

Fasting – the ultimate diet?

A. M. Johnstone

Rowett Research Institute, Aberdeen, UK

Received 22 December 2005; revised 13 March 2006; accepted 14 March 2006

Address for correspondence: Dr A Johnstone, Rowett Research Institute, Aberdeen, Scotland, UK, AB21 9SB; E-mail: A.Johnstone@rowett.ac.uk

Summary

Adult humans often undertake acute fasts for cosmetic, religious or medical reasons. For example, an estimated 14% of US adults have reported using fasting as a means to control body weight and this approach has long been advocated as an intermittent treatment for gross refractory obesity. There are unique historical data sets on extreme forms of food restriction that give insight into the consequences of starvation or semi-starvation in previously healthy, but usually non-obese subjects. These include documented medical reports on victims of hunger strike, famine and prisoners of war. Such data provide a detailed account on how the body adapts to prolonged starvation. It has previously been shown that fasting for the biblical period of 40 days and 40 nights is well within the overall physiological capabilities of a healthy adult. However, the specific effects on the human body and mind are less clearly documented, either in the short term (hours) or in the longer term (days). This review asks the following three questions, pertinent to any weight-loss therapy, (i) how effective is the regime in achieving weight loss, (ii) what impact does it have on psychology? and finally, (iii) does it work long-term?

Keywords: Body composition, dieting, obesity, weight loss.

obesity reviews (2007) **8**, 211–222

Obesity is not a new phenomenon, with Hippocrates identifying the basic concept of energy balance manipulation as an effective treatment option for obesity in the fifth century BC (1).

[O]bese people and those desiring to lose weight should perform hard work before food. Meals should be taken after exertion and while still panting from fatigue. They should, moreover, only eat once per day and take no baths and sleep on a hard bed and walk naked as long as possible.

Modern day patients faced with this treatment option may not be very compliant! There are several good historic reports on food restriction in humans, ranging from less extreme changes in food patterns for religious reasons to total or semi-starvation in subjects due to either voluntary or involuntary food restriction. A short historical perspective on fasting in humans will be summarized with particular reference to examining motivation to eat and feeding

behaviour, before more recent human experimental data are discussed.

Fasting for religious reasons

One of the most cited religious events associated with fasting is the period of Ramadan. During the fasting month of Ramadan, Muslims abstain from food and drink from sunrise until sunset. Although Ramadan does not involve a continual fast, it provides a useful insight into short-term food restriction in otherwise healthy humans. Interestingly, the data indicate that it is a misconception that this religious fast results in decreased energy intake (EI), because investigators have found either increases in EI (2) or comparable levels of EI before, during and after Ramadan (3), despite a decrease in meal frequency. Similarly, Finch *et al.* reported no change in body weight during the period of Ramadan (4). Thus, although the physiological effects of sleep deprivation and dehydration occurring during

Ramadan may provide concern, there is no evidence for restricted EI during this religious fast.

Experimental studies of semi-starvation

The most comprehensive data on semi-starvation was undertaken by Keys and his colleagues from their classic 'Minnesota Experiment', which documented the consequences of weight loss (WL) in normal weight men (5). Keys used a team of staff to assess the physiological and psychological effects of severe undernutrition and rehabilitation, for military applications concerned with nutritional rehabilitation. Thirty-six male conscientious objectors, aged 20–33, underwent semi-starvation, with a ration of 6.5 MJ d⁻¹ for 168 days (~40% of their normal EI). This regime led to a loss of 24% of body weight (to a mean body mass index [BMI] of 17.5 kg m⁻²). When subsequently fed *ad libitum*, these men became rampantly hyperphagic and consumed up to 27 MJ d⁻¹, leading to the hypothesis that overeating prevailed until lean body mass was repleted, by which time fat mass (FM) had exceeded initial levels (6–8) a phenomenon termed 'post starvation obesity' by Keys.

There has been much effort in nutritional research in understanding how food intake is regulated, because any mechanism that regulates food intake could indirectly or directly influence the amount of food eaten and hence control body weight. Some authors argue that feeding behaviour is coupled to physiological events via the process of learning (9). Other authors hypothesize that it may be that aspects of body composition and body size are regulated and that changes in feeding behaviour are functionally coupled to these processes (6–8). Furthermore, it can be appreciated that the physiological signals which affect motivation to eat and food intake are not rigidly deterministic, rather they act as cues, for feeding behaviour (10). For example, eating can occur when hunger ratings are low (11) and it is also possible to be hungry and not to eat, even to the point of death (such as in hunger strike). So, one can hypothesize that the response to this type of short-term, but extreme food restriction in previously obese subjects may be quite different, as their psychological disposition to maintain WL may override the physiological drive to overeat.

Famine and prisoner of war data

Despite development in understanding of human physiology through techniques such as calorimetry and molecular biology, the mechanisms associated with the ability of the human body to survive during extended periods of food restriction are not clearly understood. Understandably, the type of data in this area tend to be anecdotal rather than interventional studies. Elia noted that hunger, pestilence

and disease have plagued mankind throughout history, with the first recorded famine in Egypt 5000 years ago (12). A number of famines are also described in the Bible (e.g. Joseph and the 7 years famine), but such data are more qualitative (descriptive of effects) than quantitative in nutritional terms. Recently, Collins examined height and weight data from 573 victims of the 1990 famine in Somalia and reported a minimum BMI of 10.1 kg m⁻² for young (age 15–24) survivors (13). This is lower than the level previously considered compatible for life (BMI 12 kg m⁻²) (14,15). Collins suggests that the warm climate, tall stature of the population, the gradual nature of food deprivation and previous exposure to chronic energy deficiency (CED), facilitated survival at a low BMI (13). Preconditioning to CED at BMI 16.6 kg m⁻² has been described in Indian labourers able to function normally (16). Clearly, initial body composition (energy stores) play a major role in determining length of survival and this notion is supported by famine studies which have reported a gender difference in the adaptation to famine; concluding women withstand semi-starvation better than men. This could be explained by the larger initial per cent body fat (5,17).

Two Medical Research Council (MRC) reports contain accounts of energy and nutrient intakes under prisoner of war (POW) conditions. First, McCance and Widdowson documented findings from Wuppertal, in Germany following World War II, with the remit to study the effects of civilian undernutrition on the physical and moral well-being of a modern community (17). From 1948 onwards, the MRC unit was mainly occupied by POW from Russia, and of particular interest in this unique report, is Widdowson's documented response of the POW to unlimited food during re-habilitation. Nineteen men, aged 26–80 years, were given unlimited access to food for 8 weeks and recorded food intake of up to 3954 kcal (16.6 MJ) at one meal or 6000 kcal per day (25.2 MJ) over a period of weeks (17). The psychological consequences of such extreme food restriction, in the long term (years) were not documented by Keys. These data on gorging have been used as a demonstration for the hypothesis that voluntary food restriction leading to substantial WL, is casually related to binge eating (18). This has been extrapolated to the notion that dieting *per se* leads to compulsive eating or binges, at least for some individuals (19).

A further limited source of data on POW is in the form of the MRC Report 274, 1951, 'Deficiency diseases in Japanese prison camps'. In the civilian internment camps in Hong Kong, intakes of between 1300 and 2500 kcal d⁻¹ were recorded over a year, linked to the general symptoms of undernourishment (20).

The Warsaw Ghetto data, recorded 1941–1942 by Jewish physicians, account objective clinical, anatomical and physiological data on the Jewish victims living in the ghetto during World War II. These harrowing data were published

in French by Apfelbaum (21). Keys also summarized some of their findings. Information on the survivors indicated that individuals existed on 600–800 kcal d⁻¹, for a period of years, with tests carried out on groups of 10–20 subjects at a time, who showed no apparent signs of disease or disorder (5).

Hunger strike

Meyers documented one victim of hunger strike (22). The man lost 40% body weight and died after 63 days of food refusal, weighing only 36.4 kg, with a BMI of 12.3 kg m⁻². Elia also describes more recent data where the Republican prisoners in Northern Ireland in 1981 died of starvation after 57–73 days on hunger strike (data compiled from newspaper reports) (23). This is in accord with the view that death usually occurs in normal-weight mammals when there is loss of 40–50% of initial body weight (12). It follows that as the obese have a much larger total energy store, primarily in the form of adipose tissue, they can survive a fast for much longer periods than lean subjects. Elia suggested a survival time of 60–70 days for a lean subject and 200–300 days for an obese subject during fasting (23). This is in accord with the case study report of two morbidly obese female patients enduring a fast for up to 249 days to lose ~30% initial body weight (24).

Hunger strike, famine and prisoner of war situations provide unique data on the consequences of starvation or semi-starvation in previously healthy, but usually non-obese subjects. However, it should also be remembered that fear of death, illness and injury will all interact with nutritional status to determine survival time. For these reasons, these groups are far from ideal to study the influence of WL on body composition, physiology or psychology.

Therapeutic starvation as a treatment for obesity

Therapeutic starvation is the total withdrawal of calories in order to facilitate rapid WL (25). This regime has been proposed for many years by the medical profession, in an attempt to promote WL as quickly as possible, e.g. to treat 'gross refractory obesity' (26,27). Experimental studies by Bloom (28), Duncan *et al.* (29), Drenick *et al.* (30) and Cahill (31), provided a framework for therapeutic fasting as an accepted in-patient treatment for morbid obesity during the 1950s and 1960s, with total food withdrawal studies conducted on lean and obese subjects, for periods ranging from 10 to 117 days. Stuart and Flemming published data from the longest fast, 382 days, on an obese man in Dundee, making it into the Guinness Book of Records, after reaching a 75% WL (32).

What about fasting in the general population, nowadays? Some 14% of the American population reported using

short-term fasting to lose weight (33). However, starvation is not currently recommended as a clinical treatment option for obesity and should only be conducted under medical supervision. This is because starvation has been linked to serious complications (e.g. ventricular fibrillation, lactic acidosis, vitamin and electrolyte deficiency) and sudden death syndrome either during fasting or re-feeding (34). The apparent poor maintenance of WL is also an important factor in its abandonment as a medically recommended therapeutic regime for sustained WL (34). Data from the 1960s on long-term starvation in morbidly obese humans give insights into some of the dangers associated with prolonged food restriction, but do not provide an answer on how effective a short-term fast over a day or few days would be in achieving WL. Fasting is not the only WL therapy that has invoked concern regarding the risks to patients. More recently, public popularity for high-protein low-carbohydrate diets has provoked concern as to their safety from both medical (35) and nutrition (36) experts. Any medical procedure will carry a potential risk to health, but the benefits of WL need to be weighed against the negative side effects of weight gain (e.g. increased risk of type 2 diabetes, hypertension or cardiovascular disease). A short-term risk linked to the WL therapy may be outweighed by the longer-term health benefits of WL. For example, bariatric surgery carries a 0.25% risk of death and 13% risk for serious postoperative complications such as embolism, thrombosis or pulmonary complications, as indicated by the controlled Swedish Obese Subjects study (37). Nonetheless, these short-term risks are outweighed by the long-term (10 years) benefits in reduction of cardiovascular risk factors (38). Therefore, fasting should be considered in the modern day context of the range of therapies now available for WL. The risks of obesity and obesity-related conditions are now better documented and thus treatments with known but low risks may need to be re-evaluated.

Present day fasting studies

Currently, intermittent fasting is often promoted as a fashionable 'detox' diet or as a means of repenting for a previous night's indulgence of high-calorie foods and/or alcohol. Throughout the 20th century, interest in nutrition and body weight changed from concerns on the physiology of under-nutrition (e.g. Keys studies) to increasing health problems associated with overnutrition. In the UK, it is no longer the norm to be of normal weight for height, because over half of the UK population are now collectively overweight and obese (39). Treatment for obesity ultimately involves consuming less calories than expended and fasting *per se*, for a morbidly obese patient, could, in theory, provide an easy WL option, with no difficult calorie or 'carb' counting required. However, the effects of fasting as a form of obesity therapy on the human body and mind are less clearly

documented, either in the short term (hours) or in the longer term (days). Hence, this review will address the following three questions, which are pertinent to any WL therapy, and more so in assessing whether fasting is indeed the ultimate diet.

1. How effective is the regime in achieving WL in terms of actual WL (kg) and the composition of the loss (fat and lean mass)

2. What impact does it have on psychology? Or more specifically how do people feel, because this is an important indicator as to whether they will be compliant on a regime (and hence lose weight)

3. Does it work in the long term? Does the weight stay off or is the anecdotal perception of the general public and medical profession that rapid WL leads to rapid weight regain, true?

Short-term fasting

We know that humans are capable of consuming large amounts of energy to compensate for previous deficit [e.g. Keys *et al.* (5)], so we hypothesized that EI would be markedly increased immediately following a short-term fast. We conducted a study (40) that examined the extent to which healthy, lean subjects (male and female) compensated for an acute total fast (36 h, one day and one night) when subsequently allowed to feed *ad libitum*. The protocol was a within-subject randomized design with two experimental periods, (i) a 2-day control period [maintenance] where on day 1 subjects were fed to 1.6× resting metabolic rate (RMR) and then on day 2, fed *ad libitum* from a supermarket-style diet with 45 choices and, (ii) a separate 3-day test period [fast] encompassing a 36-h total fast. For the latter, on the day prior to food restriction, food was provided at 1.6× RMR to reduce any pre-fasting variability in food intake. Subjects were then fasted from 20:00 h on day 2 until 08:00 h on day 3. During this period, only water or non-calorie containing beverages were consumed. On day 3, they were then given *ad libitum* access the same 45 supermarket, ready-to-eat foods. All food intake was investigator-weighted prior to and after consumption.

Compliance to the 36 h fast was checked in three ways:

1. fasted blood glucose, with mean values at 4.0 (SD 0.3) and 3.2 (SD 0.6) mmol L⁻¹ after an overnight and 36 h fast respectively ($P < 0.05$).

2. respiratory quotient (RQ) using a metabolic cart, with a decrease from 0.81 (SD 0.04) to 0.73 (SD 0.05) an overnight and 36-h fast respectively ($P < 0.05$).

3. weight loss, all subjects lost weight during the 36-h fast (average -1.33 kg [SD 0.55] in the men and -1.00 kg [SD 0.30] for the women).

Subjects consumed much less energy than required to compensate for the energy deficit induced by the fast. Energy

intake only increased 20% above control values on the post-fast *ad libitum* day, increasing from 10.2 MJ d⁻¹ to 12.2 MJ d⁻¹ ($P = 0.049$). On the control treatment, the *ad libitum* intakes remained at approximately, 1.6× RMR, adequate to maintain energy balance for this group (41). Interestingly, in the post-fast response, the subjects preferentially selected a higher-fat intake for the first meal-time at breakfast time (5.1 MJ d⁻¹ of fat post-fast vs. 3.7 MJ d⁻¹ of fat on control, $P < 0.01$), perhaps as a mechanism to increase EI by choosing the most energy dense foods. This preferential selection of a high-fat intake at breakfast seemed to have returned motivation to eat and food intake to equilibrium. The effects of the breakfast intake on satiety appear to have swamped any further increase in urge to eat for the remainder of the day. Interestingly, both men and women appear similar in this respect.

Few data are available on subjective motivation to eat in healthy, lean individuals during fasting. Some data are available in the clinical setting, but appetite may be confounded by disease state [see Elia (12) for a review]. Blundell's group (42–44) have conducted several within-day studies examining meal skipping and shown that hunger increases in response to the energy deficit. Not surprisingly these subjects also reported feelings of elevated hunger during the 36-h fast, furthermore, the higher levels of hunger over the post-fast *ad libitum* feeding day, were driven by the elevated pre-breakfast ratings, because after this meal, hunger ratings were similar to control values. We concluded that subjects cannot, or are not inclined to, consume enough food to restore energy balance completely within one day. However, if the subjects had been followed over a longer period, the slightly elevated intake may have persisted and either restored energy balance (and body weight) or further reduced the overall energy deficit.

So in answering our three questions,

1. *How effective is the regime in achieving weight loss?* Subjects lost 1–2% body weight, which is most likely due to the mobilization of glycogen stores and water, rather than metabolism of FM.

2. *What is the impact on psychology?* There were increased feelings of hunger that were quickly diminished by a high-fat breakfast meal.

3. *Does it work long-term?* Unfortunately this was not monitored. This introduces a question on the role of intermittent fasting in the control of body weight. What would happen if the experiment was repeated once a week over a 3-month period? – would subjects quickly learn to compensate prior to and/or after fasting, or could they slowly reduce body weight, with no apparent negative impact on health and well-being? Furthermore, would obese subjects respond differently to lean subjects? Finally, would a longer fasting period provoke more efficient compensation and

how would this compare to a more conventional calorie-restricted regime?

Longer-term fasting

Study design and implementation

In order to answer some of the above questions, another series of experiments were undertaken. The strategy was to perform structured longitudinal studies in obese but otherwise healthy men, to examine how change in rate of WL influenced body composition, plus both physiological and psychological function (see Fig. 1). Rapid WL was induced by fasting. It was anticipated that changes in function would, in turn, impact on assessments of behaviour (physical activity and feeding). Three separate studies compared groups of healthy adult men ($n = 6$ per group) with a starting BMI of 30–40 [see publications (45–47) for details on study design and data]:

- Study 1 – Six consecutive days of total starvation, achieving a nominal 5% WL. Resident for 34 consecutive days.
- Study 2 – Three weeks on a very-low-calorie diet (VLCD, 2.5 MJ d⁻¹) achieving a nominal 10% WL. Total residential duration of 7 weeks.
- Study 3 – Six weeks on a low-calorie diet (LCD, 5.0 MJ d⁻¹) achieving a nominal 10% WL. Total residential stay of 10 weeks.

Subjects on all protocols followed a similar five-phase regime:

1. An initial 7-day 'Maintenance period' fed at 1.6× measured basal metabolic rate (BMR) to maintain a stable body weight. Measurements were taken on days 6 and 7.
2. Weight loss period. Measurements were taken at 5% WL and 10% WL (VLCD and LCD only), termed accordingly.
3. Another maintenance period of 7 days, fed at 1.4× measured BMR to maintain energy balance. Measurements were taken at the end of this period, termed,

'Reduced Maintenance'.

4. An 'ad libitum' feeding phase of 2 weeks, during which subjects were allowed to feed *ad libitum* from a selection of familiar supermarket ready-to-eat food items.

5. 'Follow up' at 3 months and 1 year, with minimal measurements.

The subjects were residential, living in the Human Nutrition Unit (HNU) at the Rowett Research Institute (RRI), although they were not confined to the building, being free to leave the RRI campus for leisure or work activities. If they were working, they took their food diary, packed lunch, urine bottles and hand-held computer each morning, returning to the HNU later in the day.

How effective is the regime?

Many studies have reported body-weight change in obese individuals as a result of dietary obesity therapy, from starvation (zero intake) (26,27) to calorie-controlled intakes from 400 kcal d⁻¹ to 1000 kcal d⁻¹ (40,41). Within the present study, all subjects lost the anticipated weight (Fig. 2). On average, WL in the fasting group was 6.1 kg (5.6% original body weight [OBW]) over 6 days; the VLCD group lost 5.2 and 9.2 kg (4.9% then 8.6%) over 11 and 21 days respectively. The LCD group lost 7.2 and 12.6 kg (6.8% then 11.9% OBW) over 3 and 6 weeks respectively. Mean rates of WL during the 5% WL period were significantly different ($P < 0.05$) at 1.01 kg d⁻¹, 0.52 kg d⁻¹ and 0.35 kg d⁻¹ within the starvation, VLCD and LCD treatments respectively. Rates of WL during the fasting study were similar to those of other studies, within the 0.73–0.77 kg d⁻¹ range for short-term starvation in obesity (48,49).

What was the composition of the weight loss?

Only monitoring body-weight reduction (kg) does not allow changes in body composition (fat, protein, bone and water) to be assessed and thus the suitability of the regime to be determined. Successful WL strategies aim to optimize FM loss and minimize lean tissue loss. Different body composition techniques have their advantages and disadvantages with respect to simplicity, precision and accuracy (50). Often body composition is simplified to a two-compartment model that divides the body into fat and fat-free mass (FFM) compartments (51). For example, the four-compartment model allows further information to be gained and requires body weight, body volume (densitometry), body water (isotope dilution) and the mineral fraction (DEXA) measurements (51). This model assumes that the four compartments have a constant density but does not consider glycogen separately and this is largely included in the estimation of protein mass. The model has the advantage that less assump-

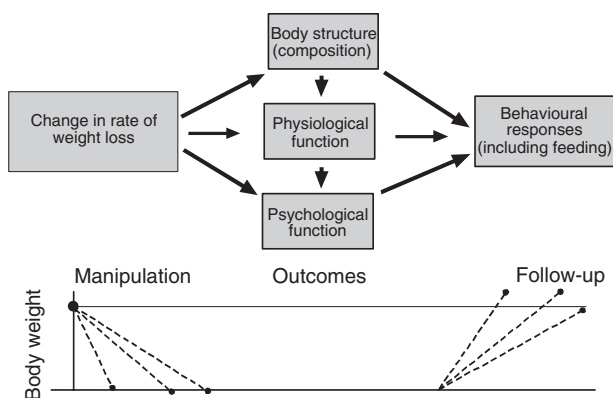


Figure 1 Diagrammatic representation of the study strategy.

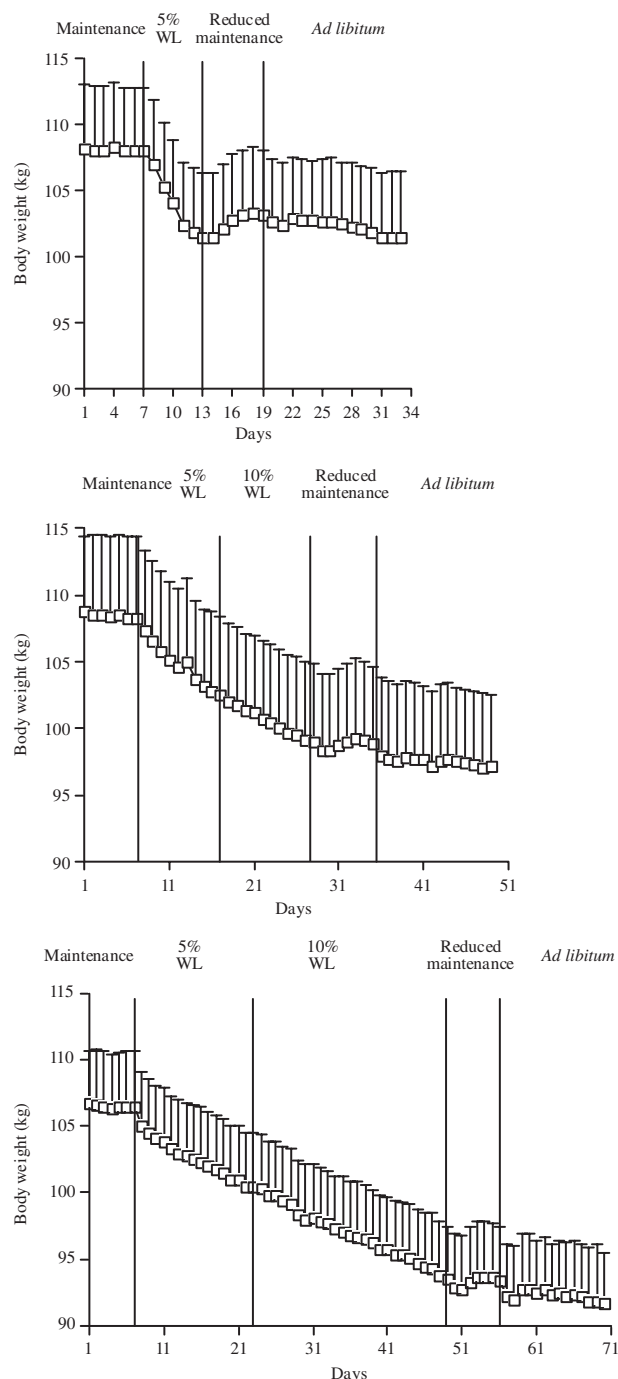


Figure 2 Average (SEM) group body weight change for each dieting group, whereby fasting is the top panel, very-low-calorie diet (VLCD) the middle panel and low-calorie diet (LCD) the bottom panel.

tions are required and therefore precision is increased. On the negative side, the accuracy of results may be decreased due to accumulation of errors from the individual techniques (52). For example, a 2% overestimation of total body water (TBW) would result in a change of protein mass

by 8%, while an error of 1% in density would produce an error of 20% in protein mass estimation. Wells *et al.* examined the propagation of methodological errors on estimations of fat and FFM and concluded that the four-component model estimates FM and FFM (or protein, as TBW and body mineral mass are already accounted) to be within ± 0.54 kg (53). Elia also suggested that body fat and protein can be estimated to within ± 0.5 – 0.75 kg using the four-component model (54). Correct interpretation of the changes in body composition requires understanding the limitations of the techniques employed. The following data are discussed with these limitations in mind.

Changes in body composition, at 5% WL, indicate the fraction of FFM to total WL was 46%, 30% and 18% for the fast, VLCD and LCD groups respectively. At 10% WL, the VLCD losses were 20% FFM and 80% FM compared with the LCD group 9% FFM and 91% for FM. Thus, the fasting group had the greatest loss of lean tissue, both when expressed in terms of percentage of WL or absolute change (kg), which is an undesirable side effect of this regime. However, much of the difference was due to the decrease in TBW. In starvation, a large component of initial WL is water loss (55,56), associated with the depletion of glycogen stores. These data indicate that the slowest rate of WL promoted the largest loss in FM (the LCD) and the smallest loss in lean mass. Starvation was only a quick fix, with minimal impact on reducing FM.

The proportion of loss as FM (54% of WL) within this study was slightly higher than other reports of similar duration. For example, Yang and Van Itallie (49) found a mean loss of 32% of WL as FM within 10 days of fasting obese males, while Benoit *et al.* (57) and Kjellberg and Reizenstein (58) reported 35% loss of FM. In these studies, however, subjects were sedentary, in comparison with the inclusion of a fixed exercise regime within our studies, which may explain the higher proportion of fat loss. In longer-term starvation studies higher FM losses occur, e.g. Barnard *et al.* fasted severely obese women for between 10 and 45 weeks and found fat accounted for between 28% and 81% of the loss (with a mean of 52%), dependent on the length of fast (59).

During starvation the body reverts to production of ketone bodies as an alternative fuel for the brain. There has been renewed interest in low-carbohydrate, ketogenic diets as a tool for WL. These diets have some similarities to starvation, in terms of the development of a controlled state of ketosis. Several studies have indicated that WL is greater with low-carbohydrate diets, compared with isoenergetic diets higher in carbohydrate [see Westman *et al.* (60) for a review]. Of the few studies that have measured body composition change, there is a trend for low-carbohydrate diets to favour loss of FM and preservation (or perhaps even increases) in lean tissue (61). This is thought to be mediated by change in hormone concentrations, specifically insulin

(62). Thus, low-carbohydrate diets that are often high in dietary protein are under intense scrutiny as to whether they are an effective tool for long-term WL (63). Further research on the physiological and psychological consequences of these diets will assist construction of advice that helps obese individuals reduce caloric intake, yet still allow optimal nutrition in terms of longer-term health.

What impact does fasting have on psychology?

Hunger data

Most overweight people want to lose weight (64,65). However, obese people find losing weight difficult and failure to achieve weight reduction in most cases is caused by poor dietary adherence (66). Increased feelings of hunger are reported to be one of the main obstacles to losing weight (67,68), because these result in poor dietary adherence (66). The extent to which hunger is increased depends on the energy content and macronutrient composition of the diet and the length of time subjects adhere to the diet. There appear, however, to be differences between the effects during starvation and dietary restriction (29,69). It might be anticipated that energy restriction would simply result in an increase in hunger and a decrease in feelings of fullness. However, Wadden *et al.* suggested 'less food eaten results in less hunger' and there is some evidence that this may be the case during complete starvation (70). Bloom (28) and Drenick *et al.* (30) report absence of hunger during starvation in obese subjects, although this was based on clinical impression rather than on an objective measurement. Similarly, Bollinger *et al.* (71) and Lappalainen *et al.* (72) found that hunger, during fasting, returned to baseline levels as the study progressed, on average 4–5 days after initiation. In contrast, Silverstone *et al.* assessed feelings of hunger in obese individuals undertaking total starvation and noted there was no decrease in mean hunger during the fast (73). None of these studies have systematically measured hunger throughout waking hours, and thus may not be representative of the whole dieting period.

A similar situation exists in some of the early work on VLCD where the frequency of ratings varies through three times per week (70) to once a day (74) and twice a day (75). These intermittent recordings may not be representative of feelings over the entire day, because hunger ratings have a circadian rhythm connected to daily meal times (76,77).

Our own study measured changes in motivation to eat (hunger) using visual analogue scales (VAS) that followed the methodology of Blundell (78) and Hill and Blundell (79). These took the form of an hourly questionnaire, during waking hours, assessing motivation to eat (including hunger, fullness, thirst, prospective consumption, desire to eat), with a mean score of 0–100 mm. The higher the score, the more hungry the volunteer. The data are shown in Fig. 3.

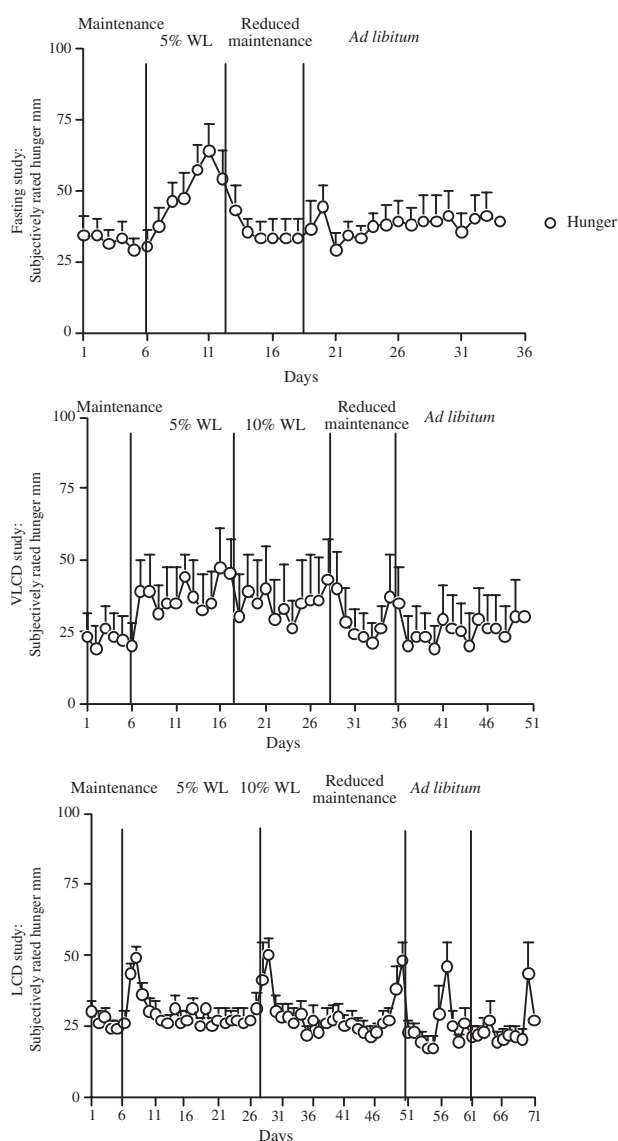


Figure 3 Average (SEM) group daily hunger for the three weight loss regimes, whereby fasting is the top panel, very-low-calorie diet (VLCD) the middle panel and low-calorie diet (LCD) the bottom panel.

Within these studies, in obese men, there was no evidence to support the argument that fasting suppresses hunger, rather, hunger scores increased as fasting time continued. The anecdotal and infrequent ratings of the previous obesity studies may not reflect motivation to eat throughout the day.

Hunger was significantly elevated within the VLCD group, but the LCD group did not report hunger as a problem. So, in obese subjects at least, there appears to be a graded response ($P < 0.05$) in hunger with different dieting regimes (fast > VLCD > LCD). The easiest regime for obese subjects to follow and maintain compliance would therefore be the LCD protocol, whereby restriction of food

intake would not necessarily result in their feeling hungry and it seems logical that the obese patient or subject may manage to refrain from breaking the diet if they feel satisfied with the food they eat. Of course, the variety of food, difficulty of preparation and WL will all impact on their sense of achievement and ultimate attrition.

What impact does fasting have on psychology?

How a subject feels during WL is very important, because this will be an indicator whether they will be compliant to the regime. If a subject does not feel well physically or mentally, then they will learn to avoid the behaviour that makes them feel unwell. The psychological response to a diet is therefore very important in terms of the subject's feelings of well-being, quality of life, libido, energy or fatigue levels, anxiety or depression. If dieting *per se* can improve these parameters, then this can add to the feeling of success and motivation to maintain the regime to lose weight. We currently have a limited understanding of the relative strengths and weaknesses of different dietary regimes for different people.

Fatigue data

Ironically, fatigue can be the result of either an excessive EI (think of Christmas day!) or a depleted EI (80). Much of the work on fatigue has been performed in the clinical setting (81,82) because fatigue is an important indicator of illness or responsiveness to medical intervention. There are anecdotal reports of fatigue during dieting, but there is a paucity of systematic measurements in obese subjects during WL. Within our own study subjective fatigue was measured hourly during waking hours, using VAS questionnaires, in an identical format to the hunger question. The data are shown in Fig. 4. The data for fasted subjects indicate that there was a significant increase in fatigue ($P < 0.001$) in response to the starvation, which remained elevated throughout the reduced maintenance period, and did not recover to pre-fast levels until after the 2-week *ad libitum* feeding period. Within the VLCD group, although fatigue increased during the 5% WL (but to a lesser extent than for the fasting group), these were abolished during the 10% WL period returning to baseline levels. The LCD group report fatigue being unchanged throughout the study.

There are many anecdotal reports that dieters feel fatigued during WL, but these feelings have never been systematically recorded by validated fatigue scales. These current data supported the notion that a rapid WL induces psychometric (subjective) fatigue. Buffenstein *et al.* also observed that a month-long severe energy restriction (VLCD) resulted in increased feelings of fatigue in overweight, but otherwise healthy women (83). This finding

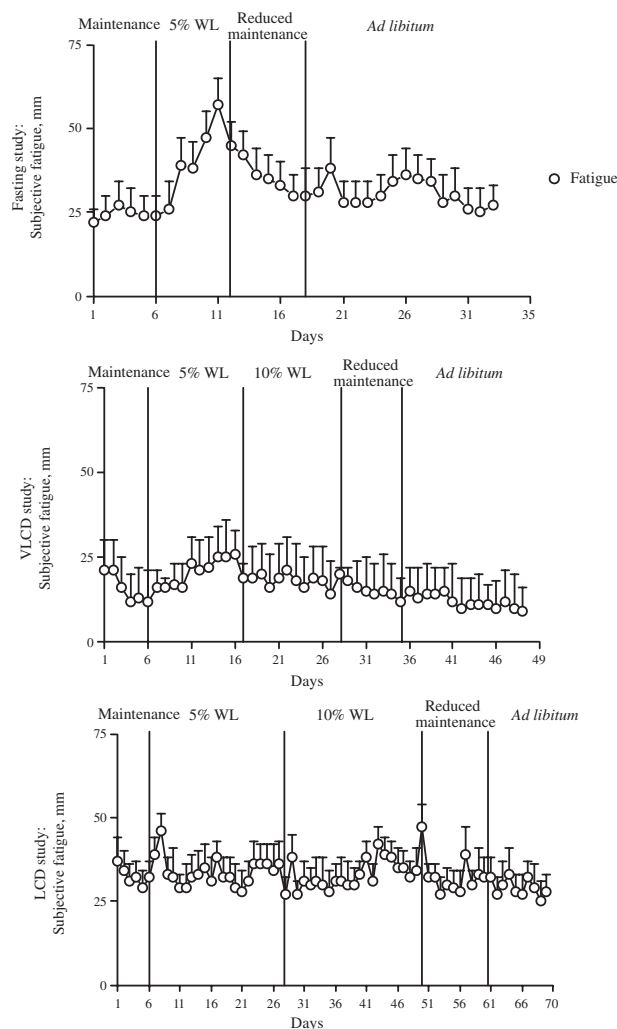


Figure 4 Average (SEM) daily ratings of fatigue for each study, measured by hourly visual analogue scale, whereby fasting is the top panel, very-low-calorie diet (VLCD) the middle panel and low-calorie diet (LCD) the bottom panel.

may be important to highlight to dieters on a VLCD, because it may be that a period of adaptation is required for subjects to become accustomed to an exercise and reduced intake regime. Compliance time may be improved if subjects are aware that the first 10 days of WL are the hardest in terms of feelings of fatigue and that maintaining their therapy will result in a decline in fatigue symptoms.

Our work also indicates that the faster the rate of WL, the greater the impact on subjective fatigue, with a graded response ($P < 0.05$), in the order fast > VLCD > LCD. It has been found previously that psychological performance decreases (as assessed by problem-solving tests) during WL and this change in mental performance may be part of the fatigue effect (84).

Measurement of physical activity is of interest, not only physiologically, but also for insight gained into the psycho-

logical status of an individual, in terms of their disposition to exercise. General observations suggest that lean individuals attempt to lower their energy output during periods of energy restriction by reducing physical activity (5,85,86). Data during obesity therapy are more limited. Our studies found a strong link between physiology and psychology during WL, with the subjective measures of fatigue reflected in the subject's behaviour, or physical activity. Within the starvation group, there was a decrease in both physical activity and total energy expenditure. The current data confirmed previous studies that have also reported an adaptive decrease in energy expenditure within groups of starved individuals in free-living conditions in lean (85) and obese subjects (55). Within the VLCD and LCD groups, this decrease was not observed, with total energy expenditure at similar levels recorded at baseline. Correlation analysis confirmed the link between the increased feelings of fatigue with a decrease in physical activity ($r = -0.476$, $P = 0.046$). The more lively subjects felt, the more active they were ($r^2 = 0.516$, $P = 0.028$). For example, while the fasting group had decreased energy expenditure and increased feelings of fatigue, the LCD group maintained energy expenditure and reported no significant change in fatigue or tiredness. Thus, psychological profile was an important predictor of daily energy expenditure (and thus energy balance).

Do short-term fasts work for long-term weight control?

During the *ad libitum* period, when subjects determined their own feeding behaviour within the HNU, the men continued to lose weight by a further -1.8 , -1.3 and -1.7 kg in the fasting, VLCD and LCD groups respectively (Table 1). Thus, subjects cognitively restrained their intake below requirements in order to control body weight. While this may be a feature of the environment within the HNU, it does show that immediate rebound following WL is not obligatory. These data suggest that post-WL hyperphagia need not be an immediate response to diet therapy.

Noticeably, subjects in the fasting group lost more weight (~ 3.5 kg) ($P < 0.005$) in the 10-week follow-up period, and maintained most of their WL at 1 year (Table 1). In con-

trast, although the VLCD and LCD groups maintained their new lower body weight for up to 3 months, by 1 year, most had regained the weight. A key question is 'how did the subjects in the fasting group maintain their new stable body weight?', because this is contrary to common sense, especially as the content of the WL included transient elements (e.g. water mobilization with glycogen store depletion). This is not easy to answer, because no measurements were made at the 1-year time-point. Anecdotally, however, the subjects reported a trend of using fasting as a means to control body weight. They had learned they could restrict food intake for a period of time with no apparent side effects. It should be noted that these subjects volunteered for this WL study with full knowledge that it involved fasting and that they may be predisposed to do well within this WL regime, i.e. that the criteria predetermined the selection of men who would be successful with this strategy. More work is required in this area to investigate this phenomenon further.

Conclusions

We can conclude that fasting is a 'quick fix' to achieve a substantial WL (up to 5% loss in 6 days). There is, however, the problem of elevated hunger during food restriction and this may provide too great a challenge to a 'faster' in not breaking compliance to the dieting regime and reaching for the biscuit barrel. Also, fasting results in minimal loss of fat tissue, in comparison with other dietary regimes and does involve substantial loss of lean (protein) tissue and this may impact on physiological function. Therefore, short-term fasting may not be a regime that optimizes the health benefits of fat loss *per se*. During fasting, increased fatigue can reduce spontaneous physical activity by ~ 1 – 2 MJ d^{-1} , and this will ultimately limit negative energy balance and may be seen as counter-productive. Nonetheless, a zero calorie intake does guarantee WL and this overrides some of the impact of reduced energy expenditure. Post WL, it is unclear what mechanisms or behavioural traits promote weight stability and whether fasting could contribute to maintenance of WL in some phenotypes. This continuous fast regime is not suitable for all individuals and would require medical supervision. For

Table 1 Average body weight (kg) for each study, by period, along with the *P*-value and SED summarizing the main period effects

Body weight (kg)	Baseline	5% WL	10% WL	Reduced maint.	<i>Ad libitum</i>	2 weeks	10 weeks	1 year	SED	<i>P</i>
Fast	107.2	101.1*	*	102.4*	100.6*	99.1*	97.2*	99.3*	1.31	<0.001
VLCD	107.3	102.1*	98.1*	97.9*	96.3*	96.2*	96.1*	106.2	1.26	<0.001
LCD	105.6	98.2*	92.8*	92.6*	90.9*	91.2*	91.2*	103.6	1.01	<0.001

SED, standard error of difference; Reduced maint., reduced maintenance period; WL, weight loss; VLCD, very-low-calorie diet; LCD, low-calorie diet.

*Difference between baseline and all other periods.

medical reasons we cannot promote it as a public health WL strategy. Nonetheless, intermittent fasting remains an intriguing intervention that may provide a novel method of body weight control for certain individuals.

Conflict of Interest Statement

No conflict of interest was declared.

Acknowledgements

The studies described were only achievable by a team effort from Dr James Stubbs, Dr Gerald Lobley, Dr Peter Faber, Prof Marinos Elia and Dr Eileen Gibney. Funding from the Scottish Executive Environment and Rural Affairs Department and Slimming World, Alfreton, UK is gratefully acknowledged.

References

1. Procope J. *Hippocrates on Diet and Hygiene*. London: Zeno, 1952.
2. Beltaifa L, Bouguerra R, Ben Slama C, Jabrane H, El-Khadhi A, Ben Rayana MC, Doghri T. Food intake, and anthropometrical and biological parameters in adult Tunisians during fasting at Ramadan. *East Mediterr Health J* 2002; 8: 603–611.
3. Gharbi M, Akrouit M, Zouari B. Food intake during and outside Ramadan. *East Mediterr Health J* 2003; 9: 131–140.
4. Finch GM, Day JE, Razak Welch DA, Rogers PJ. Appetite changes under free-living conditions during Ramadan fasting. *Appetite* 1998; 31: 159–170.
5. Keys A, Brozek J, Henschel A, Mickelsen O, Taylor HL. *The Biology of Human Starvation*. Minneapolis, MN: The University of Minnesota Press, North Central Publishing, 1950.
6. Dulloo AG, Jacquet J. The control of partitioning between protein and fat during human starvation: its internal determinants and biological significance. *Br J Nutr* 1999; 82: 339–356.
7. Dulloo AG, Jacquet J, Girardier L. Autoregulation of body composition during weight recovery in humans: the Minnesota Experiment revisited. *Int J Obes* 1996; 20: 393–405.
8. Dulloo AG, Jacquet J, Girardier L. Poststarvation hyperphagia and body fat overshooting in humans: a role for feedback signals from lean and fat tissues. *Am J Clin Nutr* 1997; 65: 717–723.
9. Stubbs RJ, Johnstone AM, Blundell JE. Appetite: psychobiological and behavioural aspects. In: Sadler M, Caballero B, Strain S (eds). *Encyclopaedia of Human Nutrition*. San Diego: Academic Press Limited, 1999, pp. 127–137.
10. Stubbs RJ. Peripheral signals affecting food intake. *J Nutr* 1999; 15: 7–8.
11. Mattes R. Hunger ratings are not a valid proxy measure of reported food intake in humans. *Appetite* 1990; 15: 103–113.
12. Elia M. Hunger disease. *Clin Nutr* 2000; 19: 379–386.
13. Collins S. The limit of human adaption to starvation. *Nat Med* 1995; 1: 810–814.
14. Henry CJK, Rivers JPW, Payne PR. Protein and energy metabolism in starvation reconsidered. *Am J Clin Nutr* 1988; 42: 543–549.
15. James WPT. Introduction: the challenge of adult chronic energy deficiency. *Eur J Clin Nutr* 1984; 48: S1–S9.
16. Shetty PS. Physiological mechanisms in the adaptive response of metabolic rates to energy restriction. *Nutr Res Rev* 1990; 3: 49–74.
17. McCance RA, Widdowson EM. *Calorie Deficiencies and Protein Deficiencies*. London: Churchill, 1951.
18. Polivy J, Zeitlin SB, Herman CP, Beal AL. Food restriction and binge eating: a study of former prisoners of war. *J Abnorm Psychol* 1994; 103: 409–411.
19. Polivy J, Herman CP. Dieting and bingeing: a casual analysis. *Am Psychol* 1985; 40: 193–201, 198.
20. Smith DA, Woodruff MFA (eds). *Deficiency Diseases in Japanese Prison Camps*. Medical Research Council Special Report Series No. 274. London: Medical Research Council, 1951.
21. Apfelbaum E. Maladie de famine. *Recherches cliniques sur la famine exécutées dans le Ghetto de Varsovie en 1942*. Warsaw: Am Joint Distribution Committee, 1946.
22. Meyers AW. Some morphological effects of prolonged inanition. *J Med Res* 1917; 36: 51–78.
23. Elia M. Effect of starvation and very low calorie diets on protein-energy interrelationships in lean and obese subjects. In: Scrimshaw N, Schurch B (eds). *Protein-Energy Interactions*. International Dietary Energy Consultancy Group, Proceedings of an IDECG workshop. Lausanne: Nestle Foundation, 1991, pp. 249–284.
24. Thomson TJ, Runcie J, Miller V. Treatment of obesity by total fasting for up to 249 days. *Lancet* 1966; 992–996.
25. Van Gaal LF, Wauters MA, Leeuw IH. The beneficial effects of modest weight loss on cardiovascular risk factors. *Int J Obes* 1997; 21: 5–9.
26. Munro JF, MacCuish AC, Goodall AD, Fraser J, Duncan LJP. Further experience with prolonged therapeutic starvation in gross refractory obesity. *BMJ* 1970; 19: 712–714.
27. Runcie J, Thomson TJ. Prolonged starvation – a dangerous procedure? *BMJ* 1970; 3: 432–435.
28. Bloom WL. Fasting as an introduction to the treatment of obesity. *Metabolism* 1959; 8: 214–220.
29. Duncan GG, Jenson WK, Fraser RI, Cristofori FC. Correction and control of intractable obesity. *JAMA* 1962; 181: 308–312.
30. Drenick EJ, Swendsoid BWH, Tuttle SG. Prolonged starvation as treatment for severe obesity. *JAMA* 1964; 187: 140.
31. Cahill GF. Starvation in man. *N Engl J Med* 1970; 282: 668–675.
32. Stuart WK, Flemming LW. Features of a successful therapeutic fast of 382 days duration. *Postgrad Med J* 1973; 49: 203–209.
33. French SA, Jeffery RW, Foster JL, McGovern PG, Kelder SH, Baxter JE. Predictors of weight change over two years among a population of working adults: the healthy worker project. *Int J Obes* 1994; 18: 145–154.
34. Wadden TA, Stunkard AJ, Brownell KD. Very low calorie diets: their efficacy, safety, and future. *Ann Intern Med* 1983; 99: 675–684.
35. Bravata DM, Sanders L, Huang J, Krumholz HM, Olkin I, Gardner CD, Bravata DM. Efficacy and safety of low-carbohydrate diets: a systematic review. *JAMA* 2003; 289: 1837–50.
36. Crowe TC. Safety of low-carbohydrate diets. *Obes Rev* 2005; 6: 235–245.
37. Sjostrom L. Surgical intervention as a strategy for treatment of obesity. *Endocrine* 2000; 13: 213–230.
38. Sjostrom L, Lindroos AK, Peltonen M, Torgerson J, Bouchard C, Carlsson B, Dahlgren S, Larsson B, Narbro K, Sjostrom CD, Sullivan M, Wedel H, Swedish Obese Subjects Study Scientific Group. Lifestyle, diabetes, and cardiovascular risk factors 10 years after bariatric surgery. *N Engl J Med* 2004; 351: 2683–2693.

39. Rennie KL, Jebb SA. Prevalence of obesity in Great Britain. *Obes Rev* 2005; **6**: 11–12.
40. Johnstone AM, Faber P, Gibney ER, Elia M, Horgan G, Golden BE, Stubbs RJ. Effect of an acute fast on energy compensation and feeding behaviour in lean men and women. *Int J Obes* 2002; **26**: 1623–1628.
41. Black AE, Coward WA, Cole TJ, Prentice AM. Human energy expenditure in affluent societies: analysis of 574 doubly-labelled water measurements. *Eur J Clin Nutr* 1996; **50**: 72–92.
42. Lawton CL, Burley VJ, Wales JK, Blundell JE. Dietary fat and appetite control in obese subjects: weak effects on satiation and satiety. *Int J Obes* 1993; **17**: 409–416.
43. Green SM, Burley VJ, Blundell JE. Effect of fat- and sucrose-containing foods on the size of eating episodes and energy intake in lean males: potential for causing overconsumption. *Eur J Clin Nutr* 1994; **48**: 547–555.
44. Delargy HD, Burley VJ, Sullivan KR, Fletcher RJ, Blundell JE. Effects of different soluble: insoluble fibre ratios at breakfast on 24-h pattern of dietary intake and satiety. *Eur J Clin Nutr* 1995; **49**: 754–766.
45. Hoggard N, Johnstone AM, Faber P, Gibney ER, Elia M, Lobley G, Rayner V, Horgan G, Hunter L, Bashir S, Stubbs RJ. Plasma concentrations of alpha-MSH, AgRP and leptin in lean and obese men and their relationship to differing states of energy balance perturbation. *Clin Endocrinol (Oxf)* 2004; **61**: 31–39.
46. Johnstone AM, Faber P, Andrew R, Gibney ER, Elia M, Lobley G, Stubbs RJ, Walker BR. Influence of short-term dietary weight loss on cortisol secretion and metabolism in obese men. *Eur J Endocrinol* 2004; **150**: 185–194.
47. Faber P, Johnstone AM, Gibney ER, Elia M, Stubbs RJ, Roger PL, Milne E, Buchan W, Lobley GE. The effect of rate and extent of weight loss on urea salvage in obese male subjects. *Br J Nutr* 2003; **90**: 221–231.
48. Runcie J, Hilditch TE. Energy provision, tissue utilisation and weight loss in prolonged starvation. *BMJ* 1974; **2**: 352–356.
49. Yang MU, Van Itallie TB. Composition of weight lost during short-term weight reduction. Metabolic responses of obese subjects to starvation and low-calorie ketogenic and nonketogenic diets. *J Clin Invest* 1976; **58**: 722–730.
50. Elia M, Jebb SA. Assessment of body composition: research techniques and bedside methods. *SA J Clin Nutr* 1990; **3**: 21–26.
51. Fuller NJ, Jebb SA, Laskey MA, Coward WA, Elia M. Four-compartment model for the assessment of body composition in humans: comparison with alternative methods and evaluation of the density and hydration of fat-free mass. *Clin Sci* 1992; **82**: 687–693.
52. Heymsfield SB, Waki M. Body composition in humans: advances in the development of multicompartiment chemical models. *Nutr Rev* 1991; **49**: 97–107.
53. Wells JCK, Fuller NJ, Dewit O, Fewtrell MS, Elia M, Cole TJ. Four-compartment model of body composition in children: density and hydration of fat-free mass and comparison with simpler models. *Am J Clin Nutr* 1999; **69**: 904–912.
54. Elia M. Energy expenditure in the whole body. In: Kinney JMT (ed.). *Energy Metabolism: Tissue Determinants and Cellular Corollaries*. New York: Raven Press, 1992, pp. 19–49.
55. Grande F. Man under caloric deficiency. In: Dill DB, Adolph EF, Wilber CG (eds). *Handbook of Physiology, Section 4, Adaptation to the Environment*. Washington, DC: American Physiological Society, 1964, pp. 911–937.
56. Gilder H, Cornell GN, Grafe WR, Macfarlane R, Asaph JW, Stubenbord WT, Watkins GM, Rees JR, Thorbjarnarson B. Components of weight loss in obese patients subjected to prolonged starvation. *J Appl Physiol* 1967; **23**: 304–310.
57. Benoit FL, Martin RL, Watten RH. Changes in body composition during weight reduction in obesity. Balance studies comparing effects of fasting and a ketogenic diet. *Ann Intern Med* 1965; **63**: 604–612.
58. Kjellberg J, Reizenstein P. Effect of starvation on body composition in obesity. *Acta Med Scand* 1970; **188**: 171–178.
59. Barnard DL, Ford J, Garnett ES, Mardell RJ, Whyman AE. Changes in body composition produced by prolonged total starvation and refeeding. *Metabolism* 1969; **18**: 564–5569.
60. Westman EC, Mavropoulos J, Yancy WS, Volek JS. A review of low-carbohydrate ketogenic diets. *Curr Atheroscler Rep* 2003; **6**: 476–483.
61. Volek JS, Sharman MJ, Love DM, Avery NG, Gomez AL, Scheett TP, Kraemer WJ. Body composition and hormonal responses to a carbohydrate-restricted diet. *Metabolism* 2002; **51**: 864–870.
62. Volek JS, Sharman MJ. Cardiovascular and hormonal aspects of very-low-carbohydrate ketogenic diets. *Obes Res* 2004; **2**(Suppl.): 115S–23S.
63. Astrup A, Meinert Larsen T, Harper A. Atkins and other low-carbohydrate diets: hoax or an effective tool for weight loss? *Lancet* 2004; **364**: 897–899.
64. Rand CSW, McGregor AMC. Morbidly obese patients' perceptions of social discrimination before and after surgery for obesity. *South Med J* 1990; **83**: 1390–1395.
65. Rand CSW, McGregor AMC. Successful weight loss following obesity surgery and the perceived liability of morbid obesity. *Int J Obes* 1991; **15**: 577–559.
66. Stunkard AJ, Rush J. Dieting and depression re-examined. *Ann Intern Med* 1974; **81**: 526–533.
67. Van Itallie TB, Yang M, Hashim SA. Dietary approaches to obesity: metabolic and appetitive considerations. In: Howard A (ed.). *Recent Advances in Obesity, Vol. I*. Westport, CT: Technomic Publishing Company, 1977, pp. 256–269.
68. Wooley SC, Wooley OW, Dyrenforth SR. Theoretical, practical and social issues in behavioural treatment of obesity. *J Appl Behav Anal* 1979; **12**: 3–25.
69. Wadden TA, Stunkard AJ, Brownell KD, Day SC. A comparison of two very-low-calorie diets: protein-sparing-modified fast versus protein-formula liquid diet. *Am J Clin Nutr* 1985; **41**: 553–539.
70. Wadden TA, Stunkard AJ, Day SC, Gould RA, Rubin CJ. Less food, less hunger: reports of appetite and symptoms in a controlled study of a protein-sparing modified fast. *Int J Obes* 1987; **11**: 239–249.
71. Bollinger RE, Lukert BD, Brown RV, Guevara RW, Stenberg R. Metabolic balance of obese during fasting. *Arch Intern Med* 1966; **118**: 3–8.
72. Lappalainen R, Sjoden PO, Hursti T, Vesa V. Hunger/craving responses and reactivity to food stimuli during fasting and dieting. *Int J Obes* 1990; **14**: 679–688.
73. Silverstone JT, Stark JE, Buckle RM. Hunger during total starvation. *Lancet* 1966; **1**: 1343–1344.
74. Rosen JC, Hunt DA, Sims EAH, Bogardus C. Comparison of carbohydrate-containing and carbohydrate-restricted diets in the treatment of obesity: effects on appetite and mood. *Am J Clin Nutr* 1982; **36**: 463–469.
75. Rosen JC. Effects of low-calorie dieting and exposure to diet-prohibited food on appetite and anxiety. *Appetite* 1981; **2**: 366–369.
76. Blundell JE, Stubbs RJ. Diet composition and the control of food intake in humans. In: Bray GE, Bouchard C, James WPT (eds). *Handbook of Obesity*. New York: Marcel Dekker, 1998, pp. 243–272.

77. de Graff C, Jas P, van der Kooy K, Leenen R. Circadian rhythms of appetite at different stages of a weight loss programme. *Int J Obes* 1993; **17**: 521–526.
78. Blundell JE. Hunger, appetite and satiety – constructs in search of identities. In: Turner M (ed.). *Nutrition and Lifestyles*. London: Applied Science Publishers, 1979, pp. 21–42.
79. Hill AJ, Blundell JE. Nutrients and behaviour: research strategies for the investigation of taste characteristics food preferences, hunger sensations and eating patterns in man. *J Psychol Res* 1982; **17**: 203–212.
80. Lee KA, Hicks G, Nino-Murcia G. Validity and reliability of a scale to assess fatigue. *Psychiatry Res* 1981; **36**: 291–298.
81. Russell DMcR, Walker PM, Leiter LA, Sima AAF, Tanner WK, Mickle DAG, Whitwell J, Marliss EB, Jeejeebhoy KN. Metabolic and structural changes in skeletal muscle during hypocaloric dieting. *Am J Clin Nutr* 1984; **39**: 503–513.
82. Johns MW. Daytime sleepiness, snoring and obstructive sleep apnea. *Chest* 1993; **103**: 30–36.
83. Buffenstein R, Karklin A, Driver HS. Beneficial physiological and performance responses to a month of restricted energy intake in healthy overweight women. *Physiol Behav* 2000; **68**: 439–444.
84. Green MW, Rogers PJ. Impaired cognitive functioning during spontaneous dieting. *Physiol Med* 1995; **25**: 1003–1010.
85. Gibney ER 2001. *The physical, psychological and metabolic effects of nutritional depletion and subsequent repletion*. PhD Thesis. Darwin College, University of Cambridge, UK.
86. Kleitman N. Basal metabolism in prolonged fasting in man. *Am J Physiol* 1926; **77**: 233–244.