outgoing air were analysed continuously and the results were recorded. Samples, withdrawn after the main stream passed the gasmeters, were analysed by a paramagnetic O_2-analyser (Servomex 540A, Servomex Ltd Crowborough, Sussex, England) and an infrared CO_2-analyser (Servomex PSA 402, Servomex Ltd, Crowborough, Sussex, England or TPA 311, Telsec Process Analyses Ltd, Peterborough, England). Ingoing air was analysed every 3 h. Air leaving the two respiration chambers was analysed continuously, alternating between chambers every 10 minutes. The response time of this analysing system was approximately 3 minutes. From these data the EE was calculated for successive half-hour periods, taking into account volume and composition of ingoing, outgoing and chamber air.

Barometric pressure, dry and wet temperature of the air in the chambers as well as the temperature of the air passing the gasmeters, were recorded continuously. Measured gas flow was adjusted to standard conditions (STDP: 0 ^{o}C, barometric pressure of 760 mm Hg, dry air).

The daily energy expenditure was calculated using Brouwer's equation (Brouwer, 1965) from the oxygen consumption, carbon dioxide production and urinary nitrogen excretion:

$$EE\ (kJ) = 16.175 * O_2 + 5.021 * CO_2 - 5.987 * Nu,$$

where EE = energy expenditure, kJ/d
O_2 = O_2 consumption, l (STDP)/d
CO_2 = CO_2 production, l (STDP)/d
Nu = urinary N excretion, g/d

Urinary N excretion was neglected when EE was calculated for one specific day only or for shorter periods.

The dry gas meters were calibrated before and after each calorimetric session. A Blakeslee piston pump with mercury seals was used for this purpose. The piston pump, in its turn, was calibrated before, after and between the slimming studies, using a calibrated wet gasmeter (van Es, 1961). The O_2 and CO_2 analysers were calibrated each session, using the composite samples analysed by Sonden apparatus. The O_2 and CO_2 content of fresh outdoor air served to check analyses of the Sonden apparatus. Total respiration equipment was checked by burning alcohol inside the chambers for 24 h. Recoveries of introduced alcohol were 99.6 ± 0.4% (sd) and 99.5 ± 0.8% for oxygen in the two chambers. CO_2 recoveries were slightly lower, being 98.7 ± 0.6% for one calorimeter and 99.0 ± 0.6% for the other.

Energy expenditure had to be adjusted for cigarette smoking during the respiration experiment, as one of the participants smoked eight cigarettes daily. Assuming tobacco to consist of carbohydrates only, the oxygen consumption as well as carbondioxide production could be calculated, after the heat of combustion of cigarette samples had been determined by bomb calorimetry. One gram of tobacco had a gross energy content of 14.7 kJ, with calculated gasexchange of + 0.69 l for CO_2 and -0.69 l for O_2.

Physical activity

Physical activity of the subjects was monitored by two Dopplermeters and one actometer but only during the stay in the respiration chamber (Saris & Binkhorst, 1977; Schutz et al, 1982).

Dopplermeters

Each respiration chamber was equipped with two Dopplermeters (Radar, MD5, Sutter Electronic AG, Thün, Switzerland). Apart from the 'prescribed' activities, such as lunching and cycling, subjects were free to perform activities of a sedentary nature. All activity was monitored by the Dopplermeters continuously and inconspiciously. The Dopplermeters were installed in two corners of the respiration chamber, opposite to each other. Doppler counts were combined, unless output of one of both units was invalid or missing. The Doppler unit emits a radar signal into the chamber. Every movement within the field of the unit changes the phase of the reflected electromagnetic waves, which is detected by a radar receiver. The sensitivity of the receiver was set at a fixed 'quantitatively unknown' level. A data acquisition system records the deloading frequency of the receiver condensator and thus gives an index of the amount of spontaneous physical activity of a subject living in the respiration chamber. The amount of energy needed to make the movements is not detected, thus only fairly coarse information on physical activity is obtained. Air turbulence, noise, changes in temperature and radio interference do not cause Doppler effects.

In the course of the study some factors appeared to affect correct measurements:

- Fluctuations in the mains voltage interfered during the first experiments. This disturbance was excluded by changing the power supply to one of the Doppler units.
- The angle of suspension of the radar unit appeared to be of importance. This angle must be kept constant if reproducibility of the measurements is essential. A change of angle results in a change of Doppler counts.
- Emitted waves could probably be reflected and changed by the movements of the wings of the fan, fixed to the ceiling inside the chamber. Reflecting surfaces, e.g. the handlebar of the ergometer, the water-tap, might assist the Doppler unit to detect movements. Therefore a small alumina-foil platelet was fixed slightly below the fan wings, during the final experiments.

Doppler counts recorded during the night were examined to assess the occurrence of disturbance. When night counts were above zero, and no sleepless nights were reported, false measurement by the radar unit due to interference was assumed to be the case, and those measurements were excluded from further analysis.

Actometer

A normal, automatically-winding wrist watch (Tussot, Switzerland) was adapted to measure physical activity (Saris & Binkhorst, 1977), by removing the escapement mechanism to connect the rotor directly to the hand. Whenever the watch was moved in the plane of its face, acceleration and deceleration were recorded. The results were expressed as hours and minutes (actometer units). The date indication facilitated counting the actometer units, because, like the date on a normal watch, the actometer date increased by 1 day unit when the small hand of the watch had made two complete rotations.

The actometer measured both the amount and the intensity of movement. It was fixed above the right ankle with the face of the watch on the inner-side of the leg.

Actometer readings (date, time) were recorded 12 times a day: immediately after rising, before and after each cycling session and just before going to bed. One had to wear the actometer during the night and during the day, except for the cycling sessions, since the date changed so often during cycling that the results could readily be misinterpreted. Before cycling the actometer was removed. After cycling it was fixed to the right ankle again. Each time a subject participated in a respiration experiment she wore the same actometer.

2.7. Analyses in food, excreta and cigarettes

Most foods and excreta required some pretreatment before analysis. Samples of bread and spiced cake were dried first at 70°C in a forced drying oven and ground after 1 to 2 days through a sieve with apertures of 1 mm diameter. Wet samples (vegetables, rice, faeces) were freeze-dried before grinding. Fluids (milk, orange juice, yoghurt, custard, soy sauce, urine) and margarine were sampled in small polyethylene bags. The fluids were dried in vacuo at room temperature. Samples of cheese, minced meat and sausage - all containing a substantial amount of fat - were mixed with silicagel powder (SiO_2, Gasil 23D) before homogenization. Samples of ground whole wheat cookies, ground cigarettes, chocolate strands, non-dairy coffee creamer,instant coffee and mashed potato flakes did not need further treatment before analysis.

The dry matter of foods and excreta was determined using weight loss on drying at 70°C or freeze drying, plus weight loss on further drying at 101°C for 4 hours. Heat of combustion was determined using a static bomb calorimeter (Record, Julius Peters, Berlin, West-Germany). Heat of combustion of the samples, weighed and analyzed in polyethylene bags, was adjusted for the heat of combustion of the bag.

The nitrogen content of food and excreta was determined by the Kjeldahl method (International Organization for Standardization, 1979) using mercury oxide as a catalyst.

Gross energy and N intake were calculated by multiplying the weight of foods provided with the assessed energy and nitrogen content. Analyses in faeces and urine were used to calculate digestibility and metabolizability.

2.8 Anthropometry and body composition

After each respiration experiment body characteristics were assessed. All measurements were made by the same trained research assistant.

Anthropometry

Weight was measured on a beam balance (calibrated to 0.05 kg) with the woman wearing minimum clothing. **Height** was taken with the woman standing against a wall, to which a flexible tape was fixed. Height was read out to the nearest 0.1 cm. **Circumferences** of body and limbs were measured at 5 sites. All cirumference readings were taken to the nearest 0.1 cm using a plastic measuring tape. **Arm-circumference** was taken midway between the shoulder-tip and the elbow. The **calf** was measured at its widest site. Body circumferences were measured at the following levels: smallest **waist** circumference, greatest **hip** circumference and greatest **thigh** circumference. **Skinfold thickness** was measured at four sites: biceps, triceps, suprailiaca, subscapula (Holtain caliper, Holtain LTD, CRYMYCH, U.K.).

All measurements were done with the subjects standing upright. Body fat was calculated from these data using the equations of Durnin & Womersley (1974).

Densitometry

Body volume was assessed by weighing under water, with a correction for lung volume by He dilution. The percentage fat was derived from body density using Siri's equation (1956). Two subjects could not be weighed under water because they were too afraid of total immersion.

2.9. Analysis of results

Treatment of daily energy expenditure data

From the continuous measurements of respiratory gas exchange, the EE was computed for periods of various length. Thus the 24 hour EE could also be partitioned into a diurnal (7.30 - 23.30) and a nocturnal part (23.30-7.30). These values were not corrected for protein oxidation as was the case for 24EE, but this correction was small, on average only 0.6 % of the 24 EE.

EE during the night is considered to be similar to the basal metabolic rate if evidence of sleep is available (Bessard et al. 1983; Schutz et al. 1984a). Data on physical activity were combined with EE data to adjust nighttime EE to zero activity, to obtain sleeping EE values (SEE). If activity peaks during the night were perceived by the Doppler units and if those coincided with EE peaks, the affected period of 30 min was not used for SEE calculation. In this way nocturnal EE was lowered by an average of 2.1 %.

The EE during daytime was partitioned somewhat artificially into EE values during two distinct activities (de Boer et al. 1987):

1) EE due to sedentary activities, defined as the difference between EE during sedentary activities and the EE due to sleeping (EEda: including all light diurnal activities except cycling, such as reading, working, preparing for bed)

2) EE due to bicycling, defined as the difference between the EE during bicycling and the sum of EE due to sleeping and sedentary activities (EEca).

Statistics

The results obtained from the slimming studies are presented as mean (with SD) for each subgroup of five women who received the same two diets in the same order (see fig. 2, design of the study). Diet effects were evaluated in two different ways.

To test differences between the weight-maintenance period and the first slimming period, the results of the studies were combined to obtain groups of 10 women, submitted to the same diet.

The paired t-test was used to test differences within subjects. To compare the effects of the different slimming diets in the first slimming period, the within-subject differences were analysed by performing one-way analysis of variance. Only if the analysis of variance showed a significant difference, was the 'least significant difference' (LSD) method used ($p<0.05$) to compare group (diet) means.

Secondly, for each slimming study, diet effects were compared within subjects, using the cross-over design described by Hills & Armitrage (1979). Mean differences were calculated for each subgroup from the individual differences of five women receiving the diets in the same order.
The average difference of both subgroups of five women was used to estimate the difference in diet-effects. The standard deviations of the differences within each subgroup were pooled to calculate a single estimate of the standard error of the difference to be tested. Thus diet order was taken into account when the data were analysed.

For the follow-up studies statistical differences were assessed by the paired t-test.

Computations were performed using the Statistical Package for the Social Sciences X (SPSSX, 1986).

Individual data are described in appendices A - H.

2.10. Ethics

The protocol of the study was approved by the ethical committee of the Department of Human Nutrition of the Agricultural University.

3. Results

Most of the data in this chapter are group means; separate data for each subject may be found in annexes A - H. Each time first attention is paid to the slimming studies and next to the follow-up studies.

3.1 Energy intake

Slimming studies: Tables 4, 4A and 4B show the gross energy intake and metabolizable energy intake throughout the slimming studies, as well as the digestibility and metabolizability of the diets. Intakes of gross energy and metabolizable energy on the slimming diets were substantially lower than similar intakes on the weight maintenance diet (S100), as table 4A shows. Metabolizable energy intake in the first slimming period averaged 4.9, 6.0, 7.2 MJ/d for C50, AB/100, A50/100 respectively. Those values represent 50 % (C50), 62 % (AB/100) and 73 % (A50/100) of the weight maintenance intake.

After 4 weeks of slimming digestibility and metabolizability of the slimming diets were not different from each other nor from the weight maintenance diet except that the digestibility for AB/100 was slightly lower than that for S100 (table 4A).

In the cross-over comparison of energy intake (table 4B) during slimming the gross energy intakes as well as the metabolizable energy intakes were significantly different for all comparisons. Digestibility and metabolizability once again were almost equal. No period effects were observed. The highest percentages for digestibility and metabolizability were found with A50/100.

Table 5 gives the energy intake and the mean composition of the diets, as calculated from a Dutch nutrient database, UCV (Hautvast, 1975). The calculated metabolizable energy intake was a few % higher than the ME intake measured from the gross energy content of the food and the faecal and urinary energy losses. Protein, fat and carbohydrate contributed to approximately 14 %, 41 % and 45 % to the energy content of the diets, respectively, but for the slimming diet AB/100 the relative contribution of

Table 4. Gross energy intake (GE), metabolizable energy intake (ME), digestibility (% DE) and metabolizability (% ME) throughout the slimming studies.

slimming study	dietary regimen			n	GE			ME			% DE			% ME		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
						(MJ/d)			(MJ/d)			(%)			(%)	
Study 1	S100	C50	AB/100	5	11.1	5.6	6.5	9.6	4.9	5.7	91.4	93.2	92.5	87.3	88.2	87.9
					(1.7)	(0.9)	(0.9)	(1.5)	(0.8)	(0.8)	(3.0)	(2.2)	(1.9)	(3.0)	(2.2)	(2.1)
	S100	AB/100	C50	5	11.0	6.8	5.2	9.7	5.9	4.6	92.7	90.7	92.6	88.9	86.3	87.9
					(0.9)	(1.0)	(0.4)	(0.8)	(0.8)	(0.3)	(1.1)	(0.9)	(2.7)	(0.9)	(0.9)	(2.3)
Study 2	S100	C50	A50/100	5	11.1	5.5	7.3	10.0	4.8	6.5	93.1	93.0	93.7	89.3	87.8	89.8
					(1.4)	(0.6)	(1.0)	(1.2)	(0.6)	(0.9)	(0.8)	(3.3)	(1.9)	(1.3)	(4.2)	(1.9)
	S100	A50/100	C50	5	10.8	7.7	4.9	9.7	6.9	4.2	94.0	92.5	91.0	90.3	89.6	85.7
					(0.9)	(0.7)	(0.4)	(0.8)	(0.7)	(0.4)	(1.6)	(1.8)	(1.5)	(1.3)	(2.1)	(1.4)
Study 3	S100	A50/100	AB/100	5	11.1	8.4	6.4	9.9	7.5	5.5	92.8	93.2	90.7	89.0	90.0	86.2
					(0.9)	(0.7)	(0.5)	(0.8)	(0.6)	(0.5)	(1.7)	(1.5)	(4.8)	(1.4)	(2.1)	(4.5)
	S100	AB/100	A50/100	5	10.8	6.9	7.1	9.6	6.2	6.5	93.5	93.3	95.2	89.6	89.5	91.1
					(0.5)	(0.6)	(0.3)	(0.5)	(0.6)	(0.1)	(0.9)	(1.3)	(2.5)	(0.8)	(1.1)	(2.5)

results expressed as means (sd)

Table 4A. Gross energy intake (GE), metabolizable energy intake (ME), digestibility (% DE) and metabolizability (% ME) before slimming (week 1) and in the last week of the first slimming period (week 5).

dietary regimen		n	GE			ME			% DE			% ME		
wk 1	wk 5		wk 1	wk 5	diff	wk 1	wk 5	diff	wk 1	wk 5	diff	wk 1	wk 5	diff
				(MJ/d)			(MJ/d)			(%)			(%)	
S100	C50	10	11.1	5.5	-5.6†	9.8	4.9	-4.9†	92.2	93.1	0.9 [a]	88.3	88.0	-0.3[b]
			(1.5)	(0.7)	(0.8)	(1.3)	(0.7)	(0.7)	(2.2)	(2.7)	(2.6)	(2.4)	(3.2)	(2.8)
S100	AB/100	10	10.9	6.9	-4.0†	9.7	6.0	-3.6†	93.1	92.1	-1.0*[a]	89.3	87.9	-1.3[b]
			(0.7)	(0.8)	(0.4)	(0.7)	(0.7)	(0.4)	(1.0)	(1.7)	(1.3)	(0.9)	(2.0)	(1.6)
S100	A50/100	10	11.0	8.0	-2.9†	9.8	7.2	-2.6†	93.3	93.2	-0.2 [a]	89.6	89.7	0.1[b]
			(0.8)	(0.7)	(0.6)	(0.7)	(0.7)	(0.7)	(1.6)	(1.5)	(2.0)	(1.5)	(1.9)	(2.6)

results expressed as means (sd)

values with similar superscripts (a, b) in the same column are not significantly different (one-way analysis of variance, $p<0.05$)

* significantly different from zero (paired t-test, $p<0.05$)

† significantly different from zero (paired t-test, $p<0.001$)

Table 4B. Gross energy intake (GE), metabolizable energy intake (ME), digestibility (% DE) and metabolizability (% ME) in the last week of each slimming period for the three slimming studies.

slimming study	n		GE			ME			% DE			% ME		
			(MJ/d)			(MJ/d)			%			%		
Study 1	10		C50	AB/100	diff	C50	AB/100	diff	C50	AB/100	diff	C50	AB/100	diff
		Mean	5.4	6.7	1.3*	4.7	5.8	+1.1*	92.9	91.6	-1.3	87.8	87.1	-0.7
		SE			0.1			0.1			0.7			0.7
Study 2	10		C50	A50/100	diff	C50	A50/100	diff	C50	A50/100	diff	C50	A50/100	diff
		Mean	5.2	7.5	2.3*	4.5	6.7	+2.2*	92.0	93.4	+1.4	86.8	89.7	+2.9
		SE			0.1			0.2			1.3			1.4
Study 3	10		A50/100	AB/100	diff	A50/100	AB/100	diff	A50/100	AB/100	diff	A50/100	AB/100	diff
		Mean	7.7	6.7	-1.1*	7.0	5.9	-1.1*	94.2	92.0	-2.2	90.5	87.9	-2.6
		SE			0.1			0.2			1.3			1.4

standard error of difference is obtained from the pooled estimate of the standard deviation of the difference (see chapter 2)

* significantly different from zero ($p<0.001$).

Table 5. Composition of the experimental diets.

Diet	S100	C50	AB/100	A50/100	S'100*	S''100*
Number of women	30	20	19	20	10	8
Metabolizable energy intake (MJ/d)	10.1	4.9	6.0	7.1	8.2	8.6
	(0.9)	(0.6)	(0.6)	(0.8)	(0.5)	(0.8)
Protein (% ME)	13.3	13.8	13.4	13.4	13.4	13.3
	(0.2)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)
animal protein (g)	48.1	23.9	23.2	33.7	39.0	40.8
	(4.8)	(3.8)	(2.5)	(3.7)	(2.3)	(3.6)
vegetable protein (g)	32.0	17.0	24.7	23.5	26.7	27.9
	(3.0)	(2.2)	(2.5)	(2.6)	(1.7)	(2.5)
Fat (% ME)	41.3	41.1	34.8	41.1	41.0	41.4
	(0.4)	(0.7)	(1.5)	(0.5)	(0.6)	(0.6)
saturated fatty acids (g)	46.5	21.4	23.4	31.8	37.2	39.3
	(4.8)	(3.5)	(2.6)	(3.9)	(2.5)	(3.8)
mono-unsaturated fatty acids (g)	31.7	14.9	15.0	21.8	24.8	26.4
	(3.2)	(2.3)	(1.7)	(2.8)	(2.3)	(2.5)
poly-unsaturated fatty acids (g)	24.2	12.7	12.9	17.8	20.6	22.6
	(1.9)	(1.6)	(1.1)	(1.4)	(1.4)	(1.6)
Carbohydrates (% ME)	45.2	45.0	51.7	45.3	45.4	45.2
	(0.7)	(0.9)	(1.5)	(0.5)	(0.6)	(0.6)
sugars (g)	117.0	68.1	58.8	86.1	96.1	96.9
	(13.2)	(7.1)	(7.6)	(10.9)	(6.7)	(11.6)
polysaccharides (g)	156.0	64.7	126.5	106.2	127.5	136.5
	(15.1)	(10.3)	(19.0)	(13.0)	(9.6)	(13.4)
Dietary fiber (g)	32.4	17.6	26.8	24.3	27.8	29.2
	(3.0)	(2.0)	(4.1)	(2.5)	(2.2)	(2.7)
Calcium (mg)	1586	824	788	1123	1288	134
	(178)	(123)	(92)	(133)	(87)	(150)
Iron (haem) (mg)	1.7	0.9	0.8	1.2	1.5	1.5
	(0.2)	(0.1)	(0.1)	(0.2)	(0.2)	(0.2)
Iron (non-haem) (mg)	11.2	5.9	8.7	8.2	9.2	9.7
	(1.3)	(0.7)	(1.2)	(1.0)	(0.8)	(1.0)
Food mass (g)	1776	1236	1005	1424	1525	1543
	(151)	(101)	(94)	(125)	(74)	(126)

means (sd) based on individual average food intake over 8 days and nutrient values from a Dutch Computerized Food Composition table (Hautvast, 1975)

* weight maintenance diets adjusted for weight loss, prescribed in the follow-up studies: 1 month follow-up (S'100) 1 year follow-up (S"100)

carbohydrates was, as expected, higher: 52 %, and the relative contribution of fat was therefore 35 % instead of 41 % as for the other diets. This higher contribution of carbohydrate was caused by the diet prescriptions that did not allow for food other than bread on one of the two alternating days. Mean bread consumption on the 'bread day' was 7.4 ± 2.3 slices (range: 4-12), or 259 ± 81 g.

Follow-up studies: Table 6 shows a significantly increased energy intake after slimming, during the follow-up studies. For the women in the 1-month follow-up study the mean energy intake was 5.1 MJ/d in the last week of the slimming study and 8.0 MJ/d in the final week of the follow-up period. For the women in the 1-year follow-up study mean energy intake was 5.0 MJ/d in the last week of slimming and 8.4 MJ/d in the final week of the follow-up period.

By comparing follow-up values with baseline values it is obvious that the former values were significantly lower. As expected, in both studies the energy intake expressed per kg body weight (about 127 kJ/kg.d) was the same before slimming and in the final week of the follow-up period, since weight changes were taken into account when the maintenance diets for the follow-up studies were designed.

The relative contributions of protein, fat and carbohydrate to ME intake were 13 %, 41 % and 45 % respectively.

3.2 Body weight and fat-free mass

Slimming studies: The gradual decline of body weight and fat-free mass throughout the slimming studies may be seen in table 7. Over the first 4 weeks of slimming (table 7A) the mean body weight decreased significantly by 5.8±0.9 kg (C50), 4.5±0.6 kg (AB/100) and 3.9±1.3 kg (A50/100). Rates of weight loss were on average 1.4 kg/week, 1.1 kg/week and 1.0 kg/week, respectively. The slimming diet C50 resulted in a significantly higher weight loss than both alternating diets. An on average similar amount of fat-free mass was lost: 1.6±1.5 kg (C50), 1.8±1.0 kg (AB/100) and 2.6±2.4 kg (A50/100), representing 27 %, 39 % and 65 % of the body weight loss, respectively.

Table 6. Metabolizable energy intake (ME) before slimming (week 1) and after slimming (week 9) and in the final week of the follow-up studies (1 month and 1 year after the end of slimming).

follow-up study	dietary regimen			n	ME	wk 1	wk 9	follow -up	follow- up - wk 1	follow- up - wk 9
	wk 1	wk 9	follow-up							
1 month*	S100	slimming diets‡	S'100	10	MJ/d	9.6	5.1	8.0	-1.6‖	2.8‖
						(1.1)	(1.0)	(0.5)	(0.8)	(1.0)
					kJ/kg.d	126	76	127	1.7	50.8‖
						(14)	(17)	(12)	(9.0)	(13.0)
1 year†	S100	slimming diets§	S''100	8	MJ/d	9.7	5.0	8.4	-1.3‖	3.4‖
						(1.1)	(1.0)	(0.8)	(0.6)	(0.5)
					kJ/kg.d	129	75	126	-2.5	51.1‖
						(12)	(13)	(8)	(8.0)	(10.0)

results expressed as means (sd)

* measured for 8 days, starting on average in wk 13 (range 12-14)

† measured for 8 days, starting on average in wk 75 (range 56-86)

‡ 5 subjects on diet C50, 3 on AB/100 and 2 on A50/100

§ 5 subjects on diet C50, 3 on AB/100 and none on A50/100

‖ significantly different from zero (paired t-test, $p<0.001$)

Table 7. Body weight and fat-free mass throughout the slimming studies.

slimming study	dietary regimen			n	body weight			fat-free mass*		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
						(kg)			(kg)	
Study 1	S100	C50	AB/100	5	77.3	71.7	68.4	46.0[1]	45.5	44.0
					(4.3)	(4.9)	(5.2)	(2.5)	(1.3)	(2.0)
	S100	AB/100	C50	5	77.6	73.0	68.5	47.5	45.4	43.7
					(7.5)	(7.6)	(7.2)	(5.1)	(5.4)	(5.1)
Study 2	S100	C50	A50/100	5	86.2	80.2	77.0	50.1	49.0[1]	47.4
					(18.6)	(18.2)	(17.6)	(8.5)	(8.8)	(8.0)
	S100	A50/100	C50	5	79.6	75.3	70.0	50.2	48.5[1]	46.0
					(9.4)	(8.3)	(7.3)	(6.8)	(3.5)	(6.5)
Study 3	S100	A50/100	AB/100	5	83.4	79.8	76.1	48.8[1]	47.8[1]	47.0[1]
					(15.4)	(15.1)	(15.2)	(4.2)	(3.4)	(3.8)
	S100	AB/100	A50/100	5	89.0	84.6	82.5	51.1[1]	49.7[1]	50.4[1]
					(11.2)	(10.9)	(10.8)	(5.9)	(4.6)	(5.5)

results expressed as means (sd)

* derived from densitometry

1 one missing value

Table 7A. Body weight and fat-free mass before slimming (week 1) and in the last week of the first slimming period (week 5).

dietary regimen		n	body weight			fat-free mass		
wk 1	wk 5		wk 1	wk 5	diff	wk 1	wk 5	diff
				(kg)			(kg)	
S100	C50	10	81.8 (13.5)	76.0 (13.3)	5.8* (0.9)	48.6[2] (6.9)	47.0[2] (6.1)	1.6[b]† (1.5)
S100	AB/100	10	83.3 (10.8)	78.8 (10.8)	4.5[a]* (0.6)	49.1[1] (5.4)	47.3[1] (5.3)	1.8[b]* (1.0)
S100	A50/100	10	81.5 (12.2)	77.6 (3.9)	3.9[a]* (1.3)	50.7[2] (4.6)	48.1[2] (3.4)	2.6[b]† (2.4)

results expressed as means (sd)
values with similar superscripts (a, b) in the same column are not significantly different (one-way analysis of variance, $p<0.05$)
1 one missing value
2 two missing values
* significantly different from zero (paired t-test, $p<0.001$)
† significantly different from zero (paired t-test, $p<0.05$)

In the second slimming period the rate of weight loss was slightly less: 1.2 kg/week (C50: 4.9±0.9 kg over 4 weeks), 0.9 kg/week (AB/100: 3.5±0.7 kg over 4 weeks) and 0.7 kg/week (A50/100: 2.6±1.0 kg over 4 weeks). Approximately 34 % of this loss was due to a loss fat-free mass with the diets C50 and AB/100 but with the diet A50/100 the loss in fat-free mass was negligible during the second slimming period.

Subjects participating in slimming study 1 reduced weight by 9.0±0.4 kg (1.1 kg/week) over 8 weeks. This weight loss was composed of 66 % fat mass and 34 % fat-free mass. With the slimming diets C50 and A50/100 (study 2) the body weight decreased by 9.4±0.6 kg (1.2 kg/week), of which 5.2 kg was fat and 4.2 kg (45 % of the weight loss) was fat-free mass. In study 3 (diets A50/100, AB/100) body weight decreased by 6.9±0.4 kg (0.9 kg/week), 82 % of which was fat mass and 18 % was fat-free mass.

Follow-up studies: Table 8 shows the mean body weights and fat-free masses before and after slimming, and in the final week of the follow-up periods. In the 1-month follow-up study the mean body weight was 9.9±1.8 kg lower than the initial body weight (76.4±5.7 kg), and 1.1 kg of this loss in weight (0.6 kg of it fat-free mass) occurred after the end of slimming.

At 1-year follow-up, body weight and fat-free mass were still lower (by 8.7±1.6 kg and 4.8±3.4 kg, respectively) than the initial values, and the body weight was only slightly higher (0.6±1.8 kg) than it was at the end of slimming, thus the weight loss achieved by 8 weeks of slimming was maintained throughout the following year. (The 1-month and 1-year follow-up values had to be compared with different initial values because the subjects were not all the same.)

3.3. Energy expenditure

The time course of 24 hour energy expenditure (24EE) for one of the subjects, as measured before slimming, is shown in fig 7. On average for all subjects, the sleeping energy expenditure, extrapolated over the whole day, accounted for 66 % of the daily energy expenditure. The additional cost of sedentary activities and bicycling amounted to 29 % and 5 % of 24EE (n=27, before slimming).

Table 8. Body weight and fat-free mass before slimming (week 1) and after slimming (week 9) and in the final week of the follow-up periods (at 1 month and 1 year respectively).

follow-up study	wk 1	wk 9	follow-up	follow-up - wk 1	follow-up - wk 9
1 month (n=10)					
body weight (kg)	76.4 (5.7)	67.6 (6.0)	66.5 (6.5)	-9.9† (1.8)	-1.1† (0.6)
fat-free mass (kg)	45.8 (3.0)	42.6 (2.8)	43.2 (2.8)	-2.6† (1.4)	0.6* (0.8)
1 year (n=8)					
body weight (kg)	75.3 (2.9)	66.0 (2.9)	66.6 (3.7)	-8.7† (1.6)	0.6 (1.8)
fat-free mass (kg)	47.8[1] (4.4)	43.9 (3.1)	43.5 (4.3)	-4.8[1]* (3.4)	-0.4 (2.3)

results expressed as means (sd)

fat-free mass derived from densitometry

1 one missing value

* significantly different from zero (paired t-test, $p<0.05$)

† significantly different from zero (paired t-test, $p<0.001$)

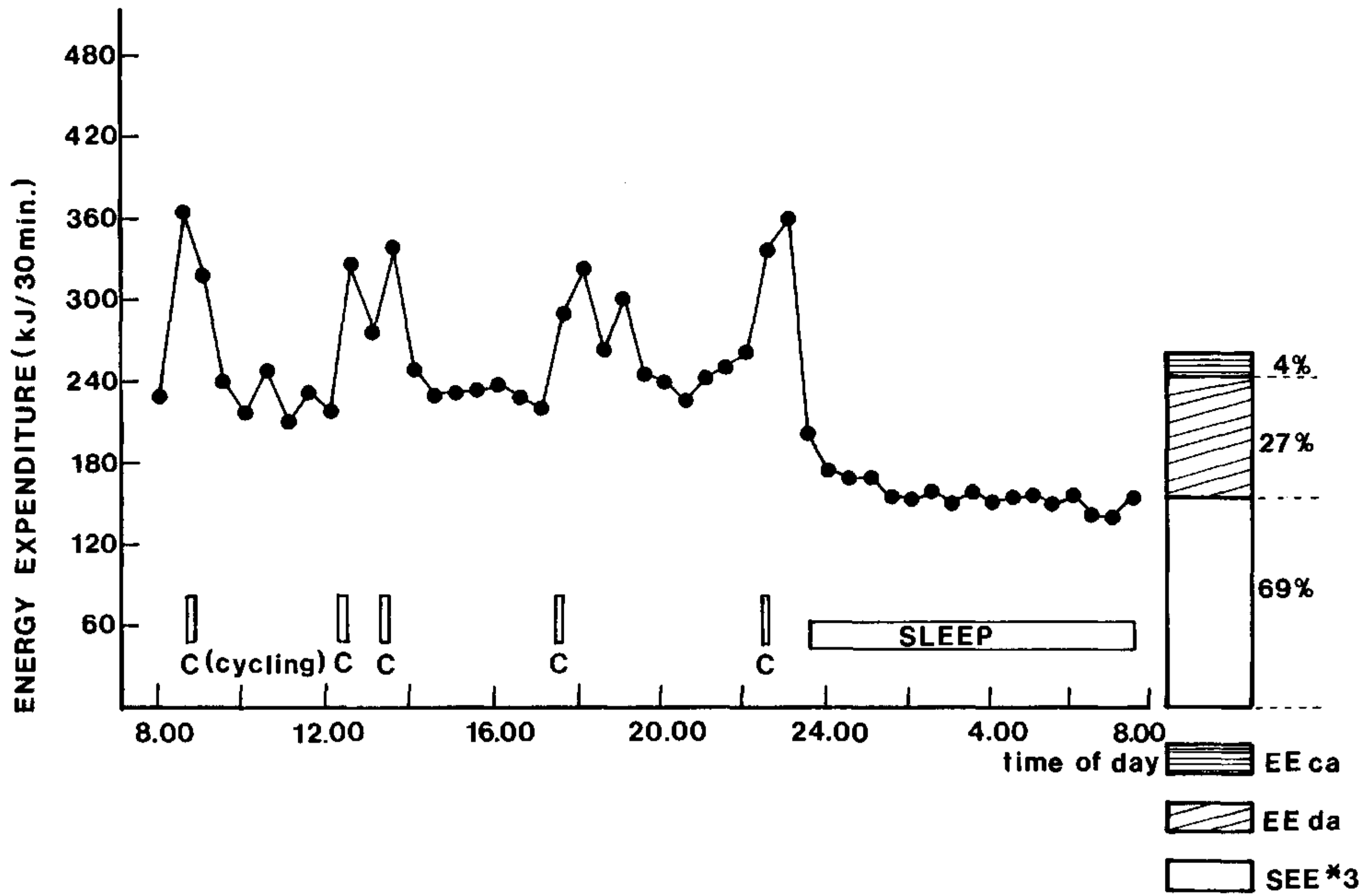


FIG. 7 PATTERN OF 24h ENERGY EXPENDITURE FOR SUBJ. 22
MEAN OF 3 DAYS (without protein correction)

In the next sections the data on 24EE, sleeping energy expenditure (SEE), diurnal energy expenditure (EEdiurnal) as well as the energetic cost of sedentary activities (EEda) and cycling (EEca) are presented separately.

3.3.1. Twenty-four hour energy expenditure

Slimming studies: Twenty-four hour energy expenditure fell in all subjects after 4 or 8 weeks of restricted energy intake (fig. 8). Table 9 shows the daily energy expenditure (24EE) throughout the slimming studies for each dietary programme. Since one woman suffered from a cold, with fever, her results are excluded from analysis.

Over the first 4 weeks of slimming the diets C50, AB/100 and A50/100 induced an average fall of 13.7 %, 10.7 % and 8.4 %, respectively, in the 24EE (table 9A). The fall caused by C50 (1337±292 kJ/d) was greater then the one caused by the alternating diet A50/100 (814±381 kJ/d). When expressed per unit body weight or fat-free mass, the fall in 24EE was still different from zero for all the comparisons, except that there was no difference between the C50- and A50/100-effects on 24EE/body weight. By subtracting the dietary induced thermogenesis (DIT), calculated from data in the literature or from our own data, from the 24EE (tables 10, 10A), the 24 hour energy expenditure was adjusted for differences in ME intake. Even then the absolute decline in 24EE over the first slimming period was apparent, though smaller (table 10). When expressed per unit body weight, the adjusted decreases in 24EE were less, and almost zero, if the DIT was assumed to be 16 %. After adjustment for ME intake, the diet C50 related to A50/100, did no longer result in a greater effect.

Over 8 weeks of slimming 24EE was reduced by 13.8 %, 15.3 % and 12.3 % for slimming studies 1, 2 and 3 respectively.

The cross-over comparison of the slimming diets (table 9B) showed small differences in 24EE for each comparison. Only slimming study 3 demonstrated any significant difference for the diets under comparison, A50/100 versus AB/100, but this difference did not reach the limits of significance after adjustment for ME intake (table 10A). Of the comparisons of 24EE per unit body weight, which were free of period effects, the only substantial difference (2.9±1.3 kJ/kg.d) was between AB/100 and C50 and this difference

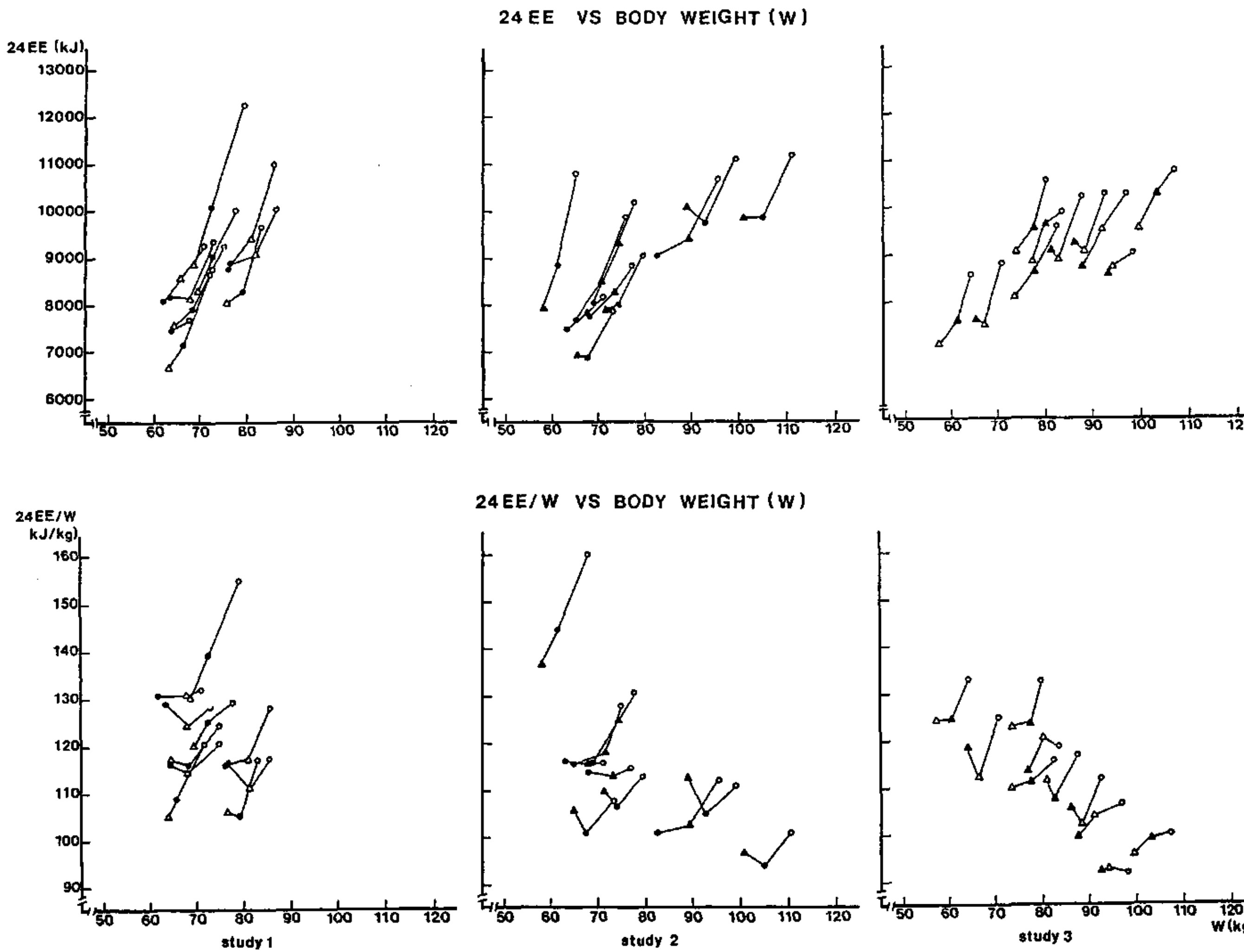


FIG. 8 TOTAL DAILY ENERGY EXPENDITURE (24EE) IN RELATION TO WEIGHT OF 27 OVERWEIGHT WOMEN BEFORE (○ : S 100) AND AFTER (● : C 50 ; △ : AB/100 ; ▲ : A 50/100) TWO ADJOINING SLIMMING PERIODS.

Table 9. Energy expenditure during 24 h* (24EE) throughout the slimming studies.

slimming study	dietary regimen			n	24EE			24EE/body weight			24EE/fat-free mass		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
					(kJ/24 h)			(kJ/kg.24h)			(kJ/kg.24h)		
study 1	S100	C50	AB/100	5	9472[1]	8518	7927	123[1]	119	116	218[2]	187	181
					(599)	(1096)	(853)	(6)	(14)	(10)	(31)	(22)	(22)
	S100	AB/100	C50	5	9714	8622	8311	125	119	122	205	191	192
					(877)	(705)	(583)	(7)	(8)	(8)	(14)	(22)	(18)
study 2	S100	C50	A50/100	5	10000	8666	8552	119	110	113	201	182[1]	181
					(1471)	(1270)	(1356)	(24)	(20)	(15)	(27)	(21)	(8)
	S100	A50/100	C50	5	9565	8678	7838	120	115	115	191	184[1]	180
					(1006)	(679)	(808)	(9)	(7)	(3)	(11)	(8)	(14)
study 3	S100	A50/100	AB/100	5	9911	9170	8542	121	116	114	204[1]	190[1]	181[1]
					(898)	(1045)	(947)	(14)	(11)	(12)	(9)	(24)	(21)
	S100	AB/100	A50/100	5	9738	8752	8682	111	104	106	188[1]	174[1]	170[1]
					(771)	(747)	(631)	(12)	(7)	(10)	(7)	(6)	(8)

results expressed as means (sd)
1 one missing value
2 two missing values
* means for 3 (wk 1) or 2 (wk 5, wk 9) days; corrected for protein oxidation.

Table 9A. Energy expenditure during 24 h (24EE) before slimming (week 1) and in the last week of the first slimming period (week 5).

dietary regimen		n	24EE			24EE/body weight			24EE/fat-free mass		
wk 1	wk 5		wk 1	wk 5	diff	wk 1	wk 5	diff	wk 1	wk 5	diff
			(kJ/d)			(kJ/kg.d)			(kJ/kg.d)		
S100	C50	9	9766	8429	$1337^{\dagger a}$	121	112	$9^{\dagger c}$	203^{2}	179^{2}	$25^{\dagger d}$
			(1137)	(1055)	(292)	(17)	(15)	(3.7)	(25)	(18)	(10)
S100	AB/100	10	9726	8687	$1039^{\dagger ab}$	118	112	6^{*c}	198^{1}	184^{2}	14^{*e}
			(779)	(688)	(392)	(12)	(11)	(4.6)	(14)	(18)	(8)
S100	A50/100	10	9738	8924	$814^{\dagger b}$	120	116	5^{*c}	196^{2}	187^{2}	9^{*e}
			(918)	(870)	(381)	(11)	(9)	(4.2)	(16)	(17)	(9)

results expressed as means (sd)
1 one missing value
2 two missing values
values with similar superscripts (a, b..) in the same column are not significantly different (one-way analysis of variance $p<0.05$)
* significantly different from zero (paired t-test, $p<0.05$)
† significantly different from zero (paired t-test, $p<0.001$)

Table 9B. Energy expenditure during 24 hours (24EE) in the last week of each slimming period for the three slimming studies.

slimming study	n		24EE			24EE/body weight			24EE/fat-free mass		
			(kJ/d)			(kJ/kg.d)			(kJ/kg.d)		
study 1	10		C50	AB/100	diff	C50	AB/100	diff	C50	AB/100	diff
		Mean	8415	8274	-140	120	117	-2.9*	189	186	-3.4
		SE			(104)			(1.3)			(3.5)
study 2	10		C50	A50/100	diff	C50	A50/100	diff	C50	A50/100	diff
		Mean	8338	8614	276	113	114	1.7	178[2]	182[2]	3.8
		SE			(133)			(1.7)			(3.8)
study 3	10		A50/100	AB/100	diff	A50/100	AB/100	diff	A50/100	AB/100	diff
		Mean	8926	8647	-279*	111	109	-2.2	180[1]	177[1]	-2.6
		SE			(97)			(1.1)			(2.7)

standard error of difference is obtained from the pooled estimate of the standard deviation of the difference

* significantly different from zero ($p<0.05$)

1 one missing value

2 two missing values

Table 10. Differences of energy expenditure during 24 hours (Δ 24EE), measured before (week 1) and in the last week of the first slimming period, adjusted for dissimilar ME intake.

dietary regimen		n	Δ 24EE (kJ/d)						Δ 24EE/body weight (kJ/kg.d)					
			correction factor						correction factor					
wk 1	wk 5		0	1	2	3	4	5	0	1	2	3	4	5
S100	C50	9	$1337^{\dagger a}$	$917^{\dagger c}$	$904^{\dagger d}$	$651^{\dagger e}$	$564^{\dagger g}$	$902^{\dagger h}$	$8.8^{\dagger i}$	4.0^{*j}	3.8^{*k}	1.0^{l}	0.0^{m}	3.9^{*n}
			(97)	(97)	(96)	(98)	(99)	(97)	(1.3)	(1.2)	(1.2)	(1.1)	(1.1)	(1.2)
S100	AB/100	10	$1039^{\dagger ab}$	$722^{\dagger c}$	$678^{\dagger d}$	522^{*e}	457^{*g}	$711^{\dagger h}$	6.6^{*i}	3.1^{j}	2.5^{k}	0.9^{l}	0.2^{m}	3.0^{n}
			(124)	(117)	(117)	(113)	(111)	(116)	(1.5)	(1.4)	(1.4)	(1.4)	(1.3)	(1.4)
S100	A50/100	10	$814^{\dagger b}$	$588^{\dagger c}$	516^{*d}	445^{*e}	398^{*g}	$580^{\dagger h}$	4.6^{*i}	2.2^{j}	1.2^{k}	0.7^{l}	0.2^{m}	2.2^{n}
			(120)	(113)	(115)	(110)	(110)	(113)	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)

results expressed as means (SE)

correction 0 none

1 dietary induced thermogenesis (DIT) = 8.7% (Schutz et al. 1984a)

2 DIT = 7.6% before weight loss, DIT = 6.2% after weight loss (Bessard et al. 1983)

3 DIT = 14.2% this study

4 efficiency factor for ME utilization (k_m) = 0.84 (de Boer et al. 1986)

5 k_m = 0.91 (de Boer et al. 1986)

values with similar superscripts (a, b..) in the same column are not significantly different (one-way analysis of variance, $p<0.05$)

* significantly different from zero (paired t-test, $p<0.05$)

† significantly different from zero (paired t-test, $p<0.001$)

Table 10A. Differences of energy expenditure during 24 hours (Δ24EE) measured in the last week of each slimming period for the three slimming studies, adjusted for dissimilar ME intake.

slimming study	n	Δ24EE (kJ/d)						Δ24EE/body weight (kJ/kg.d)					
		correction factor						correction factor					
		0	1	2	3	4	5	0	1	2	3	4	5
study 1	10	-140	-232	-206	-290*	-309*	-235*	-2.9*	-4.3*	-4.0*	-5.1*	-5.4*	-4.4*
		(104)	(101)	(102)	(100)	(100)	(101)	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)	(1.3)
study 2	10	276	81	138	-41	-81	75	1.7	-0.9	-0.1	-2.5	-3.0	-0.9
		(133)	(132)	(132)	(132)	(133)	(132)	(1.7)	(1.8)	(1.8)	(1.8)	(1.8)	(1.8)
study 3	10	-279*	-179	-208	-116	-96	-176	-2.2	-1.0	-1.3	-0.2	0.0	-0.9
		(97)	(97)	(97)	(98)	(99)	(97)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)

results expressed as means (SE)

correction 0 none

1 DIT = 8.7% (Schutz et al. 1984a)

2 DIT = 7.6% before weight loss, DIT = 6.2% after weight loss (Bessard et al. 1983)

3 DIT = 14.2% (this study)

4 k_m = 0.84 (de Boer et al. 1986)

5 k_m = 0.91 (de Boer et al. 1986)

standard error is obtained from the pooled estimate of the standard deviation of the difference

* significantly different from zero ($p<0.05$)

remained or rather enlarged when differences of ME intake were taken into account (table 10A).

Follow-up studies: One month after slimming mean 24EE (8379±739 kJ/d) had increased by 334±245 kJ/d (table 11). This increase was still significant when body weight was taken into account but not when the data were also corrected for differences in energy intake (table 12).

Compared to energy expenditure before weight loss (9505±791 kJ/d), the energy expenditure 1 month after slimming was lower. The absolute difference (-1256±585 kJ/d) was interwoven with a mean change of body weight, since 24EE/body weight was similar for both measurements (125±14 kJ/kg.d before slimming, 126±12 kJ/kg.d 1 month after slimming). Table 12 shows that adjustment for ME intake had only a slight effect on the results.

One year after slimming the 24EE was a little higher than the 24EE of wk 9, but significantly lower than the pre-slimming value. After adjustment for difference of energy intake the 24EE per unit body weight was comparable to the pre-slimming 24EE per unit body weight.

3.3.2. *Energy expenditure during daytime and evening*

Slimming studies: Table 13 presents the energy expenditure during daytime and evening (EEdiurnal: 7.30 - 23.30, cycling included) before slimming and at the end of two slimming periods. The EEdiurnal decreased steadily throughout slimming and after 4 weeks of slimming a decrease of 70±14 kJ/h, 57±19 kJ/h and 45±22 kJ/h had occurred with the diets C50, AB/100 and A50/100 respectively (table 13A). Diet C50 caused a significantly greater fall than diet A50/100. When energy expenditure was expressed per kg body weight or per kg fat-free mass, the declines were still significant. The difference between the C50- and A50/100-effect statistically disappeared for body weight related expenditure but remained for fat free mass related expenditure.

Table 13B shows small and mostly insignificant differences for the diet comparisons, except for the comparison of A50/100 with AB/100. This difference statistically disappeared when EE was expressed per unit of body weight. A difference between C50 and AB/100 became apparent when body weight

Table 11. Energy expenditure during 24 hours[*] (24EE) before (week 1) and after (week 9) slimming and in the final week of the follow-up periods (at 1 month and 1 year respectively).

follow-up study	wk 1	wk 9	follow-up	follow-up - wk 1	follow-up - wk 9
1 month (n=10)					
24EE	9505[1]	8061	8379[1]	-1256[‡2]	334[‡1]
(kJ/d)	(791)	(524)	(739)	(585)	(245)
24EE/body weight	125[1]	120	126[1]	1.0[2]	7.1[‡1]
(kJ/kg.d)	(14)	(9)	(12)	(5.6)	(4.0)
24EE/fat-free mass	209[1]	190	194[1]	-185[†2]	4.3[1]
(kJ/kg.d)	(18)	(12)	(13)	(14.1)	(6.5)
1 year (n=8)					
24EE	9570[1]	8046	8285	-1358[‡1]	239
(kJ/d)	(511)	(471)	(454)	(267)	(300)
24EE/body weight	128[1]	122	124	-3.5[†1]	2.5
(kJ/kg.d)	(4)	(7)	(4)	(3.6)	(5.2)
24EE/fat-free mass	200[2]	184	192	-7.7[2]	7.5
(kJ/kg.d)	(16)	(15)	(13)	(13.1)	(10.4)

results expressed as means (sd)

* mean of 3 (wk 1) or 2 (wk 9 and follow-up) days; corrected for urinary nitrogen

1 one missing value

2 two missing values

† significantly different from zero (paired t-test, $p<0.05$)

‡ significantly different from zero (paired t-test, $p<0.001$)

Table 12. Differences within subjects of adjusted energy expenditure during 24 h (Δ24EE) for each follow up study (1 month, 1 year) as compared to the onset (wk 1) and the end (wk 9) of the slimming study.

Comparison	Δ 24 EE (kJ/d)						Δ 24 EE/body weight (kJ/kg.d)					
	correction factor						correction factor					
	0	1	2	3	4	5	0	1	2	3	4	5
1 month (n=9)												
follow up - week 1[1]	-1256‡	1141‡	-1154‡	-1068‡	-1044‡	-1137‡	-1.0	-0.8	-0.9	-0.7	-0.7	-0.8
	(207)	(204)	(204)	(202)	(201)	(204)	(2.0)	(1.9)	(1.9)	(1.9)	(1.9)	(1.9)
follow up - week 9	334†	90	48	-64	-114	82	7.1†	3.3	2.7	0.9	0.1	3.2
	(82)	(93)	(88)	(104)	(108)	(93)	(1.3)	(1.6)	(1.5)	(1.8)	(1.8)	(1.6)
1 year (n=8)												
follow up - week 1[1]	-1358‡	-1253‡	-1266‡	-1186‡	-1164‡	-1249‡	-3.5†	-3.4	-3.3	-3.3	-3.2	-3.4
	(102)	(111)	(110)	(118)	(120)	(112)	(1.3)	(1.5)	(1.4)	(1.5)	(1.6)	(1.5)
follow up - week 9	239	-59	-91	-248†	-310†	-70	2.5	-2.1	-2.6	-4.9†	-5.8†	-2.2
	(106)	(100)	(102)	(97)	(96)	(100)	(1.8)	(1.7)	(1.7)	(1.6)	(1.6)	(1.7)

results expressed as means(SE)

* correction for difference of ME
0 none
1 dietary induced thermogenesis (DIT) = 8.7% (Schutz et al. 1984a)
2 DIT = 7,6% before weight loss, DIT = 6.2% after weight loss (Bessard et al. 1983)
3 DIT = 14.2% (this study)
4 efficiency factor for ME utilization (km) = 0.84 (de Boer et al. 1986)
5 km = 0.91

$\dagger$ significantly different from zero (paired t-test, $p<0.05$)

$\ddagger$ significantly different from zero (paired t-test, $p<0.001$)

1 one missing value

Table 13. Energy expenditure during daytime and evening* (EEdiurnal: 7.30-23.30 h) throughout the slimming studies.

slimming study	dietary regimen			n	EEdiurnal			EEdiurnal/body weight			EEdiurnal/fat-free mass		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
						(kJ/h)			(kJ/kg.h)			(kJ/kg.h)	
study 1	S100	C50	AB/100	5	464[1]	408	378	6.03[1]	5.69	5.52	10.07[2]	8.97	8.61
					(33)	(47)	(38)	(0.26)	(0.56)	(0.42)	(1.21)	(0.96)	(1.02)
	S100	AB/100	C50	5	477	419	408	6.11	5.75	5.98	10.10	9.29	9.40
					(43)	(40)	(31)	(0.27)	(0.39)	(0.42)	(0.80)	(1.15)	(0.92)
study 2	S100	C50	A50/100	5	486	418	413	5.78	5.33	5.64	9.78	8.74[1]	8.74
					(76)	(63)	(64)	(1.22)	(1.02)	(0.78)	(1.44)	(1.17)	(0.53)
	S100	A50/100	C50	5	469	418	383	6.01	5.58	5.49	9.37	8.84[1]	8.62
					(54)	(31)	(26)	(0.48)	(0.40)	(0.18)	(0.52)	(0.33)	(0.72)
study 3	S100	A50/100	AB/100	5	488[1]	442	410	5.94[1]	5.60	5.45	10.23[2]	9.10[1]	8.62[1]
					(50)	(53)	(49)	(0.74)	(0.51)	(0.53)	(0.61)	(1.19)	(1.08)
	S100	AB/100	A50/100	5	469[1]	421	416	5.45[1]	5.00	5.08	9.21[2]	8.34[1]	8.09
					(43)	(37)	(34)	(0.69)	(0.32)	(0.49)	(0.44)	(0.36)	(0.36)

results expressed as means (sd)

* protein correction factor neglected

1 one missing value

2 two missing values

Table 13A. Energy expenditure during daytime and evening (EEdiurnal) before (week 1) and in the last week of the first slimming period (week 5).

dietary regimen		n	EEdiurnal			EEdiurnal/body weight			EEdiurnal/fat-free mass		
wk 1	wk 5		wk 1	wk 5	diff	wk 1	wk 5	diff	wk 1	wk 5	diff
			(kJ/h)			(kJ/kg.h)			(kJ/kg.h)		
S100	C50	9	476	406	$70^{\dagger a}$	5.89	5.40	$0.49^{\dagger c}$	9.92^{2}	8.64^{2}	$1.28^{\dagger d}$
			(59)	(51)	(14)	(0.89)	(0.75)	(0.18)	(1.37)	(0.96)	(0.51)
S100	AB/100	9	474	417	$57^{\dagger ab}$	5.85	5.42	$0.43^{\dagger c}$	9.77^{1}	8.92^{1}	0.84^{*de}
			(40)	(35)	(19)	(0.61)	(0.53)	(0.23)	(0.79)	(1.03)	(0.44)
S100	A50/100	9	477	432	$45^{\dagger b}$	5.92	5.61	0.31^{*c}	9.66^{2}	9.11^{2}	0.56^{*e}
			(50)	(45)	(22)	(0.56)	(0.45)	(0.23)	(0.72)	(0.77)	(0.47)

results expressed as means (sd)

1 one missing value

2 two missing values

values with similar superscript (a,b ....) in the same column are not significantly different (one-way analysis of variance, $p<0.05$)

* significantly different from zero (paired t-test, $P<0.05$)

† significantly different from zero (paired t-test, $p<0.001$)

Table 13B. Energy expenditure during daytime and evening (EEdiurnal) in the last week of each slimming period for the three slimming studies.

slimming study	n		EEdiurnal			EEdiurnal/body weight			EEdiurnal/fat-free mass		
			(kJ/d)			(kJ/kg.d)			(kJ/kg.d)		
study 1	10		C50	AB/100	diff	C50	AB/100	diff	C50	AB/100	diff
		Mean	408	398	-10	5.84	5.64	0.20*	9.18	8.95	-0.23
		SE			(5)			(0.06)			(0.17)
study 2	10		C50	A50/100	diff	C50	A50/100	diff	C50	A50/100	diff
		Mean	401	416	+15	5.41	5.52	0.11	8.54[2]	8.75[2]	0.21
		SE			(7)			(0.09)			(0.19)
study 3	10		A50/100	AB/100	diff	A50/100	AB/100	diff	A50/100	AB/100	diff
		Mean	429	415	-14*	5.34	5.23	-0.11	8.59	8.48	-0.11
		SE			(5)			(0.06)			(0.14)

standard error of difference is obtained from the pooled estimate of the standard deviation of the difference

* significantly different from zero ($p<0.05$)

1 one missing value

2 two missing values

was taken into account.

Follow-up studies: The energy expenditure during daytime and evening for the follow-up studies is given in table 14. One month after weight reduction energy expenditure was increased by an average 15 kJ/h or 0.33 kJ/kg.h. As compared to mean expenditure before slimming the absolute value of follow-up EE was significantly lower, but EE related to body weight was found to be similar.

One year after slimming similar values as those obtained in the last week of slimming, were found. Follow-up values were significantly lower than baseline EE values except for fat-free mass related expenditure.

3.3.3. Sleeping energy expenditure

Slimming studies: Before weight loss, the sleeping energy expenditure (SEE, table 15) was significantly greater than it was after 4 weeks of slimming. The decrease (table 15A) induced by the diet C50, 29 ± 15 kJ/h (10.7 % of the baseline value), was greater than the one caused by the diet A50/100, 10 ± 12 kJ/h (3.7 % of the baseline value). On the diet AB/100 SEE decreased by 7.7 % (20 ± 10 kJ/h). When the SEE was expressed per unit body weight the decreases were no longer significant nor were the diet differences. The SEE/fat-free mass was significantly lowered by 9.6 % with C50 and by 4.2 % with AB/100, and there was a significant difference between the effects of C50 and that of the alternating diets. The small differences in SEE were clearly present when data for all subjects were combined, regardless their slimming diet in the first slimming period: 20 ± 14 kJ/h (7.6 % of baseline SEE), 0.07 ± 0.17 kJ/kg body weight (2.1 % of baseline SEE) and 0.27 ± 0.33 kJ/fat-free mass (4.9 % of baseline SEE).

In the second slimming period the SEE, when expressed in absolute terms, decreased further to achieve a final reduction of 13 % (study 1), 10 % (study 2), 6 % (study 3) below the baseline SEE.

In the cross-over comparison of slimming diets (table 15B) the only significant differences were between diets A50/100 and AB/100 in study 3, both in SEE and SEE/body weight. No significant effects of period were found when comparing weight related differences in SEE.

Table 14. Energy expenditure during daytime and evening * (7.30 - 23.30) before (week 1) and after (week 9) slimming and in the final week of the follow-up periods (at 1 month and 1 year respectively).

follow-up study	wk 1	wk 9	follow up	follow-up - wk 1	follow-up - wk 9
1 month (n=10)					
EEdiurnal	468[1]	390	404[1]	-68‡	15†
(kJ/h)	(42)	(26)	(38)	(29)	(14)
EEdiurnal/body weight	6.25[1]	5.80	6.06[1]	-0.15	0.33†
(kJ/kg.h)	(0.71)	(0.47)	(0.61)	(0.27)	(0.24)
EEdiurnal/fat-free mass	10.30[1]	9.18	9.37[1]	-1.07†	0.18
(kJ/kg.h)	(0.95)	(0.62)	(0.70)	(0.67)	(0.36)
1 year (n=8)					
EEdiurnal	471[1]	387	400	-74‡	13
(kJ/h)	(26)	(21)	(22)	(12)	(18)
EEdiurnal/body weight	6.29[1]	5.88	6.00	-0.27†	0.13
(kJ/kg.h)	(0.22)	(0.39)	(0.25)	(0.16)	(0.29)
EEdiurnal/fat-free mass	9.83[2]	8.86	9.24	-0.55	+0.38
(kJ/kg.h)	(0.79)	(0.82)	(0.70)	(0.65)	(0.57)

results expressed as means(sd)

* protein correction factor neglected

1 one missing value
2 two missing values

† significantly different from zero (paired t-test, $p<0.05$)

‡ significantly different from zero (paired t-test, $p<0.001$)

Table 15. Sleeping energy expenditure* - adjusted to zero activity - (23.30 - 7.30) throughout the slimming studies.

slimming study	dietary regimen			n	SEE			SEE/body weight			SEE/fat-free mass		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
					(kJ/h)			(kJ/kg.h)			(kJ/kg.h)		
study 1	S100	C50	AB/100	5	258[1]	241	235	3.36[1]	3.36	3.43	5.65[2]	5.29[1]	5.34[1]
					(6)	(32)	(28)	(0.16)	(0.42)	(0.32)	(0.40)	(0.63)	(0.69)
	S100	AB/100	C50	5	258	237	224	3.33	3.26	3.29	5.44	5.24	5.16
					(25)	(21)	(16)	(0.17)	(0.20)	(0.20)	(0.23)	(0.29)	(0.40)
study 2	S100	C50	A50/100	5	279	251	250	3.33	3.18	3.29	5.63	5.25[1]	5.29
					(28)	(34)	(40)	(0.59)	(0.40)	(0.32)	(0.64)	(0.29)	(0.10)
	S100	A50/100	C50	5	262	250	236	3.30	3.33	3.38	5.25	5.31[1]	5.31
					(21)	(25)	(24)	(0.20)	(0.22)	(0.09)	(0.49)	(0.47)	(0.48)
study 3	S100	A50/100	AB/100	5	276[1]	267	249	3.36[1]	3.39	3.32	6.03[2]	5.61[1]	5.31[1]
					(37)	(29)	(23)	(0.48)	(0.30)	(0.37)	(0.45)	(0.60)	(0.53)
	S100	AB/100	A50/100	5	263[1]	252	255	3.05[1]	3.01	3.13	5.35[2]	5.13[1]	5.13[1]
					(27)	(23)	(17)	(0.40)	(0.27)	(0.32)	(0.05)	(0.17)	(0.23)

results expressed as means(sd)

* protein correction factor excluded

1 one missing value
2 two missing values

Table 15A. Sleeping energy expenditure (SEE) - adjusted to zero activity - before (week 1) and in the last week of the first slimming period (week 5).

dietary regimen		n	SEE			SEE/body weight			SEE/fat-free mass		
wk 1	wk 5		wk 1	wk 5	diff	wk 1	wk 5	diff	wk 1	wk 5	diff
				(kJ/h)			(kJ/kg.h)			(kJ/kg.h)	
S100	C50	9	270	241	$29^{\dagger a}$	3.34	3.19	0.15^{c}	5.65^{2}	5.11^{2}	0.54^{*d}
			(23)	(30)	(15)	(0.43)	(0.33)	(0.20)	(0.57)	(0.34)	(0.37)
S100	AB/100	9	260	240	$20^{\dagger ab}$	3.21	3.13	0.07^{c}	5.41^{1}	5.18^{1}	0.23^{*e}
			(25)	(19)	(10)	(0.31)	(0.28)	(0.11)	(0.18)	(0.25)	(0.14)
S100	A50/100	9	268	258	10^{*b}	3.33	3.35	-0.02^{c}	5.51^{2}	5.50^{2}	$(0.01)^{e}$
			(28)	(28)	(12)	(0.33)	(0.26)	(0.15)	(0.64)	(0.55)	(0.28)
S100	C50 or AB/100 or A50/100	27	266	246	$20^{\dagger}$	3.29	3.22	0.07^{*}	5.53^{5}	5.26^{5}	0.27^{*}
			(25)	(26)	(14)	(0.35)	(0.30)	(0.17)	(0.47)	(0.42)	(0.33)

results expressed as means (sd)

1 one missing value

2 two missing values

5 five missing values

values with similar superscripts (a,b...) in the same column are not signficantly different (one-way analysis of variance, $p<0.05$)

* significantly different from zero (paired t-test, $p<0.05$)

† significantly different from zero (paired t-test, $p<0.001$)

Table 15B. Sleeping energy expenditure (SEE) - adjusted to zero activity - in the last week of each slimming period for the three slimming studies.

slimming study	n		SEE			SEE/body weight			SEE/fat-free mass		
			(kJ/h)			(kJ/kg.h)			(kJ/kg.h)		
study 1	10		C50	AB/100	diff	C50	AB/100	diff	C50	AB/100	diff
		Mean	233	236	3.2	3.32	3.34	+0.02	5.23	5.29	0.06
		SE			(3.8)			(0.04)			(0.11)
study 2	10		C50	A50/100	diff	C50	A50/100	diff	C50	A50/100	diff
		Mean	243	250	6.7	3.28	3.31	0.03	5.20[2]	5.29[2]	0.09
		SE			(3.7)			(0.05)			(0.10)
study 3	10		A50/100	AB/100	diff	A50/100	AB/100	diff	A50/100	AB/100	diff
		Mean	261	251	-10.9*	3.26	3.16	-0.09*	5.37[2]	5.22[2]	-0.15
		SE			(3.1)			(0.04)			(0.09)

standard error of difference is obtained from the pooled estimate of the standard deviation of the difference

* significantly different from zero ($p<0.05$)

1 one missing value

2 two missing values

Follow-up studies: Table 16 presents SEE values for the follow-up studies. One month after slimming, the SEE was higher than the SEE at the end of the slimming period but significantly lower than the SEE before slimming. After standardization for body weight or fat-free mass, the SEE per unit body weight at 1 month after slimming was still significantly higher than it was at the end of the slimming period.

One year after weight loss, SEE was significantly lower than onset-SEE, unlike SEE/body weight, which was slightly increased. When the SEE 1 year after slimming was compared with the SEE in the last week of slimming, no significant differences were found.

3.3.4. Sedentary energy expenditure, bicycling energy expenditure

Slimming studies: Table 17 summarizes the EE values above sleeping for non-cycling day-activities, mainly sedentary (EEda), and the energy expenditure due to cycling (EEca) above SEE and EEda. Along with the reduction of body size the EEda decreased over the first slimming period. After standardisation for body weight a decline of comparable size (11-18%) still occurred with all diets. No changes in the energy cost of cycling over the first 4 weeks are evident (table 17A).

Over the 8 weeks of slimming the continuous and the alternating diets affected EEda and EEca similarly (table 17B) except that the effect of AB/100 on the EEda per kilogram body weight was significantly different from that of C50.

Follow-up studies: Since the energetic cost of bicycling was similar for the weight-maintenance and the slimming diets, non-sleeping energy expenditure was not subdivided into EEda and EEca for the follow-up studies.

3.4. Physical activity

Slimming studies: Results on physical activity counts are summarized in table 18. During the cycle-exercise periods the actometer was removed from

Table 16. Sleeping energy expenditure (SEE)* - adjusted to zero activity - before (week 1) and after (week 9) slimming and in the final week of the follow-up periods (at 1 month and 1 year respectively).

follow-up study	wk 1	wk 9	follow-up	follow-up - wk 1	follow-up - wk 9
1 month (n=10)					
SEE	258[1]	230	238[1]	-24[2]†	8[1]†
(kJ/h)	(18)	(19)	(17)	(19)	(8)
SEE/body weight	3.41[1]	3.41	3.58[1]	0.13[2]	0.18[1]†
(kJ/kg.h)	(0.37)	(0.27)	(0.31)	(0.23)	(0.13)
SEE/fat-free mass	5.69[1]	5.40	5.53[1]	0.26[2]	0.08[1]
(kJ/kg.h)	(0.45)	(0.40)	(0.24)	(0.44)	(0.20)
1 year (n=8)					
SEE	254[1]	239	237	-20[1]‡	8
(kJ/h)	(14)	(21)	(14)	(6)	(12)
SEE/body weight	3.39[1]	3.46	3.56	0.15[1]†	0.09
(kJ/kg.h)	(0.11)	(0.23)	(0.09)	(0.13)	(0.21)
SEE/fat-free mass	5.29[2]	5.22	5.48	0.18[2]	0.26
(kJ/kg.h)	(0.42)	(0.43)	(0.38)	(0.44)	(0.42)

results expressed as means (sd)

* protein correction factor neglected

1 one missing value

2 two missing values

† significantly different from zero (paired t-test, $p<0.05$)

‡ significantly different from zero (paired t-test, $p<0.001$)

Table 17. Energy expenditure above sleeping energy expenditure due to sedentary activities (EEda) and bicycling EE(ca)† throughout the slimming studies.

slimming study	dietary regimen			n	EEda			EEda/body weight			EEca			EEca/body weight		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
					(kJ/min)			(J/kg.min)			(kJ/min)			(J/kg.min)		
study 1	S100	C50	AB/100	5	2.9[1]	2.3	1.9	38[1]	32	27	6.1[1]	6.6	6.6	80[1]	93	97
					(0.5)	(0.3)	(0.3)	(5)	(3)	(3)	(0.5)	(1.6)	(2.1)	(9)	(24)	(32)
	S100	AB/100	C50	5	3.2	2.5	2.5	41	34	37	6.1	6.8	7.0	80	95	105
					(0.3)	(0.5)	(0.3)	(2)	(5)	(2)	(1.0)	(1.3)	(2.4)	(15)	(26)	(45)
study 2	S100	C50	A50/100	5	2.9	2.3	2.3	34	30	31	7.3	6.0	4.9	87	74	65
					(0.8)	(0.6)	(0.5)	(1)	(11)	(9)	(1.1)	(1.2)	(1.1)	(21)	(13)	(13)
	S100	A50/100	C50	5	2.8	2.3	2.0	35	31	29	8.1	6.3	5.2	104	82	74
					(0.8)	(0.4)	(0.1)	(9)	(6)	(3)	(3.5)	(1.5)	(1.2)	(51)	(11)	(11)
study 3	S100	A50/100	AB/100	5	3.1[1]	2.5	2.3	37	31	30	5.7[1]	5.5	5.5	70[1]	70	73
					(0.4)	(0.5)	(0.4)	(6)	(5)	(4)	(0.8)	(0.8)	(1.0)	(11)	(10)	(13)
	S100	AB/100	A50/100	5	2.9[1]	2.3	2.2	34	27	27	6.2[1]	6.4	6.2	72[1]	76	76
					(0.5)	(0.3)	(0.4)	(7)	(2)	(4)	(1.8)	(1.5)	(1.7)	(18)	(16)	(22)

results expressed as means(sd)

* protein correction factor neglected

† EE above SEE and EEda

1 one missing value

2 two missing values

Table 17A. Energy expenditure during sedentary activities (EEda) and cycling (EEca) before (week 1) and in the last week of the first slimming period (week 5).

dietary regimen		n	EEda			EEda/body weight			EEca			EEca/body weight		
wk 1	wk 5		wk 1	wk 5	diff	wk 1	wk 5	diff	wk 1	wk 5	diff	wk 1	wk 5	diff
				(kJ/min)			(J/kg.min)			(kJ/min)			(J/kg.min)	
S100	C50	9	2.9	2.3	$0.6^{\dagger a}$	36	30	$5^{\dagger b}$	6.7	6.1	0.6^{c}	84	80	3^{d}
			0.6	(0.5)	(0.3)	(8)	(8)	(3)	(1.0)	(1.3)	(1.6)	(16)	(19)	(22)
S100	AB/100	9	3.1	2.4	$0.7^{\dagger a}$	38	31	$7^{\dagger b}$	6.2	6.7	-0.5^{c}	76	88	-12^{*d}
			(0.4)	(0.4)	(0.3)	(6)	(5)	(4)	(1.3)	(1.4)	(1.1)	(16)	(22)	(15)
S100	A50/100	9	2.9	2.4	0.4^{*a}	36	32	4^{*b}	7.1	5.9	1.1^{c}	89	77	12^{d}
			(0.6)	(0.4)	(0.4)	(8)	(5)	(6)	(2.8)	(1.3)	(2.8)	(41)	(13)	(40)

results expressed as means(sd)

values with similar superscripts (a,b..) in the same column are not significantly different (one-way analysis of variance, $p<0.05$)

* significantly different from zero (paired t-test, $p<0.05$)

† significantly different from zero (paired t-test, $p<0.001$)

Table 17B. Energy expenditure during sedentary activities (EEda) and cycling (EEca) in the last week of each slimming period for the three slimming studies.

slimming study	n		EEda			EEda/body weight			EEca			EEca/body weight		
			(kJ/min)			(J/kg.min)			(kJ/min)			(J/kg.min)		
study 1	10		C50	AB/100	diff	C50	AB/100	diff	C50	AB/100	diff	C50	AB/100	diff
		Mean	2.4	2.2	-0.2	34	31	-3*	6.8	6.7	-0.1	99	96	-3
		SE			(0.1)			(1)			(0.4)			(6)
study 2	10		C50	A50/100	diff	C50	A50/100	diff	C50	A50/100	diff	C50	A50/100	diff
		Mean	2.2	2.3	+0.1	30	31	+1	5.6	5.6	0.0	74	74	0
		SE			(0.1)			(1)			(0.2)			(3)
study 3	10		A50/100	AB/100	diff	A50/100	AB/100	diff	A50/100	AB/100	diff	A50/100	AB/100	diff
		Mean	2.3	2.3	0.1	29	29	0	5.9	5.9	0.1	73	74	+1
		SE			(0.1)			(1)			(0.2)			(3)

standard error of difference is obtained from the pooled estimate of the standard deviation of the difference
* significantly different from zero ($p<0.05$)

Table 18. Physical activity during daytime and evening* throughout the slimming studies as indicated by actometer and Dopplermeter values (AMrel, DMrel), relative to physical activity before weight loss.

slimming study	dietary regimen			n	AMrel		DMrel	
	wk 1	wk 5	wk 9		wk 5	wk 9	wk 5	wk 9
					%		%	
study 1	S100	C50	AB/100	5	64.7	58.0	78.5[1]	59.8[1]
					(7.9)	(14.3)	(14.3)	(6.7)
	S100	AB/100	C50	5	87.3	67.3	100.5	94.3
					(24.1)	(13.5)	(33.0)	(16.4)
study 2	S100	C50	A50/100	5	66.7	61.3	72.1	60.0
					(11.7)	(18.3)	(13.4)	(19.9)
	S100	A50/100	C50	5	78.1	72.0	82.6[1]	69.2[1]
					(26.4)	(25.6)	(18.1)	(23.0)
study 3	S100	A50/100	AB/100	5	81.1	81.9	94.5	81.2
					(25.6)	(17.0)	(10.7)	(7.6)
	S100	AB/100	A50/100	5	81.8	91.0	85.8[1]	84.8[1]
					(22.6)	(10.4)	(5.2)	(14.6)

results expressed as means (sd)

* cycling periods excluded

1 one missing value

the ankle. So the activity counts do not include activity during the cycling periods, which were of constant duration and speed. Most 'disturbances' to the activity recording by the Dopplermeters occurred at night, so it was considered better to exclude the counts for the night. Thus for comparative purposes both the actometer counts and the Dopplermeter counts do not include the cycling periods or the nights.

The actometer and the Dopplermeter both registered less physical activity once slimming had started. The fall in physical activity in the last week of the first slimming period was universal, but only statistically significant for A50/100 (actometer values) and C50 (Dopplermeter and actometer values). The greatest reduction occurred with diet C50 (AMrel, actometer counts relative to the weight maintenance period: 34.3 %, DMrel: 25.1 %; table 18A).

No differences were found in the cross-over comparison of the physical-activity indices for the end of each slimming period (table 18B). In study 1 the AM values showed significant period or habituation effects, and the same effect was reflected in the Dopplermeter values for study 2.

Follow-up studies: Table 19 shows the data on physical activity during the follow-up studies. According to the actometer percentages and less obvious to Dopplermeter percentages, the activity was increased by 13 % 1 month after slimming, but was still below the baseline physical activity.

The women who participated in the 1-year follow-up study, showed the same reduced level of physical activity that they showed in their final week of slimming. There are no Dopplermeter data for the 1-year follow-up study because the Doppler units had been remounted in new positions within the chamber so no within-subject comparisons are possible.

3.5 Computation of dietary induced thermogenesis

Fig. 9 reflects the course of daily energy expenditure, physical activity and the individual relationship between spontaneous physical activity (expressed as absolute counts) and energy expenditure (expressed as kJ over 30 minutes). For each subject the individual linear regression equation was extrapolated to zero activity. This level, including basal metabolic rate,

Table 18A. Physical activity (AMrel, DMrel) before (week 1) and in the last week of the first slimming period (week 5), relative to physical activity before weight loss (100%).

Dietary regimen		n	AMrel		DMrel	
wk 1	wk 5		wk 5	diff	wk 5	diff
			(%)		(%)	
S100	C50	10	65.7 (9.5)	34.3[†a] (9.5)	74.9[1] (13.3)	25.1[†b] (13.3)
S100	AB/100	10	84.6 (22.2)	15.4[a] (22.2)	94.0[1] (24.9)	6.0[c] (24.9)
S100	A50/100	9	79.4 (24.4)	20.6[*a] (24.4)	89.2 (14.8)	10.8[bc] (14.8)

results expressed as means (sd)
values with similar superscripts (a,b......) in the same column are not significantly different (one-way analysis of variance, $p<0.05$)
* significantly different from zero (paired t-test, $p<0.05$)
† significantly different from zero (paired t-test, $p<0.001$)
1 one missing value

Table 18B. Physical activity (AMrel, DMrel) in the last week of each slimming period for the three slimming studies.

slimming study	n		AMrel %			DMrel %		
study 1	10		C50	AB/100	diff	C50	AB/100	diff
		Mean	66.0	72.7	6.7	86.4[1]	80.2[1]	-6.2
		SE			(5.5)			(6.7)
study 2	10		C50	A50/100	diff	C50	A50/100	diff
		Mean	69.3	69.7	0.4	70.6[1]	71.3[1]	0.6
		SE			(5.0)			(5.2)
study 3	10		A50/100	AB/100	diff	A50/100	AB/100	diff
		Mean	81.8[1]	86.0[1]	4.2	89.6[1]	83.5[1]	-6.1
		SE			(10.1)			(5.6)

standard error of difference is obtained from the pooled estimate of the standard deviation of the difference

* significantly different from zero ($p<0.005$)

† significantly different from zero ($p<0.001$)

1 one missing value

Table 19. Physical activity (AMrel, DMrel) in the final week of slimming (week 9) and in the final week of the follow-up periods (at 1 month and 1 year respectively) relative to physical activity before weight loss (week 1: 100%)

follow-up study	wk 9	follow-up	follow-up - wk 1	follow-up - wk 9
1 month (n = 8)				
AMrel	62	74	-26*	+13*
(%)	(16)	(20)	(20)	(11)
DMrel	69	86	-14	+17
(%)	(28)	(27)	(27)	(32)
1 year (n = 7)				
AMrel	58	59	-41*	-0.4
(%)	(15)	(24)	(24)	(12)
DMrel	-	-	-	-
(%)				

results expressed as means (SD)
* significantly different from zero (paired t-test, $p<0.05$)

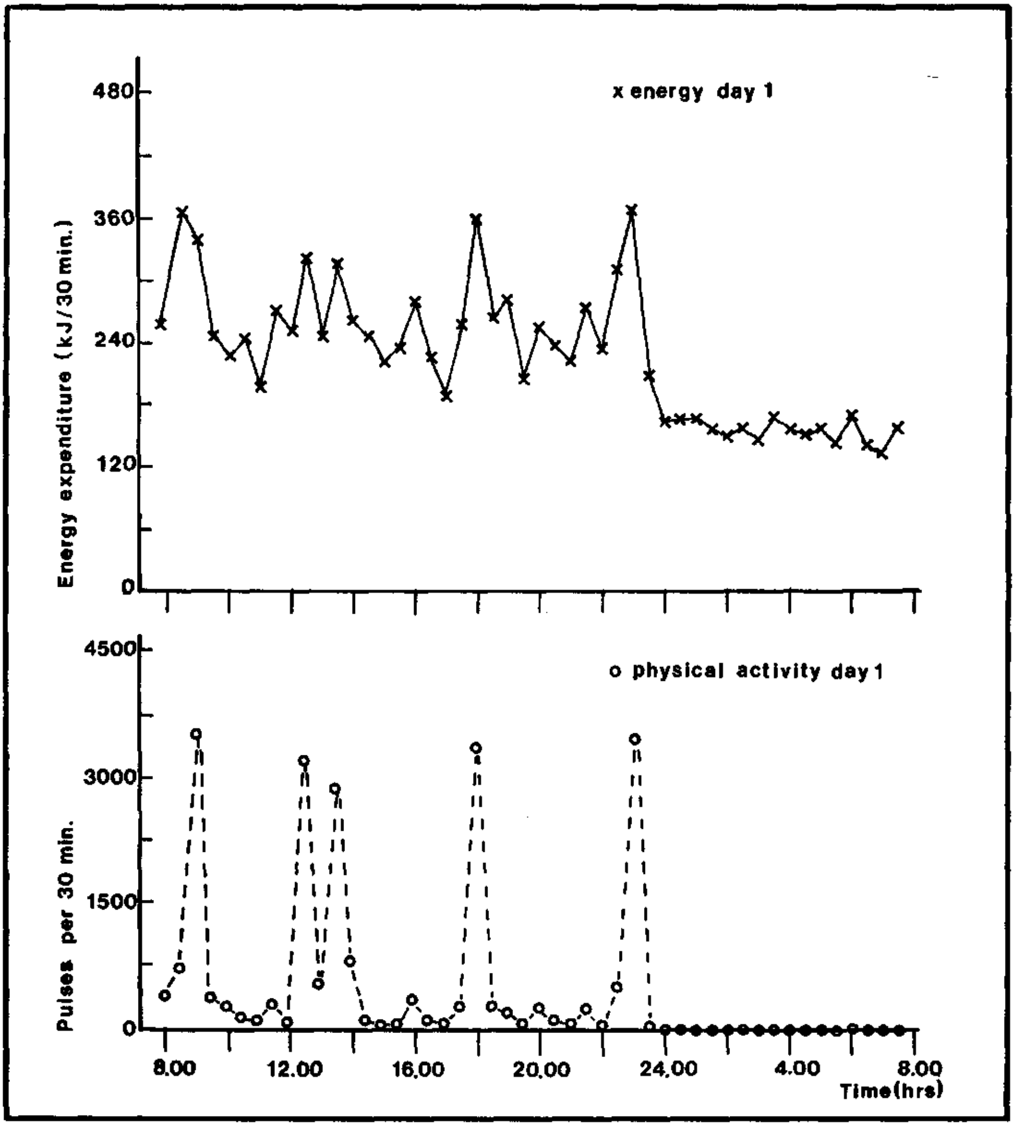


Fig. 9 Course of energy expenditure and physical activity over 24 h of subject no. 22
Individual regression equation (sleeping and cycling periods excluded):
y (kJ/30 min) = 207 (Res. SD 18) + 0.199 (SE 0.022) * activity count
r = 0.891 (p < 0.01)

postural energy cost and average post-prandial thermogenesis, was compared with the sleeping energy expenditure to calculate the dietary induced thermogenesis (Schutz et al. 1984a). Table 20 summarizes the results of those calculations for seven women whose EE correlated well ($r \geqslant 0.7$) with their activity counts. Obviously dietary induced thermogenesis appeared to amount to 14.2 ± 1.0 %.

3.6. Respiratory quotients, energy balances and nitrogen balances

Respiratory quotients, not corrected for protein oxidation, were 0.85 ± 0.01, 0.79 ± 0.01, 0.82 ± 0.02 and 0.81 ± 0.01 for the diets S100, C50, AB/100 and A50/100, respectively.

Energy balances varied around zero for subjects on the 100 % diets before weight reduction (table 21). They became negative during weight reduction and differed for the three diets in the comparison over the first slimming period ($p<0.001$) as well as in the cross-over comparison for each slimming study ($p<0.05$).

One month after slimming the RE was slightly but not significantly lower (-437.5 ± 403.7 kJ/d) than the baseline RE (-198.6 ± 583.0 kJ/d).

The mean energy balance of eight subjects who participated in the 1-year follow-up study was -195.8 ± 413.2 kJ/d at the onset measurement and 99.7 ± 520 kJ/d at the follow-up measurement.

Nitrogen balances were close to zero during the S100 measurements. Mean values during slimming were either slightly positive (e.g. study 3, wk5, diet A50/100: 0.2 ± 0.9 g/d) or slightly negative (e.g. study 1, wk5, diet C50: -1.3 ± 0.7 g/d). After slimming N balances averaged 0.5 ± 0.9 g/d (1-month follow-up) and -0.1 ± 0.8 g/d (1-year follow-up).

3.7. Anthropometry

Results of anthropometric measurements are presented in table 22. Along with the loss of body weight, the body fat percentages fell by approximately 3.2 %. Over 8 weeks the circumferences of arm, waist, hip, upper thigh and calf were lower than the original circumferences by 6.9, 7.9, 6.3, 6.3 and

Table 20. Dietary induced thermogenesis on weight-maintenance diet S100, expressed as a multiple of SEE and as a percentage of metabolizable energy intake.

Woman	ME	SEE	EEno activity	DIT over BMR*	DIT over E intake†
	(kJ)	(kJ/min)	(kJ/min)		(%)
7	9730	4.24	6.32	1.49	17.9
10	10208	4.58	6.58	1.44	16.4
14	8951	4.03	5.28	1.31	11.6
17	9421	4.28	5.66	1.32	12.3
19	9394	4.00	5.32	1.33	11.7
22	10811	5.21	6.87	1.32	12.9
27	9334	4.34	6.12	1.41	16.1
Mean				1.37	14.2
(SE)				(0.03)	(1.0)

* EEno act/SEE

† $\frac{\text{(EEno act - SEE)}}{\text{ME}}$ * 840 (min) * 100 (%)

equations are derived from Schutz et al. (1984a) using the relationship between activity level and energy expenditure to estimate EE at zero activity (EEno activity)

Table 21. Energy balance (RE), and nitrogen balance (N-balance) throughout the slimming studies.

slimming study	dietary regimen			n	RE			N-balance		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
						(kJ/d)			(g/d)	
study 1	S100	C50	AB/100	5	-384	-3581	-2218	-0.9	-1.3	-0.1
					(315)	(371)	(450)	(1.4)	(0.7)	(0.9)
	S100	AB/100	C50	5	18	-2725	-3751	0.3	-0.7	-1.1
					(311)	(608)	(497)	(0.3)	(0.5)	(0.9)
study 2	S100	C50	A50/100	5	-50	-3869	-2023	0.0	-1.2	-0.3
					(972)	(1144)	(484)	(1.3)	(0.9)	(1.1)
	S100	A50/100	C50	5	164	-1766	-3841	0.2	0.2	-1.6
					(583)	(901)	(481)	(0.4)	(2.5)	(0.4)
study 3	S100	A50/100	AB/100	5	-7	-1650	-3001	0.4	0.2	-0.9
					(522)	(697)	(897)	(0.5)	(0.9)	(1.2)
	S100	AB/100	A50/100	5	-107	-2569	-2187	0.2	-0.9	-0.1
					(527)	(758)	(583)	(0.5)	(1.3)	(1.4)

results expressed as means (sd)

Table 22. Body weight, body fat %, circumferences, waist-to-hip ratio (WHR) and waist-to-thigh ratio before slimming (wk 1) and in the last week of each slimming period (wk 5, 9).

parameter	wk 1	wk 5	wk 9	wk 9 - wk 1
	(n=27)	(n=27)	(n=27)	(n=27)
Body weight (kg)	81.4	76.8	73.0	-8.5*
	(12.1)	(11.9)	(12.0)	(1.9)
Body fat%				
- 3 skinfolds	37.7	36.4	34.5	-3.2*
	(4.3)	(4.1)	(4.5)	(1.0)
- 4 skinfolds	39.2[1]	37.9[1]	36.0[1]	-3.2*
	(3.6)	(3.7)	(4.4)	(1.4)
- densitometry	39.9[1]	38.3[1]	36.8[1]	-3.1*
	(6.2)	(6.6)	(6.8)	(2.0)
Circumferences				
- arm (cm)	33.5	32.4	31.2	-2.3*
	(3.1)	(3.4)	(3.3)	(0.8)
- waist (cm)	89.6	85.3	82.5	-7.1*
	(10.7)	(10.4)	(10.5)	(2.0)
- hip (cm)	111.0	108.1	104.9	-7.0*
	(8.0)	(7.8)	(7.9)	(1.5)
- upper thigh (cm)	66.8	65.0	62.6	-4.2*
	(5.4)	(5.5)	(5.6)	(1.4)
- calf (cm)	38.8	38.1	37.5	-1.3*
	(3.0)	(5.6)	(3.0)	(0.5)
WHR	0.81	0.79	0.79	-0.02*
	(0.07)	(0.06)	(0.07)	(0.0)
WTR	1.34	1.32	1.32	-0.02*
	(0.14)	(0.13)	(0.12)	(0.0)

* significantly different from zero (paired t-test, $p<0.001$)

1 one missing value

3.3 %, respectively. A small decline (0.02 units) was found for the waist-to-thigh ratio and the waist-to-hip ratio.

4. Discussion

The slimming and follow-up studies are discussed separately in this chapter.

4.1. Slimming studies

Experimental conditions

In the slimming studies described in this thesis four different diets were used: a weight-maintenance diet (S100) and three slimming diets (C50, AB/100, A50/100). The digestibility and metabolizability were found to be similar for the S100 and the slimming diets C50 and A50/100: on average 93 % and 89 %, respectively. Digestibility and metabolizability of the diet AB/100 were only somewhat lower: 92 % and 87 %, respectively. The lower digestibility of AB/100 was probably due to its higher dietary fibre content per MJ ME (table 5). De Boer et al. (1986) reported a lower metabolizability of a 4.2 MJ diet compared to the same diet eaten at the weight-maintenance level of intake. This was explained by higher urinary nitrogen losses during the 4.2 MJ diet. Energy content in urine was proved to be strongly correlated with its nitrogen content (van Es et al. 1984) and N balances during the low energy diet were negative. Energy intakes in the present study exceeded 4.2 MJ per day and nitrogen balances were only slightly negative (table 21). Both factors probably contribute to the smaller decrease in metabolizabilities of the prescribed slimming diets in this study as compared to a 4.2 MJ diet reported by de Boer et al. (1986).

The actual ME intakes of the slimming diets amounted to 50 % (C50), 62 % (AB/100) and 73 % (A50/100) of the weight-maintenance intake, so they closely approached the planned intakes.

All the slimming studies had a similar design. After 1 week on a weight-maintenance diet each subject was involved in two successive slimming periods of 4 weeks. At the end of each slimming period the subject stayed in a respiration chamber. The activity pattern in the respiration chamber was standardized to mimic light housekeeping or sedentary work. From 24EE and SEE the physical activity index (24EE/BMR) could be calculated. It amounted to 1.52 (SD 0.09) for the weight-maintenance measurements. This value is similar to the activity index for a housewife in an affluent society (1.52) as reported by the FAO/WHO/UNU (1985). Garby, Lammert & Nielsen (1986) recently reported a similar value, 1.53 (SD 0.11), for eight men involved in an activity programme consisting of light activities such as sleeping, lying on a bed, sitting, walking, moving objects and light bicycle work. However, our measurements on physical activity by Dopplermeters and actometers indicate a reduction of spontaneous activities during slimming (tables 18-19). The large coefficients of variation of our measurements imply a wide between-subject variation in activity reduction. Moreover, Dopplermeter and actometer results do not agree with each other. Nevertheless they give a clear-cut indication of reduced spontaneous physical activity during the slimming studies, though they cannot discriminate between diet effects. It should be pointed out that behavioral changes are not necessarily the resultant of dieting but may be ascribed to habituation (getting accustomed to the procedure in the respiration chamber) as is suggested by the lower activity in the second slimming period compared to the first period of slimming. Whatever their origin, the behavioral changes influence the EE measurements. Information on their size is valuable despite their inaccuracy.

Weight loss and its composition

Weight loss over the first 4 weeks of slimming was most pronounced on the C50 diet (5.8 kg, of which 1.6 kg was fat-free mass) as compared with the alternating diets AB/100 (4.5 kg body weight, 1.8 kg fat-free mass) and A50/100 (3.9 kg body weight, 2.6 kg fat-free mass). During the second slimming period weight was lost more slowly than during the first period: C50: 4.5 kg (1.8 kg fat-free mass), AB/100: 3.5 kg (1.2 kg fat-free mass), A50/100: 2.6 kg (0.0 kg fat-free mass). A number of factors may influence the changing rate of weight loss. First, the reduction of ingested food and gut contents account for an additional 'weight loss' of at least 0.5 kg during the first days of weight reduction. Second, during the first week of weight reduction there is a reduction of glycogen stores and an early loss of lean tissue usually accompanied by an 'obligatory' water loss. Third, severe energy restriction is associated with ketosis and consequently with increased diuresis, resulting in increased mobilization of fat reserves and sometimes dehydration. There is no doubt that weight loss is also caused by breakdown of body fat. Loss of body fat, however, is not accompanied by obligatory water loss, instead to a small extent water may replace fat. Moreover, the weight loss associated with fat breakdown is not large, because of the high energy content of fat. Since energy restriction in our studies was not severe - the slimming diets provided at least 4.2 MJ per day - ketosis was not likely to occur in the present studies. Therefore the first and the second factors were mainly responsible for the changing rate of weight loss in the second compared to the first slimming period.

Over 8 weeks of slimming weight was lost, in our studies, at a rate of 0.9 - 1.1 kg/week. At the lowest rate of weight loss (slimming study 3) the smallest amount of fat-free mass was lost. It must be noted that data on changes of body composition are still liable to considerable error. Since Garrow et al (1979) showed that replicate measurements of fat mass had a precision of 0.3 kg (SD), the main source of error probably lies in the assumptions made about the composition of fat-free mass. Moreover, we cannot be sure that the fat-free mass remains of constant composition when weight changes. It is not likely that the constituents of fat-free mass (bone mineral, protein and water) contribute to weight loss in the same proportions in which they originally occur (Burkinshaw & Morgan, 1985). Still, the objective of weight reduction is to reduce fat stores without excessive loss of fat-free mass. Webster, Hesp & Garrow (1984) investigated the composition of excess weight in obese women by reviewing the results of measurements of body composition in 104 women, ranging from normal weight to severe obesity. Their findings led them to conclude that the target for treatment of overweight should be that no more than 22 % of the weight lost should be fat-free mass. In the first slimming period of our slimming studies, weight loss was due to far more than 22 % fat-free mass. Only diet C50 approached this target percentage (28 %). Loss of fat-free mass might have been even higher if it had not been restricted by protein supplementation during the first half of the C50 slimming period. The relatively small weight loss over the the first A50/100 period, in combination with initial 'obligatory' losses, was probably associated with the high contribution (67 %) of fat-free mass to weight loss. Also Garrow et al. (1979) observed unfavourable losses of fat-free mass when they studied 19 obese women over a period of only about 3 weeks on a diet supplying 800 kcal (3.4 MJ) per day. The observed ratio of fat to fat-free mass lost for the first 5 kg of weight loss was 50:50 rather than 78:22. Pooling the data for our three slimming studies, the composition of weight lost over 8 weeks was 66 % fat and 34 % fat-free mass. Other investigators (Bessard et al. 1983; Ravussin et al. 1985; de Boer et al. 1986) report losses of fat-free mass of about 25 %. Their subjects tended to lose relatively less fat-free mass at substantially greater energy deficits. This can be attributed to the continuous protein supplementation of the slimming diets in their studies. However, when data for our studies are pooled for the second slimming period, the proportion of fat-free mass (26 %) in the weight lost approached the value reported by the previously-mentioned investigators.

Quantitative information about the composition of weight loss permits us to estimate its caloric equivalent, assuming that 1 g of fat and 1 g of fat-free mass are equivalent to 38.9 kJ and 4.27 kJ, respectively (Van Itallie, Yang & Hashim, 1974). Since substantial shifts in water balance may occur early in weight reduction, the caloric equivalent was calculated for the second slimming period. The highest value was observed for A50/100 (32.9 MJ/kg weight loss) and lower values for C50 and AB/100 (26.6 and 29.5 MJ/kg weight loss, respectively).

Reduction in energy expenditure rates

Twenty-four hour energy expenditure: Few data are available in the literature on the effect of slimming and weight loss on 24EE, measured under carefully controlled experimental conditions. As for the effect of daily alternating reduced energy intake, no information at all can be found. We observed average falls in 24EE values over the first 4 weeks of slimming of 13.7 % (C50), 10.7 % (AB/100) and 8.4 % (A50/100). The observed decrease of 24EE over 8 weeks of slimming (12-15 %) is in agreement with previously reported declines during the dynamic phase of weight loss (Apfelbaum et al. 1971; Webb & Abrams, 1983; Ravussin et al. 1985). In other studies, the 24EE measured at weight maintenance before slimming, was not compared with 24EE measured at the end of the slimming period, as was done in the present studies but with 24EE measured after a week of refeeding a weight-maintenance diet (Bessard et al. 1983; de Boer et al. 1986). This resulted in a smaller fall (10 %) of overall daily energy expenditure.

It may be argued that in our studies energy expenditure on a weight-maintenance diet, the first of our three measurements, was elevated due to stress. However, subjects were familiarized with the equipment and experimental routine for more than 24 h a few months before the studies. We observed a mean coefficient of variation within subjects of 1.5 % for three consecutive 24EE measurements during the first measurement period (week 1). This value is close to the coefficient of variation for well-adapted subjects as reported by de Boer et al. (1987) and Murgatroyd, Davies & Prentice (1987). Therefore we assume that the first measurements of 24EE were not affected by stress due to unfamiliarity with the respiration chamber and experimental routine.

It is certain that the reduction of 24EE after slimming and weight loss can be attributed to three main factors:

(1) the reduced body mass, in particular fat-free mass;

(2) the lower energy intake, fed during slimming and as a consequence a lower obligatory thermogenic response to food;

(3) the decrease in the energy cost of physical activity because of weight loss.

The contribution of the first factor can be eliminated to a large extent by expressing 24EE per unit body mass. In our studies, both body weight and fat-free mass correlated well with 24EE at weight maintenance ($r = 0.81$ and $r = 0.79$ respectively). In an earlier study at this institute with 47 women (lean or obese) a higher correlation coefficient of weight and 24EE (0.91) was shown. We found 24EE/W to decrease significantly over the first slimming period. For the diet C50 it decreased from 121 kJ/kg to 112 kJ/kg, a decrease of 7 %. Comparable declines for the alternating diets AB/100 and A50/100 amounted to 5 % (from 118 to 112 kJ/kg) and 4 % (from 120 to 116 kJ/kg) respectively. From the results of Webb & Abrams (1983) a significant decline of 24EE/W (7 %) can be computed. No decline can be found when the data on body weight and 24EE as reported by Ravussin et al. (1985) are analysed. The data on 24EE mentioned so far, as well as our own, however, are obscured by differences of ME intake. De Boer et al. (1986) and Bessard et al. (1983) measured 24EE after the return to a weight-maintenance diet.

In both studies the 24EE/W was similar before and after weight loss.

The 24EE per unit fat-free mass was also observed to decrease in our studies (table 9A). Similar results were reported by de Boer et al. (1986) and Ravussin et al. (1985). Comparison of our results with those found in other studies is however not only hampered by the differences in diet type and duration, but also by differences in the methods used to estimate body composition, all of which have their limitations. We estimated body fatness from underwater weighing. Ravussin and Bessard estimated it from skinfold thicknesses at four sites. Unfortunately, skinfold thickness is difficult to measure in obese subjects and the table of Durnin and Womersley (1974) does not cover obese or formerly-obese adults (Scherf et al. 1986; Barrows & Snook 1987a). The problem of estimating fat content is furthermore compounded by the fact that adipose tissue may vary in its fat content, which tends to increase with adiposity (Martin et al. 1985). For reasons of comparison, and because of the influence of weight-bearing activities on the 24EE and the uncertainties associated with determining body composition, we prefer to express the 24EE per unit body weight rather than per unit fat-free mass.

No clear evidence was found that the alternating diets counteracted the decrease in the 24EE. Diet AB/100 even resulted in a significantly lower 24EE/W (117 kJ/kg) than diet C50 (120 kJ/kg) in slimming study 1. A lower amount of physical activity might have contributed to the lower energy expenditure. Subjects were released from the obligation to prepare meals on the bread days of diet AB/100. This explanation is not however, confirmed by the actometer or Dopplermeter measurements.

We eliminated the effect of the second factor, the difference in dietary intake, by subtracting dietary induced thermogenesis (DIT) from total energy expenditure. Various values for the DIT may be found in the literature. Some investigators have reported blunted thermogenic responses to mixed meals in obese individuals with a family history of obesity (Shetty et al. 1979; Schutz et al. 1984a; Swaminathan et al. 1985). It has been suggested that the thermogenic defect is constitutional rather than a consequence of excessive body weight. Studies of the postprandial thermogenic responses in obese subjects have shown that the thermogenic defect does not disappear (Shetty et al. 1979; Bessard et al. 1983; Schutz et al. 1984b). We used figures reported by Bessard et al. (1983), Schutz et al. (1984b) and de Boer et al. (1986) (section 3.3.1) and calculated dietary induced thermogenesis as reported by Schutz et al. (1984a) using our own data (section 3.5). The absolute differences in 24EE persisted after adjustments for differences in ME intake. This was to be expected, because they were mainly due to differences in body weight. When the DIT was assumed to be 6 - 9 % of the ME intake, the differences in the 24EE per unit body weight on weight-maintenance and slimming diets were significant for diet C50, but not for the alternating diets. Dietary induced thermogenesis did not account for the difference of 24EE/W on the slimming diets in study 1 (C50, AB/100). It may be argued that the higher contribution of carbohydrate to the ME of diet AB/100 (52 ME% instead of 45 ME%) affected the dietary response. However, dietary carbohydrates were replaced by fat rather than protein. Both nutrients, fat and carbohydrates, lead to a nearly similar thermogenic response when directly oxidized (Flatt, 1978).

It is difficult or even impossible to indicate the right adjustment for differences in ME intake. From our own data the DIT was found to be 14.2 %. One shortcoming of the method used to calculate the DIT is that the energetic cost of posture (sitting at zero activity) elevates energy expenditure in the inactive state over sleeping values. Furthermore it is postulated that the dietary response is manifested over 840 minutes (table 20). It is unlikely that this period of time is correct and equal for all the diets involved. Schutz et al. (1984a) reported a DIT of similar magnitude for non obese controls. Obese subjects of comparable weight showed a lower DIT (8.7 %). We did not select obese women on the basis of family history of obesity as Schutz did. This fact, combined with the postural effect, may explain the higher DIT we found. If 14.2 % is an overestimate, then the lower values of 6 - 9 % are probably closer to reality (Belko et al. 1987).

The third factor - reduced energy cost of physical activity because of weight loss - is difficult to evaluate. By standardizing the activity pattern within the respiration chambers and restricting it to mainly sedentary activities, the contribution of weight-bearing activities to 24EE is minimized. Since total body weight fell throughout slimming, the energy cost for the same physical activity must have been somewhat reduced after weight loss. It is worth noting that the apparent decrease of EEda/W during slimming mainly occurs during the periods of sedentary activities. Neither the absolute cost nor the weight-related cost of cycling seemed to decrease, which suggests there was no change in cycling efficiency. Results from the literature (Warnold, Carlgren & Krotkiewski, 1978) lead one to believe that there is no change of work efficiency during domestic activities. So only body weight and the amount of spontaneous movements are left as factors that influence activity induced thermogenesis. After adjustment for differences in ME intake, a difference of 4 kJ/kg has to be explained for the S100-C50 and the AB/100-C50 comparisons. Strolling about for 15 minutes or standing for 30 minutes may account for this difference (FAO/WHO/UNU, 1985). Such differences in behaviour are not unlikely to occur, even within the confines of the respiration chamber. Moreover, our measurements of physical activity indicate a reduction of spontaneous activities during slimming. Furthermore, the amount of physical activity still tends to decline after the first slimming period. On the one hand, this may suggest that the subjects were still not fully accustomed to the procedure in the respiration chamber. On the other hand, it is also possible that - due to growing acquaintance with life in the respiration chamber - activities in the chamber were better organized, and prepared for at home, in the course of the study. During the 1-month follow-up measurements, physical activity tended to be higher than in the last week of slimming. Therefore it is likely that a part of reduced physical activity during slimming results from low energy intake. Our results are in contrast to those of Ravussin et al. (1985) and Bessard et al. (1983) who concluded from their radar-measurements that physical activity was unaltered.

In free-living conditions, the body-weight related cost of physical activities and behavioural adaptations must play a more important role in overall energy expenditure. At home, spontaneous physical activity is increased compared to that within the experimental setting of our studies. Behavioral adaptations may then include cutting out discretionary (non-occupational) activities and adjustments in the rate of doing work. However the relationship between EE and changes in physical activity still has to be conclusively demonstrated for short term energy restriction.

Since the observed decrease in the 24EE could be explained by changes in body weight, energy intake and physical activity, there is little need to invoke other adaptive mechanisms to account for the reduction in 24EE.

Nevertheless, diet and activity induced thermogenesis might be influenced by sympathetic activity. It is suggested that suppression of sympathetic activity occurs during fasting or caloric restriction (Landsberg & Young, 1982, 1983; Young & Landsberg, 1982) thus mediating changes in energy output that accompany changes in dietary intake. A reduction of circulating catecholamines (Sowers et al. 1982; Schwarz et al. 1983) and a fall in the excretion of catecholamine metabolites (Jung et al. 1980; Koppeschaar et al. 1985) occurs in humans during caloric restriction. Fasting rats demonstrate a reduced noradrenalin (NA) turnover (Young and Landsberg, 1982). As a result of diet-related reduction in sympathetic activity, undernourished people show an increase in adrenoceptor sensitivity (Jayarajan & Shetty, 1987). The possible relationship between DIT and sympathetic nervous system activity was recently investigated (Schwartz et al. 1987). It was suggested that the activity of the sympathetic nervous system, as reflected by NA-appearance rate, could explain the facultative component of DIT. The mechanisms for facultative thermogenesis are unknown at present. Its counterpart, the obligatory component of DIT, includes the energy expended due to digestion, absorption, transportation and storage of ingested nutrients. We did not measure plasma NA-kinetics in the present study. It is therefore difficult to evaluate their role in the regulation of 24EE. It is still open to question whether the reduced sympathetic drive influences either DIT or activity induced thermogenesis, or both.

Sleeping energy expenditure: The present study confirms the observations of a diminishing RMR along with weight reduction (table 1). We used measurements on EE during the night - which is considered to be similar to basal metabolic rate if evidence of sleep is available (Bessard et al. 1983; Schutz et al. 1984a) - to express BMR. The BMR in our studies was 3 % lower than the BMR predicted by the FAO/WHO/UNU equations (1985). Over the first 4 weeks of slimming, the SEE decreased by 10.7 % (from 270 to 241 kJ/h on C50), 7.7 % (from 260 to 240 kJ/h on AB/100) and 3.7 % (from 268 to 258 kJ/h on A50/100). A further decrease of 6-13 % was achieved in the second slimming period. Declines of similar size (6-13 %) have been reported by other authors (Garrow et al. 1978; Welle et al. 1984; Ravussin et al. 1985; de Boer et al. 1986; Welle & Campbell, 1986; Belko et al. 1987). We found diet A50/100 to reduce the SEE less than diet C50 (in the first 4 weeks of slimming) and diet AB/100 (in slimming study 3). This might be due to a persistent dietary induced thermogenesis during the night while on diet

A50/100 - since energy intake on diet A50/100 was higher than on diet AB/100 or diet C50 - resulting in a residual effect on sleeping energy expenditure.

To eliminate the effects of reduced body weight and change of body composition on SEE, we expressed the SEE per kg body weight (SEE/W) and per kg fat-free mass (SEE/FFM). In our studies the sleeping energy expenditure correlated well with body weight (r = 0.80) and fat-free mass (r = 0.75). Webb (1981) found quiet-sleeping energy expenditure of 15, predominantly non-obese subjects, to be a function of fat-free mass (r = 0.93). Nevertheless, since changes of body composition cannot easily be determined, we prefer to express SEE per unit body weight. We found that the SEE/W did not fall significantly over the first 4 weeks of slimming. Each slimming diet resulted in a similar small decline in the SEE/W. The values remained within the range 3.1-3.3 kJ/kg.h. The only significant difference in the SEE/W was between A50/100 and AB/100 (3.26 kJ/kg.h vs 3.16 kJ/kg.h) in slimming study 3. However, this difference was small, and might have been due to the persistence of diet induced thermogenesis with diet A50/100 during the night. Moreover, comparisons of the two alternating diets with C50 both indicated a similar effect. Few authors express the BMR, RMR or SEE during weight loss per unit body weight. Our results are in agreement with those of Bessard et al. (1983), Ravussin et al. (1985), Mathieson et al. (1986), Barrows & Snook (1987b), and Belko et al. (1987), none of whom report a fall of SEE/W.

With regard to the SEE/FFM no diet differences emerged from our cross-over comparisons. The SEE/FFM for C50 and AB/100 did decrease over the first 4 weeks of slimming, but for diet A50/100 no such decline in SEE/FFM was observed. If we compare published results on changes of BMR/FFM across studies, differences in FFM and RMR measurement are striking and contradictory results are reported. In the moderately overweight women, studied by Ravussin et al. (1985) and Belko et al. (1987) the RMR/FFM was maintained in spite of slimming. On the other hand, Bessard et al. (1983), Barrows & Snook (1987b) and van Dale et al. (1987) demonstrated a fall in the RMR/FFM of overweight individuals with low energy intakes. In these last studies (very) low energy diets were prescribed that provided only 1.7 - 2.9 MJ/d, while in our studies and those of Belko and Ravussin the energy intake during slimming was less restricted. During severe energy restriction, fasting and very low calorie diets, plasma triiodothyronine

(T3) concentrations are decreased (Grant et al. 1978; Visser et al. 1978; Jung et al. 1980; Rabast et al. 1981; Serog et al. 1982; Danforth 1983, 1985; Welle & Campbell, 1986; Barrows & Snook, 1987b). It may be postulated that a decrease in plasma T3 contributes to lower resting/basal energy expenditure. Although T3 may decline together with the resting metabolic rate, there is still no conclusive evidence for a cause-and-effect relationship (Danforth, 1983).

In summary, all subjects completed the slimming study succesfully. A weight reduction of 6.9 - 9.0 kg was achieved, depending on the combination of diets prescribed. Along with weight loss, the energy expenditure decreased. The decrease of 24EE could partly be explained from (a) changes of body weight and (b) reduced energy intake. The remaining decrease may be ascribed to (c) reduced cost and amount of physical activity. For the slimming diets the relative contributions of the three components were:

- C50 : (a) 47 %, (b) 31 %, (c) 22 %;
- AB/100 : (a) 48 %, (b) 31 %, (c) 21 %;
- A50/100: (a) 52 %, (b) 25 %, (c) 23 %.

Neither of the alternating diets prevented the decrease of energy expenditure.

4.2. Follow-up studies

After the slimming studies, the subjects continued to visit the laboratory regularly. This may have helped them to maintain their body weights at the lowered levels. Several investigators have reported the difficulty in maintaining weight loss under free-living conditions. Relapse has been observed within 3-4 months (Sjöstrom, 1981), and a return to the original weight occurs in about 50 % of the subjects within 1 to 3 years (Stunkard & McLaren-Hume, 1959; Bender & Bender, 1976; Drenick & Johnson, 1978). We must agree with Wing & Jeffery (1979) that providing external support, in this study by means of frequent contact, helps to maintain reduced body weight.

In the follow-up studies the 24EE and SEE were higher than during the last week of slimming, significantly at 1-month follow-up but less obvious at 1-year follow-up. As in the slimming studies, these differences could have been due to: an increase or decrease in body mass, diet induced thermogenesis, activity induced thermogenesis. It is still uncertain whether differences in thyroid status or sympathetic activity are involved as well. Since the differences in body weight (follow-up minus week 9) were small, both at 1 month (1.1 kg) and 1 year post slimming (0.6 kg), the weight changes could have influenced the differences of energy expenditure to only a minor extent. Dietary induced thermogenesis, however, must have been more important, since the ME intake was higher in the follow-up measurements by 2.8 MJ/d (1-month) and by 3.4 MJ/d (1-year). After adjustment for dietary intake, the differences in the 24EE were smaller and were no longer significant in the 1-month follow-up study. The 24EE also included variations in the metabolic responses due to small differences in spontaneous movements and routine tasks such as bedmaking and personal care. Our data on physical activity indicate an increase in spontaneous movement at 1 month after slimming, so activity induced thermogenesis may have contributed to the increment of 24EE in the 1-month follow-up study.

As in the initial measurements before slimming, also in the follow-up studies the ME intake closely matched the 24EE, and in both follow-up measurements the 24EE and SEE were clearly below initial values. A part of the decrease was certainly due to the lower body weight. During the follow-up studies the mean body weights were still 9.9 kg (1-month) or 8.7 kg (1-year) below the initial values. In the 1-month follow-up study SEE, per unit body weight or per unit fat-free mass, was similar to the initial values and in the 1-year follow-up SEE/W was even slightly higher than the initial SEE/W. The weight-related 24EE (24EE/W) at 1 month post slimming was similar to the initial value, but at 1 year post slimming it was below initial 24EE/W (3.5 kJ/kg). This difference was no longer significant when the 24EE was adjusted for the difference in ME intake, which was 1.6 MJ/d below the initial ME intake at 1 month post slimming and 1.3 MJ/d below at 1 year post slimming. During the follow-up studies the level of physical activity was lower than before slimming, and the energy cost of similar standardized activities must have been lower because of the reduced body weight. It is not unlikely that both activity related factors (amount and energy cost of physical activity) accounted for a difference of 3 kJ/kg remaining in the comparison of 24EE before slimming and after slimming, after adjustment for body weight and ME-intake.

Studies on refeeding after starvation or semistarvation also report increases of resting metabolic rates (Grande, 1958; Drenick & Dennin, 1973; Barrows & Snook, 1987b). Moreover, the serum T3 levels and sympathetic activity rise towards normal within 72 hours of refeeding (Jung et al. 1980; Koppeschaar et al. 1984).

Geissler et al. (1987) made a particularly interesting study of the EE in 16 post-obese women, who were compared with control subjects of similar age, height, weight and lean body mass. Daily expenditure of the post-obese was circa 15 % lower than that of the lean controls and their energy cost of sleep was circa 90 % that of the lean. The differences could not be accounted for by differences in their activities (described in an activity diary) or in dietary induced thermogenesis. It has been postulated that the differences in metabolic rate arise from differences in metabolic efficiency. A defective thermogenic response to noradrenaline infusion before and after weight reduction (Jung, Shetty & James, 1979) points towards a constitutive thermogenic abnormality. Low serum concentatrions of free T3 in post-obese patients are in line with these findings. However, low concentrations were found in post-obese patients treated with very low calorie diets but not for patients treated with gastroplasty (Stokholm, Andersen & Lindgreen, 1987). In contrast to Geissler et al. (1987), James, Lean & McNeill (1987) reported a normal BMR and normal energy requirements in post-obese women. The existence of thermogenic defect finds favour with Jéquier & Schutz (1985) who postulate that one third of obese women has a reduced thermogenesis. Further studies aiming at the heterogeneity of obesities and at the origin of possible thermogenic defects are needed. Thus far it is still open to question whether possible defects are intrinsic or the resultant of long-term restrained eating.

5. Conclusions

Each of the slimming diets resulted in a substantial loss in body weight. Weight loss over the first 4 weeks of slimming was most pronounced with the C50 diet (5.8 kg) and less with the alternating diets AB/100 (4.5 kg) and A50/100 (3.9 kg). In the second month of slimming, weight was lost at a rate of 1.2 kg/week, 0.9 kg/week and 0.7 kg/week on diets C50, AB/100 and A50/100, respectively. In the combined period of 8 weeks the average composition of weight lost was 74 % fat and 26 % fat-free mass.

Digestibilities and metabolizabilities were similar for the weight-maintenance and the slimming diets: 93 % and 89 % respectively. Metabolizable energy intakes were 50 % (C50), 62 % (AB/100) and 73 % (A50/100) of the weight-maintenance intake.

Twenty-four hour energy expenditure fell during slimming. Three components of this decrease were obvious. First, the decrease in body mass which accompanied slimming provoked a decrease in 24EE. Second, diet induced thermogenesis diminished when the food intake was restricted. Third, activity induced thermogenesis was reduced due to the lower cost of similar activities at decreased body weight and to an observed reduction in the amount of spontaneous movement during slimming. The first factor contributed about 50 % to the observed decrease of 24EE, the second about 30 %, and the third factor is presumed to be responsible for the remaining 20 %. Sleeping energy expenditure, expressed per unit body weight did not fall significantly. Our data suggest that the diet- and activity-related decrease of 24EE mainly occurred during daytime and not at night. Since the decrease of 24EE could be explained by changes of body weight, energy intake and physical activity, there is no need to theorize about other adaptive mechanisms influencing 24EE. Rapid changes in weight are likely to result from appreciable changes in either physical activity or food energy intake (or both) despite subtle adaptive mechanisms, of which the metabolic basis and even the existence still have to be shown.

With regard to the main question of this thesis 'Does a low-energy diet based on alternating energy intake, counteract the adaptation to low energy intake?', our answer must be 'no'. Neither of the alternating diets (AB/100, A50/100) decreased the 24EE/W and SEE/W less than the diet C50. The 24EE/W on diet C50 was even significantly higher than on AB/100. Since alternating diets are often used successfully, other, non-metabolic factors must be responsible for their success. With the 'bread-diet' the following factors are possible.

1. the ease and simplicity of the diet, since only bread is allowed on the slimming day;
2. the prospect of normal energy intake after each bread day may stimulate diet-adherence;
3. the low cost of the diet.

Our follow-up studies demonstrate a lower 24EE after slimming as a result of the reduced body weight. It is clear from this study that overweight women who have reduced their body weight cannot return to their original intake without gaining weight. Weight-adjusted differences in EE occurred mainly during daytime and evening. Differences in ME intake and spontaneous physical activity may be fully responsible. Therefore there is little need to consider other adaptive mechanisms that may persist after slimming.

Due attention must be paid to the reduced possibilities of physical activity within the confines of the respiration chamber. The observed tendency to reduce physical activity probably results from slimming as well as from getting accustomed to the procedure in the respiration chamber, and a sense of feeling 'at home'. In normal life spontaneous physical activity is higher than that within the experimental setting of our studies. Therefore, at home, behavioral adaptations may have a stronger influence on 24EE. Measurements of EE by the doubly-labeled water technique (Westerterp et al. 1985) may provide information on the EE with restricted energy intakes under free-living conditions at home.

Furthermore we must emphasize that our results only concern short-term adaptations to restricted energy intake. It has been suggested that also in developing countries, short- or long-term adjustments in energy requirements may be accomplished, mainly by adjustments in spontaneous physical activity and by slow changes in body weight rather than by metabolic adjustments in energy utilization (James & Shetty, 1982). Experimental studies on possible adaptations to long-term restricted energy intakes still need to be carried out.

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Annexes

Annex A. Individual values on gross energy intake (GE), metabolizable energy intake (ME), digestibility (% DE = 100 DE/GE) and metabolizability (% ME = 100 ME/GE) throughout the slimming studies

Annex B. Individual values on body weight and body fat-free mass throughout the slimming studies

Annex C. Individual values on metabolizable energy intake, body weight, body fat-free mass, energy expenditure and physical activity in the last week of the follow-up studies

Annex D. Individual values on energy expenditure during 24 h (24EE) throughout the slimming studies

Annex E. Individual values on energy expenditure during daytime and evening, EEdiurnal (7.30-23.30), throughout the slimming studies

Annex F. Individual values on sleeping energy expenditure adjusted to zero activity (23.30-7.30) throughout the slimming studies

Annex G. Individual energy expenditure due to daily sedentary activities (EEda) and bicycling (EEca) throughout the slimming studies

Annex H. Individual actometer and Dopplermeter values relative to activity counts before weight loss (AMrel, DMrel)

Annex A. Individual values on gross energy intake (GE), metabolizable energy intake (ME), digestibility (% DE = 100 DE/GE) metabolizability (% ME = 100 ME/GE) throughout the slimming studies.

Slimming study	dietary regimen			woman	GE			ME			% DE			% ME		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
						(MJ/d)			(MJ/d)			(%)			(%)	
Study 1	S100	C50	AB/100	1	9.5	4.7	5.8	8.6	4.2	5.1	94.2	92.2	92.9	90.4	87.4	88.3
				3	14.0	7.0	8.0	12.2	6.3	7.0	90.8	94.0	91.5	87.0	89.2	87.1
				6	10.7	5.5	6.2	9.6	5.0	5.7	94.6	96.6	95.6	90.2	91.4	91.5
				8	10.2	5.1	5.9	8.5	4.4	5.1	87.7	91.0	91.4	83.6	85.6	86.5
				27	10.9	5.5	6.5	9.3	4.8	5.6	89.5	92.2	91.1	85.5	87.2	86.3
	S100	AB/100	C50	2	12.4	8.5	5.9	11.0	7.3	5.1	92.7	90.2	92.0	89.0	86.1	86.6
				4	10.2	6.3	4.9	9.0	5.3	4.4	92.2	89.6	95.1	88.3	84.9	89.9
				5	10.0	6.0	4.9	8.9	5.2	4.3	93.0	91.1	91.1	89.4	86.8	87.1
				7	11.1	6.7	5.3	9.7	5.8	4.5	91.2	90.6	89.2	87.7	86.4	84.1
				26	11.1	6.7	5.0	10.0	5.9	4.5	94.3	92.1	95.5	90.0	87.2	90.0
Study 2	S100	C50	A50/100	9	10.6	5.3	6.8	9.3	4.3	6.3	92.2	87.8	96.7	87.7	81.5	92.4
				12	12.2	5.4	8.1	10.8	4.6	7.3	92.8	91.7	94.4	88.8	85.7	90.5
				14	9.8	4.9	6.2	9.0	4.6	5.5	94.3	95.4	92.8	91.4	92.1	89.8
				15	13.0	6.5	8.6	11.6	5.8	7.6	92.7	93.9	92.9	89.0	89.1	88.8
				24	10.1	5.2	6.7	9.1	4.7	5.8	93.4	96.1	91.7	89.5	90.6	87.4
	S100	A50/100	C50	10	11.5	8.6	5.1	10.2	7.7	4.5	92.6	92.2	93.2	88.8	90.0	87.6
				11	11.7	7.1	5.2	10.5	6.1	4.4	94.0	91.3	90.3	89.9	86.0	84.5
				13	10.8	8.1	4.9	10.0	7.4	4.2	96.5	95.5	91.6	92.5	91.3	86.3
				16	10.5	7.8	4.8	9.5	7.1	4.1	92.7	92.3	90.8	90.2	90.2	86.0
				25	9.4	6.9	4.3	8.5	6.2	3.6	94.0	94.0	89.3	90.3	90.6	84.2
Study 3	S100	A50/100	AB/100	11	10.2	7.6	6.6	9.1	6.8	5.9	92.8	94.0	93.0	89.1	89.5	88.6
				18	11.0	8.3	6.4	9.6	7.7	5.1	90.6	94.8	83.9	86.8	92.4	80.0
				19	10.4	7.8	5.6	9.4	7.0	5.1	94.9	93.8	96.6	90.5	89.3	91.4
				21	12.0	9.1	6.9	10.7	8.3	6.1	91.1	92.5	91.3	88.7	90.9	87.6
				22	12.0	9.0	6.6	10.8	7.9	5.5	93.8	91.1	88.6	89.7	87.5	83.4
	S100	AB/100	A50/100	12	10.6	6.5	7.0	9.4	5.8	6.5	93.2	93.7	96.9	89.2	89.3	92.6
				15	11.0	6.8	7.3	10.0	6.2	6.4	95.0	94.8	92.4	90.9	90.9	87.5
				17	10.6	7.7	7.0	9.4	6.9	6.5	92.9	92.5	94.8	89.2	90.4	92.2
				20	10.2	6.2	6.8	9.1	5.5	6.4	93.0	94.1	98.4	88.9	88.9	93.6
				23	11.4	7.4	7.5	10.3	6.5	6.7	93.6	90.9	93.3	90.0	88.1	89.5

Annex B. Individual values on body weight and body fat free mass throughout the slimming studies.

Slimming study	dietary regimen			woman	Body weight			Body fat-free mass*		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
						(kg)			(kg)	
Study 1	S100	C50	AB/100	1	71.8	66.4	63.4	47.6	45.2	45.4
				3	79.0	72.4	68.6	48.3	46.1	45.5
				6	77.7	72.4	69.3	-	47.1	44.7
				8	75.0	68.4	64.3	45.6	45.3	43.6
				27	83.2	79.1	76.6	42.8	43.7	40.7
	S100	AB/100	C50	2	85.7	80.9	75.8	55.0	53.2	51.8
				4	72.6	68.2	64.4	44.7	42.7	40.7
				5	70.8	66.0	62.0	41.4	38.9	38.2
				7	73.0	68.1	63.4	49.3	47.9	44.4
				26	85.7	81.6	76.8	46.9	44.4	43.2
Study 2	S100	C50	A50/100	9	67.5	61.4	58.1	43.6	41.6	41.2
				12	111.1	105.1	100.9	58.3	57.1	56.3
				14	72.8	67.6	65.6	42.7	41.2	40.4
				15	99.8	92.8	89.0	60.3	56.2	55.9
				24	79.7	74.2	71.4	45.9	-	43.0
	S100	A50/100	C50	10	77.6	74.4	69.2	50.3	49.0	46.6
				11	95.6	89.4	82.4	57.8	53.2	50.5
				13	77.0	73.4	68.0	47.4	43.5	42.2
				16	76.8	71.7	66.6	55.2	48.0	47.2
				25	70.8	67.8	63.6	40.5	-	37.0
Study 3	S100	A50/100	AB/100	11	82.7	77.6	73.6	53.4	51.5	50.7
				18	83.5	79.5	77.0	-	-	-
				19	64.0	61.2	57.0	43.3	43.6	42.0
				21	79.9	77.4	73.4	50.0	49.1	49.1
				22	107.1	103.3	99.5	48.5	46.8	45.9
	S100	AB/100	A50/100	12	96.8	91.2	87.7	56.3	53.9	54.5
				15	87.5	82.6	81.2	55.6	52.8	54.1
				17	97.9	94.2	92.8	48.3	48.1	50.3
				20	70.4	66.6	64.6	44.2	43.9	42.7
				23	92.3	88.4	86.4	-	-	-

* derived from underwaterweighing

Annex C. Individual values on metabolizable energy intake, body weight, body fat-free mass, energy expenditure and physical activity in the last week of the follow-up studies.

Study	woman	dietary regimen	ME	Body weight	fat-free mass	24* EE	EEdiurnal	SEE	AM rel	DM rel
			MJ/d	(kg)	(kg)	(kJ/24h)	(kJ/h)	(kJ/h)	(%)	(%)
1 month	3	S'100	8.79	66.9	45.5	9321	435	266	53.5	110.5
follow-	4	S'100	7.57	63.3	40.4	7495	352	214	100.2	66.0
up	7	S'100	7.79	62.4	43.6	8877†	432†	251†	79.5	75.2
	8	S'100	7.58	62.5	44.1	7915	376	242	59.6	113.0
	9	S'100	7.94	56.0	41.6	8382	416	222	76.1	77.2
	10	S'100	8.10	68.2	48.1	8582	413	254	46.0	44.5
	24	S'100	7.66	70.6	43.1	8256	407	235	-	80.6
	25	S'100	7.67	62.5	38.6	7316	351	219	82.4	-
	26	S'100	8.80	76.2	44.4	9487	465	246	97.5	123.5
	27	S'100	8.00	76.6	41.7	8656	421	247	-	-
1 year	3	S''100	10.00	70.6	45.6	8800	418	262	42.1	-
follow-	4	S''100	7.34	63.2	38.4	7627	363	230	107.0	-
up	5	S''100	7.93	60.2	35.8	7909	387	214	60.4	-
	6	S''100	8.56	70.6	46.4	8699	422	242	63.6	-
	7	S''100	8.19	66.5	47.8	8520	408	237	37.0	-
	8	S''100	8.22	66.5	43.1	7784	375	232	61.3	-
	10	S''100	8.71	69.7	46.9	8641	419	249	39.8	-
	16	S''100	8.08	65.6	43.8	8301	405	230	-	-

* mean of 2 days, corrected for urinary N

† excluded from analyses: fever

Annex D. Individual values on energy expenditure during 24 h (24EE)* throughout the slimming studies.

Slimming study	dietary regimen			woman	24EE			24EE/body weight			24EE/fat-free mass		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
					(kJ/24h)			(kJ/kg.24h)			(kJ/kg.24h)		
Study 1	S100	C50	AB/100	1	8690	7183	6677	121	108	105	183	159	147
				3	12327†	10062	8922	156†	139	130	255†	218	196
				6	10098	9059	8318	130	125	120	-	192	186
				8	9376	7968	7544	125	116	117	205	176	173
				27	9725	8320	8172	117	105	107	227	190	201
	S100	AB/100	C50	2	11039	9450	8832	129	117	117	201	178	170
				4	8717	7707	7480	120	113	116	195	180	184
				5	9362	8692	8137	132	132	131	226	223	213
				7	9404	8150	8201	129	120	129	191	170	185
				26	10046	9112	8907	117	112	116	214	205	206
Study 2	S100	C50	A50/100	9	10818	8862	7965	160	144	137	248	213	193
				12	11180	9854	9860	101	94	98	192	173	175
				14	7872	6852	6962	108	101	106	184	166	172
				15	11080	9780	10081	111	105	113	184	174	180
				24	9054	7983	7891	114	108	110	197	-	183
	S100	A50/100	C50	10	10177	9332	8050	131	125	116	202	190	173
				11	10705	9425	9046	112	105	110	185	177	179
				13	8860	8293	7766	115	113	114	187	191	184
				16	9856	8481	7715	128	118	116	179	177	163
				25	8227	7858	7476	116	116	117	203	-	202
Study 3	S100	A50/100	AB/100	11	9604	8659	8153	116	112	111	180	168	161
				18	9915	9662	8853	119	121	115	-	-	-
				19	8576	7630	7108	134	125	125	198	175	169
				21	10641	9575	9034	133	124	123	213	195	184
				22	10818	10323	9564	101	100	96	223	221	209
	100	AB/100	A50/100	12	10332	9505	8760	107	104	100	183	176	161
				15	10235	8911	9159	117	108	113	184	169	169
				17	8990	8756	8594	92	93	93	186	182	171
				20	8805	7514	7660	125	113	119	199	171	180
				23	10330	9076	9236	112	103	107	-	-	-

* mean of 3 (S100) or 2 (C50, AB/100, A50/100) days; corrected for urinary N
† excluded from analyses due to fever

Annex E. Individual values on energy expenditure during daytime and evening (EEdiurnal)* (7.30-23.30) throughout the slimming studies.

Slimming study	dietary regimen			woman	EEdiurnal			EEdiurnal/body weight			EEdiurnal/fat-free mass		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
						(kJ/h)			(kJ/kg.h)			(kJ/kg.h)	
Study 1	S100	C50	AB/100	1	419	349	320	5.85	5.26	5.04	8.82	7.72	7.04
				3	574†	474	417	7.25†	6.55	6.08	7.92†	10.28	9.16
				6	494	426	396	6.35	5.87	5.72	-	9.04	8.86
				8	461	384	361	6.14	5.62	5.61	10.11	8.48	8.28
				27	481	409	395	5.78	5.17	5.16	11.24	9.35	9.72
	S100	AB/100	C50	2	536	461	433	6.26	5.69	5.71	9.74	8.65	8.35
				4	425	364	360	5.86	5.34	5.59	9.52	8.52	8.85
				5	462	421	402	6.53	6.37	6.50	11.17	10.82	10.54
				7	462	395	405	6.32	5.80	6.38	9.36	8.25	9.10
				26	502	453	439	5.86	5.56	5.73	10.71	10.21	10.17
Study 2	S100	C50	A50/100	9	534	435	392	7.92	7.09	6.75	12.26	10.45	9.50
				12	549	474	475	4.94	4.51	4.70	9.41	8.31	8.43
				14	374	323	330	5.14	4.78	5.03	8.76	7.84	8.16
				15	533	469	481	5.34	5.05	5.40	8.83	8.35	8.59
				24	441	390	388	5.54	5.26	5.44	9.62	-	9.03
	S100	A50/100	C50	10	501	449	386	6.46	6.04	5.57	9.96	9.17	8.28
				11	529	450	428	5.53	5.03	5.19	9.14	8.44	8.47
				13	426	393	372	5.53	5.36	5.46	8.99	9.03	8.81
				16	489	417	370	6.37	5.82	5.55	8.87	8.70	7.82
				25	401	381	361	5.66	5.63	5.67	9.90	-	9.74
Study 3	S100	A50/100	AB/100	11	-	412	386	-	5.30	5.25	-	7.99	7.62
				18	497	474	432	5.95	5.94	5.60	-	-	-
				19	415	367	337	6.48	5.99	5.91	9.59	8.42	8.03
				21	515	458	431	6.45	5.92	5.87	10.30	9.32	8.78
				22	524	499	462	4.89	4.83	4.64	10.80	10.67	10.07
	S100, AB/100, A50/100			12	-	453	417	-	4.97	4.75	-	8.40	7.65
				15	493	421	435	5.63	5.09	5.36	8.87	7.97	8.04
				17	438	423	409	4.47	4.50	4.41	9.06	8.80	8.14
				20	429	359	364	6.10	5.38	5.63	9.71	8.17	8.52
				23	517	449	455	5.60	5.07	5.27	-	-	-

* correction for oxidized protein neglected
† excluded from analyses

Annex F. Individual values on sleeping energy expenditure* - adjusted to zero activity (23.30-7.30) - throughout the slimming studies.

Slimming study	dietary regimen			woman	SEE			SEE/body weight			SEE/fat-free mass		
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
					(kJ/h)			(kJ/kg.h)			(kJ/kg.h)		
Study 1	S100	C50	AB/100	1	252	205	197	3.51	3.09	3.11	5.29	4.54	4.34
				3	364†	288	270	4.58†	3.98	3.94	7.54†	6.25	5.93
				6	266	257	243	3.42	3.54	3.50	-	5.46	5.42
				8	254	227	219	3.39	3.31	3.41	5.58	5.00	5.02
				27	260	228	245	3.13	2.88	3.19	6.08	5.22	6.01
	S100	AB/100	C50	2	298	271	243	3.48	3.35	3.21	5.42	5.09	4.70
				4	237	220	203	3.27	3.23	3.16	5.30	5.16	5.00
				5	237	220	217	3.35	3.34	3.50	5.73	5.67	5.69
				7	256	234	221	3.48	3.44	3.49	5.16	4.90	4.98
				26	263	238	236	3.07	2.92	3.07	5.60	5.38	5.46
Study 2	S100	C50	A50/100	9	291	236	218	4.31	3.85	3.75	6.67	5.68	5.28
				12	303	290	289	2.73	2.76	2.86	5.20	5.09	5.13
				14	242	213	217	3.33	3.16	3.32	5.67	5.17	5.39
				15	304	284	298	3.05	3.06	3.34	5.04	5.05	5.32
				24	256	230	228	3.21	3.10	3.20	5.57	-	5.31
	S100	A50/100	C50	10	275	272	241	3.54	3.65	3.47	5.46	5.54	5.16
				11	288	278	274	3.01	3.11	3.33	4.98	5.22	5.43
				13	262	252	231	3.40	3.43	3.39	5.53	5.78	5.47
				16	250	225	216	3.25	3.14	3.25	4.53	4.69	4.58
				25	233	224	218	3.29	3.30	3.43	5.76	-	5.89
Study 3	S100	A50/100	AB/100	11	-	268	243	-	3.45	3.30	-	5.20	4.78
				18	249	265	248	2.98	3.31	3.22	-	-	-
				19	240	223	214	3.75	3.64	3.76	5.55	5.11	5.10
				21	305	280	261	3.81	3.62	3.55	6.09	5.71	5.32
				22	312	301	277	2.92	2.91	2.78	6.44	6.43	6.03
	S100	AB/100	A50/100	12	-	284	266	-	3.11	3.03	-	5.27	4.88
				15	301	261	271	3.44	3.16	3.34	5.42	4.94	5.02
				17	257	253	263	2.62	2.69	2.83	5.32	5.27	5.22
				20	235	221	231	3.33	3.32	3.58	5.31	5.03	5.41
				23	260	244	247	2.81	2.76	2.86	-	-	-

* correction for oxidized protein neglected
† excluded from analyses: fever

Annex G. Individual energy expenditure due to daily sedentary activities* (EEda) and bicycling† (EEca) throughout the slimming studies.

Slimming study	dietary regimen			woman	EEda						EEca					
	wk 1	wk 5	wk 9		wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9	wk 1	wk 5	wk 9
					(kJ/min)			(J/kg.min)			(kJ/min)			(J/kg.min)		
Study 1	S100	C50	AB/100	1	2.28	1.83	1.48	31.8	27.6	23.4	6.62	7.26	7.22	92.2	109.2	113.8
				3	2.80	2.47	1.76	35.4	34.1	25.7	8.76	8.10	8.82	110.8	111.8	128.8
				6	3.31	2.20	1.92	42.6	30.4	27.7	6.22	7.86	8.12	80.0	108.4	117.3
				8	3.01	2.25	2.07	40.1	32.9	32.2	5.52	4.78	3.80	73.7	70.0	59.0
				27	3.20	2.62	2.13	38.4	33.1	27.8	6.16	5.06	4.88	74.1	63.9	67.3
	S100	AB/100	C50	2	3.45	2.66	2.78	40.3	32.8	36.7	6.54	6.42	4.88	76.3	79.4	64.3
				4	2.76	1.96	2.20	38.0	28.7	34.2	4.90	5.60	5.20	67.6	82.0	80.9
				5	3.17	2.69	2.23	44.8	40.8	36.0	7.48	8.26	10.94	105.7	125.2	176.7
				7	3.02	2.04	2.47	41.3	30.0	39.0	5.52	8.12	7.48	75.7	119.3	118.1
				26	3.50	3.15	2.89	40.9	38.6	37.6	6.26	5.50	6.44	73.0	67.3	83.9
Study 2	S100	C50	A50/100	9	3.46	3.00	2.64	51.3	48.9	45.4	7.66	4.00	3.38	113.6	65.2	58.4
				12	3.43	2.55	2.74	30.9	24.3	27.1	8.38	6.54	4.58	75.4	62.2	45.2
				14	1.72	1.37	1.48	23.6	20.3	22.5	6.20	5.82	5.02	85.2	86.2	76.6
				15	3.33	2.55	2.56	33.4	27.5	28.7	6.08	6.82	6.28	61.0	67.4	70.5
				24	2.47	2.14	2.25	31.0	28.8	31.4	7.98	6.80	5.42	100.0	91.6	75.8
	S100	A50/100	C50	10	3.34	2.54	2.09	43.0	34.1	30.2	5.56	5.38	4.18	71.6	72.4	60.4
				11	3.29	2.17	1.99	34.4	24.3	24.1	9.38	8.80	7.24	98.0	98.5	88.0
				13	2.21	1.84	1.98	28.7	25.1	29.2	6.66	6.62	4.70	86.4	90.1	69.0
				16	3.57	2.78	2.19	46.5	38.7	32.9	5.34	5.50	4.66	69.4	76.8	70.0
				25	1.73	2.23	1.98	24.5	32.9	31.0	13.64	5.00	5.10	192.6	73.7	80.2
Study 3	S100	A50/100	AB/100	11	-	1.96	1.87	-	25.2	25.4	-	5.60	6.68	-	72.0	90.8
				18	3.62	2.98	2.62	43.3	37.3	34.0	6.68	6.56	5.54	80.0	82.2	72.0
				19	2.54	2.04	1.69	39.7	33.2	29.6	4.74	4.68	4.64	74.0	76.5	81.4
				21	3.06	2.59	2.49	38.3	33.4	33.9	5.74	4.72	4.42	72.0	61.0	60.2
				22	3.07	2.84	2.60	28.7	27.5	26.1	5.74	5.98	6.22	53.6	57.8	61.4
	S100	AB/100	A50/100	12	-	2.39	2.07	-	26.3	23.6	-	5.38	5.70	-	59.0	65.0
				15	2.87	2.23	2.40	32.8	26.9	29.5	4.16	5.66	4.26	47.6	68.4	52.4
				17	2.47	2.33	1.97	25.2	24.7	21.2	7.00	6.48	6.12	71.4	68.8	65.8
				20	2.80	1.87	1.74	39.8	28.1	27.0	5.58	5.42	6.06	79.4	81.2	93.9
				23	3.65	2.71	2.77	39.5	30.6	32.1	8.26	8.92	9.06	89.6	101.0	104.8

* extra expended above SEE
† extra expended above SEE and EEda

Annex H. Individual actometer and Doppler-meter values* relative to activity counts before weight loss (AMrel, DMrel).

Slimming study	dietary regimen			woman	AMrel		DMrel	
	wk 1	wk 5	wk 9		wk 5	wk 9	wk 5	wk 9
					(%)		(%)	
Study 1	S100	C50	AB/100	1	75.2	58.5	74.8	50.2
				3	56.1	40.1	99.6	65.0
				6	64.0	56.7	71.2	63.6
				8	69.9	54.8	68.5	60.6
				27	58.3	80.0	-	-
	S100	AB/100	C50	2	65.6	59.8	64.1	67.8
				4	101.7	89.0	75.9	91.4
				5	107.0	62.5	107.5	104.7
				7	56.9	54.3	106.0	97.7
				26	105.5	70.8	149.2	109.9
Study 2	S100	C50	A50/100	9	77.6	56.1	92.6	54.2
				12	57.2	90.3	70.1	63.7
				14	79.2	64.2	66.2	72.1
				15	66.0	55.4	75.2	80.7
				24	53.3	40.6	56.3	29.1
	S100	A50/100	C50	10	60.7	50.9	61.7	45.0
				11	114.0	105.0	75.4	59.5
				13	93.4	84.6	103.8	99.0
				16	47.3	42.2	89.4	73.2
				25	75.3	77.5	-	-
Study 3	S100	A50/100	AB/100	11	100.5	106.3	105.1	79.8
				18	-	-	91.5	87.9
				19	80.6	67.2	86.8	83.8
				21	45.1	74.4	82.7	85.8
				22	98.1	79.6	106.3	68.7
	S100	AB/100	A50/100	12	99.8	73.2	78.6	64.9
				15	55.2	93.7	89.9	99.4
				17	103.3	91.9	89.1	84.5
				20	90.5	96.5	85.6	90.4
				23	60.1	99.6	-	-

* during daytime and evening, cycling periods excluded

Summary

Previous studies had suggested that periods of low energy intake evoke compensatory adaptations in energy metabolism, which retard weight loss, and promote weight regain when energy intake returns to normal. The aim of this thesis was to investigate whether a slimming (low-energy) diet based on alternating energy intake could counteract this decrease in energy requirement. The persistance of the reduction of energy metabolism was studied 1 month and approximately 1 year after weight reduction.

The effects of three slimming diets were compared pairwise in three separate studies. To this end, a cross-over design was used (fig. 2). Two alternating diets (diet AB/100: one day solely bread, water, coffee and tea, the other day providing 100 % (normal diet) the daily energy need and diet A50/100: one day providing 50 % of the daily energy need, the other day 100 %) and one continuous diet (C50: providing 50 % of daily energy need every day) were prescribed or supplied. Ten women participated in each study. First each subject lived on a weight-maintenance diet (S100) for 8 days, then two periods of low energy intake, of 4 weeks each, followed immediately afterwards. Energy balances were determined during the final 8 days of each diet period. The 24 hour energy expenditure was measured in a respiration chamber for 2 or 3 successive days. The activity pattern in the respiration chamber was standardized. Dopplermeters and actometers were used to record physical activity.

Follow-up measurements of energy balance were made on ten subjects 1 month after slimming and on eight subjects energy balance was determined approximately 1 year after slimming. Weight-maintenance diets, adjusted for weight loss, were supplied during the follow-up measurement periods.

Over the first 4 weeks of slimming body weights decreased by averages of 5.8 kg (C50), 4.5 kg (AB/100) and 3.9 kg (A50/100). The average weight losses over 8 weeks were 6.9 to 9.0 kg. After 8 weeks at a low energy intake 24 hour energy expenditure had declined by 12 - 15 %. This decline was partly (50 %) accounted for by the reductions in body weight and partly (30 %) by reduced dietary induced thermogenesis. The remaining part (20 %) of the decline was probably due to the reduced cost and amount of physical activity which was indicated by Dopplermeter counts and actometer counts.

Sleeping energy expenditure also decreased during slimming by 6 - 13 %, but this was no more than could be expected from weight loss.

Weight reduction by alternating (low with normal) low energy intakes resulted in a reduction of energy expenditure which, when weight loss and energy intake were taken into account, was similar to the reduction by continuous low energy intake, thus alternating low energy intake did not prevent energy expenditure rates from declining.

Subjects participating in the follow-up studies maintained their reduced body weights successfully. Their 24 hour energy expenditure rates in the follow-up studies were still below the rates measured before slimming. When body weight and energy intake were taken into account, both the 24 hour energy expenditure values and the sleeping energy expenditure values were the same before slimming, and 1 month or 1 year after slimming.

The changes of energy metabolism were determined by alterations in body weight and energy intake and probably in physical activity as well. It remains to be investigated whether other adaptive mechanisms are evoked when energy intake is restricted more severely or for longer periods.

Samenvatting

De resultaten van onderzoekingen naar het effect van gereduceerde voedselopname wijzen op een adaptatie van het energiemetabolisme tijdens en enige tijd na afslanken. Het voorkomen van deze adaptatie zou kunnen resulteren in een groter gewichtsverlies alsmede in een toenemend blijvend succes van afslanken. Het in dit proefschrift beschreven onderzoek beoogde na te gaan of door alternerende normale respectievelijk verlaagde voedselopname de energiebehoefteverlaging te beperken is. Tevens werd aandacht geschonken aan het energiemetabolisme 1 maand en ongeveer 1 jaar na gewichtsreductie.

In een drietal studies werden drie vermageringsvoedingen volgens een 'cross-over' schema paarsgewijs vergeleken (fig. 2). Alternerend waren de afslankvoedingen AB/100 (de ene dag uitsluitend brood, water, koffie en thee, de andere dag 100 % (normale voeding) van de energiebehoefte) en A50/100 (om de dag 50 % danwel 100 % van de energiebehoefte). Voeding C50 leverde elke dag dezelfde hoeveelheid energie, die voorzag in 50 % van de energiebehoefte. Aan elke studie namen 10 vrouwelijke proefpersonen deel. Na een periode van 8 dagen op een normale voeding (S100: 100 % van de energiebehoefte) volgden aansluitend twee afslankperiodes, die ieder 4 weken omvatten. Elke proefperiode werd afgesloten met een energie-balansproef. Tijdens deze proef kregen de deelneemsters een proefvoeding verstrekt, zodat de energie-opname bekend was. Het energieverbruik werd gemeten tijdens een 2 à 3 dagen durend verblijf in een respiratiekamer. In de respiratiekamer volgden de deelneemsters een voorgeschreven activiteitenschema. Dopplermeters en actometers werden gebruikt om de lichamelijke activiteit in het oog te houden. Tien proefpersonen namen deel aan een vervolgmeting, een maand na afslanken; bij acht proefpersonen werd een jaar na afslanken een vervolgmeting gedaan. Tijdens de vervolgmetingen werd een proefvoeding geconsumeerd die de energiebehoefte dekte.

Het gewichtsverlies over de eerste 4 weken was gemiddeld 5.8 kg (C50), 4.5 kg (AB/100) en 3.9 kg (A50/100). Over 8 weken bedroeg het gewichtsverlies 6.9 tot 9.0 kg. Het 24 uurs energieverbruik van de deelneemsters was na 8 weken verlaagde energieopname gedaald met 12 - 15 %. Deze daling kon voor circa 50 % verklaard worden uit veranderingen van het lichaamsgewicht en voor circa 30 % uit verminderde voedingsgeinduceerde thermogenese. Uit de

activiteitsregistraties mocht geconcludeerd worden dat de hoeveelheid activiteit tijdens afslanken zeer waarschijnlijk gereduceerd was. Het resterende deel van de daling in het 24 uurs energieverbruik, circa 20 %, werd daarom toegeschreven aan gereduceerde (hoeveelheid en energetische kosten) fysieke activiteit. Gedurende de nacht nam het energieverbruik na 8 weken verlaagde energieopname af met 6 - 13 %, dit kon verwacht worden op basis van het verminderde lichaamsgewicht.

Gewichtsreductie door middel van alternerende energiebeperking leidde tot een daling van het energieverbruik die, rekening houdend met gewichtsvermindering en energieopname, niet afweek van de daling die waargenomen werd tijdens continu beperkte energieopname. Geconcludeerd kan worden dat een daling van de energiestofwisseling niet voorkomen kon worden door alternerend beperkte energieopname.

Zij die aan de vervolgstudies deelnamen, na 1 maand of na ongeveer 1 jaar, hadden het gewichtsverlies gehandhaafd. Het energieverbruik tijdens de vervolgmetingen bleef lager dan het verbruik gemeten voor gewichtsreductie. Wanneer rekening gehouden werd met het lichaamsgewicht en de energieopname tijdens de diverse metingen, bleken tijdens de vervolgstudies zowel het 24 uurs energieverbruik als het energieverbruik gedurende de nacht gelijk te zin aan de waarden gemeten voor de afslankperiodes.

In de beschreven studies bleken voornamelijk het lichaamsgewicht, de energieopname en waarschijnlijk de fysieke activiteit de waargenomen veranderingen in energieverbruik te bepalen. Het dient nader onderzocht te worden of andere adaptieve mechanismen in het leven geroepen worden wanneer de energieopname sterker of langduriger beperkt wordt.

Curriculum vitae

De auteur werd op 17 juli 1960 geboren te Riel. In 1978 behaalde zij het gymnasium-ß diploma aan het Theresia-lyceum te Tilburg. In datzelfde jaar begon zij haar studie aan de Landbouwuniversiteit te Wageningen, om in januari 1984 het doctoraal-examen te behalen, met Voedingsleer als hoofdvak en Dierfysiologie, Gezondheidsleer en Pedagogiek & Didactiek als bijvakken. Van februari 1984 tot januari 1985 was zij als statistisch analiste werkzaam bij de vakgroep Humane Voeding der Landbouwuniversiteit. Per 1 januari 1985 trad zij in dienst bij de vakgroep Dierfysiologie te Wageningen als wetenschappelijk assistente, alwaar, met financiele steun van de Nederlandse Hartstichting, gedurende drie jaar het in dit proefschrift beschreven onderzoek werd verricht.