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NARRATIVE REVIEW

What is the best diet to recommend when treating obesity by an increase of habitual physical activity? Part 3. The roles of water, fibre intake, and other possibly helpful nutritional options.

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Abstract

Background. The objective of this three-part narrative review has been to examine empirical data on the optimal type of diet to recommend when individuals with established obesity are being treated by a programme of moderate exercise coupled with some reduction of daily energy intake. The final section of this review considers the potentially beneficial influence of an increased water and fibre intake, along with other possibly helpful nutritional options. **Methods.** Information obtained from Ovid/Medline, PubMed and Google Scholar through to September 2019 has been supplemented by a search of the author's extensive personal files. **Results.** Drinking additional water or adding water to a food product may reduce immediate hunger and thus the overall intake of food, replace the previous consumption of sugar-containing drinks, and possibly increase thermogenesis by an osmotic mechanism. Longitudinal studies give tentative evidence that increased water ingestion has some beneficial effect upon body mass, greater in the obese than in individuals of normal weight. A high fibre content also increases satiety, but randomized controlled trials show that such a diet has little advantage in terms of eventual weight loss. Other potentially beneficial options include an increased consumption of nuts, yogurt and calcium. In cross-sectional analyses, nut consumption is inversely associated with body weight, but short-term experimental increases of nut consumption have had little influence upon body mass. Yogurt has also been suggested as helping the process of weight loss, but again there are as yet few randomized controlled trials supporting such an idea. Cross-sectional and cohort studies, almost without exception, have shown better weight regulation in groups receiving calcium supplements or an increased intake of dairy products, but in contrast there is either no effect or at most a quite small benefit to be seen in randomized trials. **Conclusions.** Available randomized studies suggest that the fat loss achieved by a combination of moderate physical exercise and some restriction of energy intake is similar for those following a variety of diets and nutritional tactics. Challenges to health professionals are to maintain a blood glucose level that avoids a deterioration of mood and a reduction of voluntary exercise, to maintain lean tissue mass and thus resting metabolic rate, and to sustain satiety and thus the enthusiasm needed to persist with the prescribed regimen. **Health & Fitness Journal of Canada 2020;13(1):38-98.**

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Introduction

In considering the best diet to recommend to clients who are following an exercise-centred programme of weight regulation, previous sections of this review have explored optimal eating patterns and the influence of the sugar and salt content of foods (Shephard, 2020a), as well as the relative merits of high-carbohydrate, high-fat and high-protein diets (Shephard, 2020b). In the final section of this review, we explore questions of water and fibre intake, and other possibly helpful nutritional options such as an increased consumption of nuts and yogurt, and the provision of calcium supplements.

The effects of ingesting additional water

There is a growing body of evidence suggesting that an increased ingestion of water may facilitate the process of weight loss. Several investigators have reported beneficial changes in body mass index, waist circumference and/or body fat content in response to an increased intake of water (Dennis, Dengo, & Comber, 2010; Stookey, Constant, Popkin & Gardner, 2008; Van Walleghen, Orr, Gentile & Davy, 2007; Vij & Joshi, 2013, 2014). In particular, Stookey et al. (2008) evaluated 173 premenopausal women who were following various diets in an attempt to reduce their body mass. Decreases in weight, waist circumference and body fat content were all significantly correlated with increases in the individual's water intake, independently of either other features of their diet or the person's level of habitual physical activity.

Potential mechanisms of benefit from a greater intake of water include a temporary reduction in hunger and thus a smaller intake of food, an increase of thermogenesis, and an avoidance of sugar-containing beverages that might otherwise have been consumed. We will summarize the findings of several systematic reviews and discuss a number of pertinent empirical studies of this question.

Systematic reviews.

Several systematic reviews have supported the idea that the decrease in body mass of a dieter can be increased and the process of subsequent weight maintenance can be facilitated by increasing the daily ingestion of water (Daniels & Popkin, 2010; Dennis, Flack, & Davy, 2009; Muckelbauer, Sarganas, Grüneis, & Müller-Nordhorn, 2013). Nevertheless, Dennis et al. (2009) and Daniels et al. (2010) both concluded that there is still only a limited amount of research pointing to the conclusion that an increased daily water intake is helpful in weight loss and subsequent weight maintenance.

Mucklebauer et al. (2013) accumulated 11 relevant articles, but argued that the quality of individual investigations was too low to reach strong conclusions about the benefits of increasing water ingestion when seeking to reduce body weight. It appeared that if pursued consistently for periods of 3-12 months, it could be an effective tactic to facilitate weight loss and subsequent weight maintenance in obese individuals, but that increased water intake had little impact on the subsequent body mass of populations that were already at or approaching a normal body weight. A further review from the same laboratory was restricted to studies of children and adolescents (Muckelbauer et al., 2014). It focused on 9 cross-sectional and 4 longitudinal reports. On a cross-sectional basis, a larger water consumption was actually associated with a greater body weight, but in the longitudinal data there was at least a suggestion that water consumption had a weight-reducing effect, possibly by encouraging a reduced consumption of sugar-containing beverages.

Stookey (2016) argued that the effects of water ingestion varied with the circumstances. However, with an ad libitum food intake, drinking water reduced energy intake relative to drinking an equivalent volume of energy containing beverages, and in metabolically inflexible obese individuals, water drinking appeared to increase energy expenditures.

Analysis of data from the 2010 US National Youth Physical Activity and Nutrition Study of 11,049 students in grades 9 through 12 (Park, Blanck, Sherry, & O'Toole, 2012) highlighted the problem of covariates in cross-sectional analyses. In their sample, a low intake of water was associated with a poor overall diet, the frequent consumption of fast food, and physical inactivity, all of which in themselves could give rise to obesity.

Individual empirical data.

Individual empirical data have been classified according to the suggested mechanisms apparently underlying any beneficial effect of the added water ingestion (Table 1). Hypotheses have included a reduction of appetite, a decreased intake of food (Vij & Joshi, 2014), a reduced consumption of sugar-containing beverages, a stimulation of thermogenesis, and a specific increase of fat metabolism associated with hypo-osmolarity (Keller, Szinnai, Bilz, & Berneis, 2003).

No specific hypothesis. Many authors have reported their empirical findings, without speculating as to the mechanisms underlying any beneficial effects of an increased ingestion of water. Akers et al. (2012) worked with a group of 39 older adults (age ~63 yr) who had previously lost an average of 6.7 kg in body mass through dieting. Over the following year, they kept a daily record of body mass, physical activity (as measured by a pedometer), fruit and vegetable intake, and water intake. A half of the group deliberately drank 16 oz of water before each meal, and over the course of a year they showed a 1.7 kg advantage of weight relative to the remaining subjects (a loss of 0.7 kg, as compared with a gain of 1.0 kg). The authors of this report linked their finding to a suggestion that on average the water consumers ingested 0.8 MJ less energy per day.

Al-Muammar et al. (2013) used a simple questionnaire to make a 3-category classification of the water drinking habits in 107 Saudi-Arabian schoolgirls aged 12-15 years. Only a small proportion of their sample was overweight (12%) or obese (6%). They used a simple chi2 test to make a cross-sectional analysis of their data, finding no relationship between water drinking and a 4-level classification of the girls' BMIs.

Cullen et al. (2004) examined 145 African-American girls aged 8-10 years, looking at the correlates of daily servings of water as reported in two 24-hour dietary recall records. A positive cross-sectional association was found between water-servings and BMI, but this relationship disappeared after allowing for various covariates, particularly the socio-demographic characteristics and energy consumption of the students.

Fiore et al. (2006) studied data for 1890 US children aged 12-16 years. A cross-sectional analysis showed that a greater intake of water (reported as cups per day) was associated with an increased

Table 1. Influence of increased water ingestion on energy balance, categorized according to the mechanisms proposed by the authors concerned.

Author	Sample	Intervention	Findings	Comment
No specific proposed mechanism				
Akers, Cornett, Savia, Davy, and Davy (2012)	40 adults aged ~63 yr, previously ldecreased body mass ~6.7 kg	Daily record of wt, phys. activ., fruit/veg. intake, water intake	16 oz water 3 times/d reduced food intake 35.7 kJ/d relative to peers	
Al Muammar, El-Shafie, and Feroze (2013)	107 Saudi-Arabian girls aged 12-15 yr	Questionnaire on water consumption (3 categories)	Water intake not related to BMI category on simple chi^2 test	
Cullen, Baranowski, and Klesges (2004)	145 African-American children aged 8-10 yr	Two 24 h dietary recalls	Positive association of water servings/day and BMI	Correlation disappeared after introduction of covariates
Fiore, Travis, Whalen, Auinger, and Ryan (2006)	1890 US children aged 12-16 yr	Questionnaire, cups of water/day	Increased water consumption increased obesity risk only if obese parents	
Jormeus, Karlsson, Dahlgren, Lindstrom and Nystrom (2010)	20 healthy adults	Water intake increased by 30 mL/kg per day for 2 wk	No difference of body wt between exp. and control phases of study	2 weeks too short an intervention?
Kant, Graubard, and Atchison (2009)	4112 US adults	Intake of plain water and other forms of water	Body weight not consistently related to plain water intake, but increased with total water intake	
Kucmarkski, Mason, Schwenk, Evans and Zonderman (2010)	1987 low-income US adults	Daily intake of water and other beverages	Water intake did not differ between normal, overweight and obese individuals	No covariates in analysis
Lee, Park and Kim (2014)	1270 S. Korean adolescents aged 15-18 yr	Interviewed regarding water consumption	Less likely to be underweight if consumed <4 cups/d of water	Adjusted for various covariates including other drinks and phys. activity
Makkes, Montenegro-Bethancourt, Groeneveld, Doak and Solomons (2011)	356 children aged 8-10 yr	Reported consumption of water and other beverages	BMI unrelated to water consumption in last 24 h (yes/no)	Data stratified by socio-economic status
Stookey et al. (2008)	173 premenopausal obese women aged 25-50 yr	Increased drinking of water > 1L/d for 12 months	Significant correlation with decreased wt, waist circumference and fat loss	Effect independent of diet or physical activity
Reduced hunger and lesser intake of food				
An and McCaffrey (2016)	18,311 US adults aged > 18 yr	Change in intake of plain water/d between two 24-h assessments	1% increase in water intake reduced food intake 35.7 kJ/d	Independent of ethnicity, income, education & body wt
Davy, Dennis, Dengo, Wlison and Davy (2008)	24 obese & overweight adults, age ~ 61 yr	Meal with or without 500 mL water pre-load	Energy intake reduced by 13% with water preload	

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Author	Sample	Intervention	Findings	Comment
Reduced hunger and lesser intake of food				
Dennis et al. (2010)	48 adults, aged 55-75 yr, BMI 25-40 kg/m^2	Hypocaloric diet, vs. diet + 500 mL of water at each meal	Added water increased weight loss by 2 kg over 12 wks	Water preload reduced initial energy intake by 179 kJ/meal
Lappalainen, Mennen, van Weert and Mykkänen (1993)	8 normal weight women	400 mL of water at breakfast vs. no water	Hunger reduced and satiety increased during meal but not after it	Did not study actual food intake
Rolls, Bell and Thorwart, 1999)	24 lean women	Water alone vs. water added to food	Mixing water in food reduced hunger and food intake	Effect greater than water taken separately
Van Walleghen et al. (2007)	29 young and 21 older non-obese adults	Meal with or without water (350 mL F, 500 mL M)	Water cut food intake 241 kJ/d in older subjects, not in young adults	Water preload increases satiety in older subjects
Increased thermogenesis				
Boschmann , Steiniger, Hille, Tank, Adams, Sharma, et al. (2003)	14 healthy, normal weight subjects	Ingestion of 500 mL water	Metabolic rate increased by 30-40% after ingestion	40% of effect due to warming water to 37º C (100 kJ)
Boschmann , Steiniger, Franke, birkenfeld, Luft and Jordan (2007)	16 overweight or obese men and women	Crossover, 500 mL water vs. 500 mL saline vs. 50 mL water	Metabolic rate increased 24% by 500 mL water, only persisted for 60 min	Effect not due to gastric distension- ? a portal osmoreceptor mechanism
Brown, Dulloo, and Maontani (2006)	8 healthy volunteers	500 mL of room temperature or 3 C water vs. 0.9% saline vs. 7% sucrose	Thermal response only seen with 7% sucrose	
Dubnov-Raz, Constantini, yariv, Nice, and Shapira (2011)	21 overweight children aged 9.9 yr	10 mg/kg cold water	Increased resting metabolism by 25% for ~40 min	Recommended daily dose of water equates to 1.2 kg less body mass/yr
Vij and Joshi (2013, 2014)	50 overweight females	Water intake increased by 500 mL 3/d for 8 wks	Wt loss 1.4 kg, skin-folds - 3 mm	Appetite score also reduced
Reduced intake of sweetened beverages				
Daniels and Popkin (2010)	Review of observational studies	Pre-meal water or sugar-containing beverage	Energy intake 7.8% lower with water than with sweetened beverage	
DuBuisson, Zech, Dassy, Jodogne, and Beauloye (2012)	144 children aged ~10.5 yr	~2.2 yr treatment	Wt. loss related to water intake & inversely related to sweetened drinks	
Johnson, Mander, Jones, Emmett and Jebb (2007)	521, 682 children	3-day diet records at ages 5, 7 yr, fatness measured at age 9 yr	Sweet drink consumption at 5, 7 yr unrelated to fatness at age 9 yr	Association seen at 9 yr because obese children opt for low energy drinks?
Pan et al. (2013)	50,013 & 52,987 women, 21,988 men	Changes in beverage consumption over 4 yr	Cup/d water reduces wt 0.13 kg. Small effects of changes in other beverages	

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Author	Sample	Intervention	Findings	Comment
Reduced intake of sweetened beverages				
Papandreou, Andreou, Heraclides and Rousso (2013)	607Greek children aged 7-15 yr	Beverage choices and risk of obesity	Those drinking sweetened beverages 2.57 times more likely to become obese	Water intake not associated with risk of obesity
Park, Blanck, Sherry, Brener and O'Toole (2012)	11,049 students, grade 9-12	Correlates of low water intake (<3/d)	Reduced likelihood of obesity	Also related to consumption of sweetened drinks, fast food & phys. inactivity
Peters et al. (2014)	303 men and women	Water vs. non-nutritive sweetened (NNS) beverage over 12 wk,	Wt. losses 4.1 vs. 6.0 kg	NNS beverage reduced hunger more
Popkin, Barclay and Nielsen (2005)	4755 participants in U.S. NHANES study 1999-2001	Water consumers (87% of sample, 1.5 L/d average) vs. non-consumers	Daily energy intake 807 kJ smaller for water ingesters	Healthier food patterns and less sugary soft drinks ingested by water drinkers
Sichieri, Paula Trotte, de Souza and Veiga (2009)	1140 Grade 4 students, Brazil	Intervention group reduced sweetened drinks by 56 ml/d relative to controls over school year	Non-significant reduction of BMI, greater in those initially obese	
Tate et al. (2012)	318 overweight & obese adults	Replacing caloric with non-caloric beverages	Over 6 months, wt. reduced by diet beverages (2.5%) and water (2.0%)	Intention to treat analysis

risk of obesity, but only in those youth whose parents were also obese.

Jormeus et al. (2010) had 20 healthy adults deliberately increase their water intake by 30 mL/kg per day for a period of two weeks. Over this relatively short experimental interval, no differences in body mass were observed relative to the control phase of the investigation.

Lee et al. (2014) interviewed 1270 Korean adolescents aged 15-18 years. In a cross-sectional analysis of reported water intakes, Lee et al. found that those students falling below a proposed criterion of adequate water consumption (<4 cups/day) were likely to be either underweight or overweight rather than of normal weight, after adjusting for various covariates that included age, sex, the consumption of fruit, vegetables, other drinks and habitual physical activity. However, water consumption was unrelated to the consumption of "sodas" in this study; possibly, milk was a more popular alternative to water for these Korean adolescents.

Makkes et al. (2011) undertook a meta-analysis of cross-sectional studies examining associations between the reported consumption of water and other beverages and BMI in a sample of 356 children aged 8-10 years. An increased intake of sweetened beverages was associated with weight gain, but attempts to reduce the intake of sweetened beverages did not decrease body weight. Water consumption over the past 24 hours (a simple yes/no response) was unrelated to the child's BMI.

Reduction of appetite and a decreased food intake. Whether taken alone or added to the food during cooking, water increases the bulk of a meal, with no increase of energy intake. It is thus not surprising that several trials have demonstrated that pre-loading with water shortly before a meal can increase immediate satiety and thus decrease the quantity of food ingested shortly thereafter.

An and McCaffrey (2016) analyzed the effects of a change in water consumption between two 24-hour dietary recall assessments that were made 3-10 days apart in a sample of 18,311 US adults aged > 18 years. Individuals with a 1% increase in their intake of plain water at the second assessment showed a 35.7 kJ/day decrease in their intake of food energy, this association being independent of ethnicity, income, education or weight status.

In a crossover trial, Davy et al. (2008) examined 24 older obese and overweight adults with an average age of ~ 61 years and an average body mass index of ~ 34 kg/m2. Introducing a 500 mL water preload 30 minutes before breakfast decreased the energy intake of this group by 13% relative to presentation of the same meal without the water preload.

Dennis et al. (2010) compared the response to a hypo-caloric diet (5.0-6.2 MJ/day) alone with that seen when the same hypo-caloric diet was combined with a pre-meal drink of 500 mL of water. Over comparable one-week periods, the addition of water augmented the decrease of body mass by 2 kg relative to dieting alone in a sample of 48 older individuals (aged 55-75 years). The extra benefit appeared due in part to a smaller ingestion of food (there was an early decreased intake of 179 kJ/meal, although this was not seen when the energy intake was again measured at the end of the week) (Dennis et al., 2010).

Kant et al. (2009) compared responses to the intake of plain water and other presentations of water in a sample of 4112 US adults. Body weight and energy intake were not consistently related to the intake of plain water (which on average amounted to about a third of the total water intake), but body weight was positively associated with the total fluid intake. Further, the individual's intake of sweetened beverages was inversely related to his or her water intake.

A cross-sectional analysis by Kucmarkski et al. (2010) looked at the beverage intake of 1987 low-income adults in the U.S., considering the ingestion of water and a variety of other beverages. The daily intake of plain water did not differ between those of normal weight, the overweight and the obese, but no covariates were considered in this analysis.

Lappainen et al. (1993) had 8 women take 400 mL of water with each of 3 successive breakfasts, and then eat 3 breakfasts without drinking any water. On the days when water was provided, feelings of hunger and satiety were reduced during the meal, but not afterwards. No measurements were made to examine the impact of these changes in hunger and satiety upon actual food intake.

In a study of 24 lean women. Rolls et al. (1999) compared the effects of drinking water separately versus that of incorporating it into a form of a soup. On each of 3 visits to the laboratory, a preload of 1.13 MJ of chicken was eaten 17 minutes before lunch. On one occasion, 356 g of plain water was taken with the pre-load, and on a second occasion the same amount of water was mixed with the chicken to form a soup. The soup reduced immediate hunger and subsequent food intake by 0.43 MJ, but the same volume of water did not have this effect when it was drunk alone. Other experiments by the same research group (Rolls et al., 1998) suggested that the greatest appetite suppressant effect was obtained from the ingestion of large volume, low-energy density drinks.

Van Walleghen et al. (2007) studied responses in 29 younger and 21 older adults, none of who were obese. The amounts of food eaten were compared with and without water pre-loading (by volumes of 350 mL in women and 500 mL in men). In the older individuals, water pre-loading reduced food intake by 241 kJ/meal, apparently by reducing sensations of hunger and increasing ratings of fullness, but in the younger subject's food intake was unchanged by water preloading.

Influence of water intake upon thermogenesi*s*. One laboratory suggested that the ingestion of water might increase weight loss in part through a water-induced increase in thermogenesis (Boschmann et al., 2003). The phenomenon was at first attributed to the energy needed to heat the ingested water to body temperature. However, both the concept and this explanation remain controversial, and any effect of increased thermogenesis upon daily energy expenditures is likely small.

The original proponents of this concept claimed that the ingestion of additional water could induce a 24-30% increase of resting metabolism, with the added heat loss persisting for up to an hour (Boschmann et al., 2003). Dubnov-Raz et al. (2011) had 21 overweight children ingest 10 mL/kg of cold water, and observed a rise of resting energy expenditure, peaking at a 25% increase 57 minutes after drinking the water. They estimated that the added energy expenditure associated with drinking the recommended daily volume of water could reduce body mass by as much as 1.2 kg over the course of a year.

Boschmann et al. (2003) calculated that about 100 kJ of energy would be required to bring 500 mL of water from an initial temperature of 22º C to 37º C. However, a further study from the same laboratory compared the effects of ingesting 50 or 500 mL of water or 500 mL of saline in 16 overweight or obese men and women. In this second trial, subjects who ingested an additional 500 mL of water showed a 24% increase of metabolism that persisted for 60 minutes, but the other two interventions did not change resting metabolism significantly. It was thus hypothesized that a portal osmoreceptor mechanism was involved in the increased thermogenesis, rather than any warming of the ingested water to body temperature (Boschmann et al., 2007). In the view of Boschmann et al., the altered osmolality increased both sympathetic nerve activity and noradrenaline concentrations.

In an uncontrolled study of 50 overweight young females, Vij and Joshi (2014) reported that the thrice daily ingestion of an additional 500 mL of water reduced the formal appetite score of their subjects. Over the course of an 8-week trial there was a 1.4 kg decrease in body mass, and a 3 mm decrease in the total thickness of skin-folds. The authors of this report considered an osmotically engendered increase of thermogenesis as an important factor contributing to the observed decrease in body weight.

Other investigators have not found any substantial thermogenic effect from the ingestion of water, whatever its initial temperature. Brown et al. (2006) noted that thermogenic effects of water ingestion were lacking in 10 of 11 published trials. They compared possible thermal responses to four drinks: 500 mL of water, 0.9% saline or 7% sucrose at room temperature, and 500 mL of water at 3º C. Even the very cold water induced only a small thermal response, and although the ingestion of the 7% sucrose solution increased metabolism substantially, the response to this beverage (the generation of 33 kJ of additional heat over 90 minutes) was in line with the dietary thermogenesis that would be expected following the ingestion of a similar amount of carbohydrate.

Scott, Greenwood, Gilbey, Stoker and Mary (2001) suggested that the body normally compensated for any energy needed to warm cold drinks to body temperature through a vasoconstriction of the cutaneous blood vessels rather than by an increase of metabolism.

Effects of increased water intake on consumption of sweetened beverage*s*. It seems very likely that in many people an increased intake of water will lead to a reduced consumption of other beverages, many of which contain substantial amounts of sugar (Daniels & Popkin, 2010; Zheng, Allman-Farinelli, Heitmann & Rangan, 2015).

Mattes, Shikany, Kaiser and Allison (2011) made a meta-analysis of 12 randomized trials where the nutritionally sweetened beverage intake had been increased or reduced. All six studies where the intake of sweetened drinks had been increased showed a dose-dependent increase in body mass. However, when attempts had been made to reduce the intake of such drinks, no benefits were seen unless one limited the analysis to individuals who were initially overweight.

Zheng et al. (2015) reviewed six studies where sweetened beverages had been replaced by water or low-energy drinks; they found evidence that such substitution reduced body weight in both cohort and randomized trials.

Daniels and Popkin (2010) reviewed observational studies on this question, finding consistent differences of total energy intake in response to pre-loading with water versus pre-loading with sweetened beverages. Those drinking water before their meals consumed a total of 7.8% less energy than those subjects who were provided with sweetened drinks.

DuBoisson et al. (2012) followed 144 children initially aged 10.5 years for an average of 2.2 years. Their weight loss over this period was related to the child's initial water intake, and (inversely) to the initial intake of sweetened drinks.

Johnson et al. (2007) used 3-day diaries to examine the diet of children at the ages of five (n = 521) and 7 (n = 682) years. The consumption of sweetened beverages at these ages was unassociated with dual energy x-ray absorptiometry estimates of body fatness at age 9 years. However, perhaps because many overweight children had finally been advised to change their diet, at the age of 9 years, obese children tended to consume less sweetened beverages than their peers.

Pan et al. (2013) examined large samples of data from the Nurses' Health Study (50,013 and 52,897 women) and the male health professionals study (21,988 men), looking at the impact upon body weight of changes in the consumption of various beverages over a four-year interval. Multi-variate analysis suggested that on average an increased water intake of one cup of water/day reduced body weight by 0.13 kg over the 4 years of observation. Corresponding changes for other beverages were sweetened drinks +0.36 kg, fruit juice +0.22 kg, coffee -0.14 kg, tea -0.03 kg, and diet drinks -0.11 kg.

Papandreou et al. (2013) examined the impact of the beverage choices of 607 Greek children aged 7-15 years upon their risk of obesity. No relationship was found for water intake, but those drinking sweetened beverages were 2.57 times more likely to become obese than their peers.

Park et al. (2012) examined the correlates of a low daily consumption of water (<3 cups/day) in 11,049 US students in grades 9-12. Contrary to other reports, such students were less likely to be obese than their peers who were drinking >4 cups of water/day. However, interpretation of the findings was complicated in that relative to other students those consuming little water also consumed a greater quantity of other drinks, including sweetened beverages; further, they were more likely to eat fast food, and to be physically inactive.

Peters et al. (2014) compared the effects of drinking water with that of a non-nutritive sweetened beverage in 303 men and women who were dieting. The respective decreases of body mass over 12 weeks were 4.1 and 6.0 kg, the somewhat better performance with the non-nutritive sweetened drink apparently being due to a greater reduction in sensations of hunger than that obtained from drinking an equivalent volume of water.

Popkin et al. (2005) made a cross-sectional analysis of data for 4755 U.S. adults, collected during the 1999-2001 NHANES survey. Water consumers (87% of the sample) drank an average of 1.5 L over the course of a day, and their daily energy intake averaged 807 kJ less than that of people who did not deliberately ingest water. However, benefit cannot be attributed with certainty to the water drinking, since the water drinkers showed a number of other particularities of lifestyle, including healthier overall food choices, and a lesser consumption of sugar-containing drinks (Popkin, D'Anci, & Rosenberg, 2010).

Sichieri et al. (2009) attempted to reduce the sweetened drink consumption of the experimental fraction of 1140 grade 4 students in Brazil. An average reduction of 56 ml/day was achieved over a school year, and this change was associated with a non-significant reduction of BMI, the trend being greater among those who were initially obese than in those students who were of normal weight. One problem in this study was that in the Brazilian students, a high intake of water was associated with a high intake of fruit juice, and a1 glass/day increase in the latter type of beverage was associated with a small increase of BMI (0.16 kg/m^2).

Tate et al. (2012) carried out a randomized controlled trial with 318 obese adults who were initially drinking sweetened beverages. They were allocated between a control group and groups that replaced their sweetened beverage by either water or a diet drink. Over a 6-month trial, the water group reduced their weight by 2.0% relative to controls, and in the group switching to diet drinks the effect was slightly larger (2.5%). Combining findings for the 2 experimental groups, these individuals were twice as likely as the controls to achieve a 5% weight loss over the 6-month trial.

Zheng et al. (2015) reviewed 6 cohort studies and 4 randomized controlled trials. All of these reports demonstrated that if sugar-sweetened drinks were replaced by alternative beverages, the total energy intake was reduced and the subsequent weight gain of the individual was smaller.

Summary. In summary, there is some evidence of an association between the water intake of adults and changes in their body mass. In cross-sectional data, the relationship is clouded by inter-individual differences in important covariates, including salt intake, socio-economic factors and overall lifestyle, but a limited volume of longitudinal data also points towards a decrease in body weight from an increased water intake, more obvious in individuals who are obese than in those of normal weight. In children as in adults, longitudinal data give tentative support to the view that an increased water intake is associated with a decreased risk of obesity. In contrast, cross-sectional data for children often show a positive association between water intake and obesity, but the meaning of this relationship is clouded by many intervening covariates.

The influence of increased fibre intake

We will look briefly at the various types of dietary fibre that have been proposed for the treatment of obesity, and will examine some of the suggested ancillary health benefits of an increased fibre intake, before considering systematic reviews and empirical data on the effectiveness of an increased fibre intake in the control of obesity.

Types of dietary fibre. Dietary fibre or roughage includes a wide range of constituents that the body can neither digest nor absorb (Schweizer & Edwards, 1992). Potential elements include polysaccharides (built from long chains of monosaccharide units such as starch and cellulose), oligosaccharides (composed of a relatively small number of monosaccharide units), and lignins (woody, plant-based complex organic polymers). Some of these materials are water-soluble (including the pectins, gums, mucilages and storage polysaccharides such as glycogen), but others (such as cellulose, hemi-cellulose and lignin) are not soluble in water.

Soluble fibres dissolve in water to a gel-like format. If ingested, they undergo partial or complete bacterial fermentation in the large intestine, breaking down to short-chain fatty acids that have beneficial effects on lipid metabolism, mucosal barrier function and apoptosis. Among other sources, soluble fibres are found in such common foods as oats, peas, beans, apples, citrus fruits, carrots, and barley.

The insoluble fibres are much less susceptible to bacterial fermentation in the large intestine, but they have water-attracting properties that are particularly helpful in providing bulk and thus countering constipation. Readily available sources of insoluble fibre include such foods as whole-wheat flour, wheat bran, nuts, and vegetables such as cauliflowers, beans and potatoes.

Commercially packaged cereal products such as corn flakes and rice crispies are another possible source of fibre, but they tend to suffer from the disadvantage of a high sugar content. Commercial fibre supplements such as psyllium-derived metamucil powder are also readily available in pharmacies, but they lack the variety of fibres, minerals and vitamin constituents usually found in untreated natural products.

The recommended minimum daily intake of fibre is age dependent. For those under 50 years of age, suggested daily doses are 38 g in men and 25 g in women, and the corresponding figures for older people are 30 g and 21 g per day. Most North American diets unfortunately fall substantially short of these recommendations.

Ancillary health benefits of a high dietary fibre intake. A high habitual fibre intake has a number of important ancillary health advantages, independently of its effectiveness as a source of low-energy bulk that creates satiety and helps a person in the problem of tackling obesity (Table 2).

The bulkiness of fibre facilitates bowel movements, reducing the risk of constipation (Cummings, 1984), clearing carcinogens from the colon and reducing the risk of colo-rectal tumours (Murphy et al., 2012). By adding bulk to food, it also curtails the spiking of blood glucose levels and the resultant increased risk of developing diabetes mellitus (Salmerón et al., 1997). Further, it enhances the lipid profile, reducing the risks of cardiovascular disease (Jenkins, Kendall, Axelsen, Augustin, & Vuksan, 2000) and it is associated with an increase of overall life expectancy.

In terms of facilitating weight loss and subsequent weight maintenance, fibre has the attraction of being a food source with considerable bulk but a very low energy density. Thus, an increased intake of dietary fibre might seem a more useful modification of diet than many of the weight regulation options we have discussed in earlier sections of this review. The ancillary health benefits of fibre are well-documented, but nevertheless its efficacy in terms of weight management remains more controversial. Experimental studies generally show an increased fibre intake as inducing a short-term increase of satiety. These seem to be cephalic and gastric responses to the bulking effects of fibre (Burton-Freeman, 2000). Through their viscosity, some fibres also modify gastro-intestinal function and delay fat absorption (Burton-Freeman, 2000), improving the lipid profile. But because high-fibre foods have only a low energy content, their effects on satiety tend to be short-lasting, and indeed the addition of fibre to one meal does not generally have any effect on the amount of food ingested at a subsequent meal (Slavin & Green, 2007). Further, some soluble forms of fibre have surprisingly little effect even upon short-term satiety.

Cross-sectional studies have often shown an association between a high fibre intake and improved weight control, but in long-term randomized trials additional fibre intake has generally had little effect on body mass relative to control diets (Babio, Balanza, Basulto, Bulló, & Salas-Salvadó, 2010; Papathanasopoulos & Camilleri, 2010).

Table 2. Suggested benefits of adopting a high-fibre diet.
• Facilitates loss of weight, maintenance of weight loss • Relieves constipation • Reduces risk of colo-rectal cancers • Reduces spiking of blood glucose levels and associated risk of diabetes mellitus • Reduces serum cholesterol and associated risk of cardiovascular disease • Increases overall life expectancy

Systematic reviews. A systematic literature review by Fogelholm, Anderssen, Gunnarsdottir and Lahti-Koski (2012) concluded that the proportions of macro-nutrients in the diet was unimportant with regard to weight management, but that a diet providing plenty of fibre-rich foods was associated with a reduced risk of weight gain in prospective cohort studies.

A review by Howarth, Saltzman and Roberts (2001) concluded that in the very short term (<2 days), mixed fibres increased satiety in 7 of 9 studies, soluble fibres had a similar effect in 5 of 6 studies, and insoluble fibres increased satiety in 2 of 3 studies. When fibre intake was increased for periods of longer than 2 days, benefit was seen in 17 of 18 trials, with significant advantages in 13 studies. Averaging across these various reports, an additional 14 g of fibre intake per day was associated with a 10% decrease of total energy intake; further, this led to a 1.9 kg decrease of body mass over an average period of 3.9 months, with greater benefits seen in the obese than in those of normal weight.

Slavin and Green (2007) also examined the effects of fibre intake upon satiety. They concluded that the largest effects were seen with viscous fibres. An earlier review from the same laboratory (Slavin, 2005) noted that in cross-sectional epidemiological data, fibre intake showed a consistent inverse association with body weight and body fat content; moreover, this relationship held at all levels of fat intake, after controlling for potential confounding factors. Findings from interventional studies were more mixed, although many such reports also suggested that fibre reduced food intake, thus tending to reduce body mass.

Brownlee, Chater, Pearson and Wilcox (2017) commented specifically on the paradox that whereas observational studies consistently showed a lower body mass among individuals with a high fibre intake, relatively little benefit was demonstrated with experimental interventions. They suggested that one factor limiting the response to such initiatives may have been the relatively short time frame of most investigations.

Empirical data. Empirical data on fibre intake and weight regulation are summarized in Table 3. Anderson et al. (1999) tested the effects of 8 weeks of psyllium treatment (5.1 g, twice per day) relative to a control diet in a group of 34 men, all with type 2 diabetes and mild cholesterolaemia. Those assigned to the active treatment showed a small decrease of body mass (0.3 kg), as compared to the increase of 1.5 kg that was seen in the controls. The psyllium also improved glycaemic and lipid control in the test group.

Azadbakht et al. (2005) assigned 116 patients with the metabolic syndrome to a "healthy" diet, a high cereal diet, or a control group. At 6 months, the weight loss relative to the control group was 13 kg for those following the healthy diet, and 16 kg for those eating the high fibre diet.

Beck et al. (2009) examined the effects of adding varying doses of beta-glucan, a fibre found in barley, to the breakfasts of 7 men and 7 women who were obese or overweight. Subjective satiety was increased at a dose of 2.2 g per day, and the energy intake at a subsequent meal was reduced by 0.4 MJ. Cholecystokinin levels were also increased, and insulin secretion was decreased by this treatment.

Cunha et al. (2010) made a cross-sectional analysis of diets on 10,009 adults aged 20-65 years, living in a poor area of Rio de Janeiro. Diets fell into three categories- a western-style diet, a mixed diet, and a traditional diet centred on rice and beans. Women following the rice and beans regimen had a low BMI and waist circumference relative to the other two dietary options.

Hangdong-Du et al. (2010) enrolled 89,432 Europeans initially aged 20 to 78 years in a 6.5-year cohort study. Gains in body mass and waist circumference over this period showed a weak inverse relationship to fibre intake. An additional intake of 10g/day of dietary fibre was associated with a 39 g/year smaller increase of body mass, and an 0.08 cm/year smaller increase in waist circumference relative to other members of the group. The beneficial effects appeared attributable mainly to cereals rather than to the fibres found in fruit and vegetables.

Jenkins, Kendall Augustin, Martini, Axelsen, Faulkner et al. (2002) carried out a cross-over trial on 16 men and 7 women with type 2 diabetes mellitus. Over a period of 3 months, their subjects consumed either a high or a low cereal diet. No changes of body mass were seen in either 3-month period, and moreover no improvements of glycaemic control or reduction in cardiovascular risk factors were seen in response to the high cereal regimen. Jenkins et al. (2008) also carried out a larger experiment, where 210 adults with type 2 diabetes mellitus were assigned to either a high cereal diet or to routine advice on adopting a low glycaemic regimen. At 6 months, a comparison between the 2 groups showed a non-significant weight advantage to those following the low glycaemic diet (respective weight losses of 1.6 and 2.5 kg).

Kacinik et al. (2011) tested a highly viscous water-soluble synthetic polysaccharide polyglycoplex (PGX) in a group of 45 overweight and obese women. They followed a 4.2 MJ diet for 3 days; a half of the group received PGX (5 g at breakfast, lunch and dinner) and the remainder were given a placebo. The PGX increased satiety, decreasing hunger, the desire to eat and prospective consumption of food.

Liu et al. (2003) made a prospective study of 74,091 nurses, initially aged 38-63 years. Information was collected on their intake of fibre and whole or refined grains. Over a 12-year follow-up, women who consumed more grains consistently weighed less than their peers. Those with the greatest increase of fibre intake finally showed a 1.5 kg lesser gain in body mass than those with the smallest increase of fibre intake.

Ludwig et al. (1999) followed a cohort of 2909 adults initially aged 18-30 years for 10 years. Body weights at the end of this period were inversely related to quintiles of reported fibre intake, with the highest fibre intake quintile having a weight advantage of some 3.7 kg over the lowest fibre intake quintile. Further, women in the highest quintile of fibre intake had a 49% lower risk of major weight gain relative to those in the lowest quintile.

Pal et al. (2011) tested the effects of 12 weeks of supplementation with psyllium, a fibre prepared from the husks of plantago ovata seeds. A sample of 72 Australian adults was divided into 4 groups; one followed a normal diet that provided about 20 g of fibre per day, and the remaining 3 groups all consumed meals containing 50-60 g of fibre per day. Over the 12 weeks, all three experimental groups lost about 2.5kg of body mass relative to the controls.

Psman et al. (1997) took a group of 31 women who had previously reduced their body mass, providing 20 of them with a high fibre Guar gum-based diet. Over the next 14 months, administration of this fibre did not help in weight maintenance relative to those who did not receive the fibre supplement.

Table 3. Effects of increased fibre intake on body weight.				
Author	**Sample**	**intervention**	**Findings**	**Comments**
Anderson, Allgood, Turner Oeltgen, & Daggy (1999)	34 men with type 2 diabetes mellitus, mild hypercholesterolemia	10.2 g/day psyllium or normal diabetes diet for 8 wk	Wt loss 0.3 kg vs. gain of 1.5 kg in controls	Glycaemic and lipid control improved
Azadbakht, Mirmiran and Esmaillzadeh, Azizi & Azizi (2005)	116 patients with metabolic syndrome	Comparison of "healthy" diet vs. high fibre diet vs. control	At 6 months, wt. loss healthy diet 13 kg, high fibre diet 16 kg	
Beck, Tosh, Batterham, Tapsell and Huang (2009)	7 obese men, 7 obese women	Assessed effects of various doses of beta-glucan	Satiety increased by 2,2 g at breakfast,	Subsequent food intake reduced 0.4 MJ
Cunha, Moritz, Sichieri and Pereira (2010)	1009 Brazilian adults aged 20-65 yr	Cross-sectional comparison, western vs. mixed vs. traditional diet	Traditional rice & bean diet inversely associated with BMI & waist circumf. in F	
Hangdong-Du et al. (2010)	89,432 Europeans initially aged 20-78 yr	Total fibre intake vs. change in wt and waist circumf.	10 g/d fibre reduces weight gain 39 g/yr, and waist circumf. gain 0.08 cm/yr	6.5 yr follow-up
Jenkins, Kendall, Augustin. Martini, Axelsen, Faulkner, et al. (2002)	16 men, 7 women with type 2 diabetes mellitus	Cross-over trial, 3 months high cereal vs. 3 months low cereal	No change of weight, either phase	No improvements of glycaemic control or CV risk factors
Jenkins, Kendall, McKeown-Eyssen, Josse, Silverberg, Booth, et al. (2008)	210 adults with type 2 diabetes mellitus	High cereal diet vs. low glycaemic dietary advice	At 6 months, wt loss 1.6 kg vs. 2.5 kg	Inter-group difference not significant
Kacinik et al. (2011)	45 overweight & obese women	Diet 4.2 MJ; half of group had PGX 5g, 3 times/day, vs. control	Over 3 days, increased satiety, decreased hunger,	Decreased prospective consumption of food
Liu et al. (2003)	74,091 nurses aged 38-63 yr	Intake of fibre & whole or refined grains	Those with greatest intake of fibre gained 1.5 kg less wt.	12 yr prospective study
Ludwig et al. (1999)	2909 adults, initially aged 18-30 yr	Dietary fibre intake measured	Over 10 yr, 3.7 kg wt advantage in those with highest quintile fibre intake	Evolution of blood lipids also favoured by high fibre intake
Pall, Khossousi, Binns, Dhaliwal and Ellis,(2011)	72 adults	Controls, 20 g fibre, 3 other groups 50-60 g fibre per day	Over 12 wks, all experimental groups lost about 2.5 kg relative to controls.	
Pasman et al. (1997)	31 women after weight reduction	Guar gum supplementation in 20 of 31	No benefit on weight maintenance over next 14 months	
Salas-Salvadó et al. (2008)	200 overweight or obese adults	4 g of fibre twice or thrice daily vs. placebo	At 16 wk, wt. loss 4.5, 4.6 kg vs. 0.8 kg in placebo (ns)	Fibre increased satiety, beneficial effects on plasma lipids
Tucker & Thomas (2009)	252 women followed for 20 months	7-day dietary records	1 g/d increase in fibre decreased weight gain by 0.25 kg, fat gain by 0.25%	Relationship not weakened by covariates except energy intake
Woodgate and Conquer (2003)	24 obese adults aged 20-50 yr	Proprietary dietary supplement with glucomannan vs. placebo	Over 6 wk, treatment reduced body wt 2.3 kg, fat mass 2.0 kg	Also decreases in abdominal circumference

Salas-Salvadó et al. (2008) studied 200 overweight or obese adults, comparing their response to mixed fibres (3 g of plantago ovata and 1 g of gluco-manna derived from the roots of the elephant yam) taken twice or 3 times per day) with the findings in a placebo control group. After 16 weeks, there was a non-significant trend to greater weight loss with both doses of fibre (4.5, 4.6 kg) than that seen with the placebo (0.8 kg), and the fibre treatment also gave a significant increase in satiety, with favourable changes in plasma lipids.

Tucker and Thomas (2009) followed a group of 252 women for 20 months, relating changes in body mass to an initial 7-day assessment of their diet. For each 1 g increase in their reported initial daily fibre intake, there was an 0.25 kg reduction in their weight gain and an 0.25% less increase of body fat over the 20-month trial.

Woodgate and Conquer (2003) enrolled 24 obese adults in a trial that compared a proprietary dietary supplement containing glucomannan (elephant yam) fibre with a placebo. Over a period of 6 weeks, the active treatment led to a significantly greater loss of both body mass (2.3 kg) and body fat (2.0 kg) than that seen with the placebo.

Summary. In summary, longitudinal studies suggest that any additional loss of weight occurring in subjects provided with fibre supplements is quite small relative to that seen in controls, and often the benefit is statistically non-significant. This is perhaps not surprising, given that any increase in satiety induced by the fibre often does not persist long enough to affect food intake at the next meal.

Other potentially helpful dietary options

Other dietary options sometimes recommended to help in the process of weight regulation have included a substantial intake of nuts, yoghurt, or calcium, along with specific supplements intended to counter oxidative stress and sustain immune function during rigorous dieting.

Nuts

We will comment briefly on the chemical composition of common edible nuts and suggested ancillary health benefits that arise from their consumption before evaluating evidence on the possible contribution of a high nut intake to programmes of weight management.

Chemical composition of edible nuts. Nuts are generally high in fat, low in carbohydrates, and provide a good source of nutrients such as vitamin E, magnesium and selenium (Ros, 2010). Venkatachalam and Sathe (2006) found a moisture content ranging from 1.5 to 9.5%; other constituents included proteins (7.5-21.6%), lipids (42.8-66.7%), ash (1.2-3.3%), soluble sugars (0.6-4.0%), tannins (0.01-0.8%), and phylates (0.15-0.35%), with most of the fat being in the form of mono- and polyunsaturated fatty acids.

Ancillary health benefits of a substantial nut consumption. Like the choice of high fibre diets, a substantial dietary intake of nuts has the anthropological attraction that it approximates the eating pattern to which many humans adapted during their period as hunter-gatherers.

Various ancillary health benefits have been ascribed to a diet that is rich in nuts (Ros, 2010) (Table 4). Whether taken in a meal or as a snack, nuts are reputed to make people feel full and increase their sense of satiety (Bes-Rastrollo, Sabaté, Gómez-Garcia, Alonso, Martínez, & Martínez-González, 2007; Bes-Rastrollo, Wedick, Martínez-González, Li, Sampson, & Hu, 2009; Mattes, Kris-Etherton, & Foster, 2008), thus helping in the process of controlling the intake of other foods. Further, despite the apparently high energy content of most nuts, much of this energy remains unabsorbed from the intestines, so that substantial quantities of nuts can usually be eaten without leading to weight gain (Mattes, Kris-Etherton, & Foster, 2007).

Albert, Gaziano, Willett and Manson (2002) followed 21,454 male physicians for a period of 17 years. Albert et al. (2002) found that their subjects' nut consumption was significantly associated with a decreased risk of sudden cardiac death, after adjusting their data for other known cardiac risk factors. For those consuming nuts at least twice per week, the cardiac risk was only 0.53, relative to those who rarely or never ate nuts. In contrast, nut consumption had no effect on the risk of non-sudden cardiac deaths or non-fatal myocardial infarctions. Fraser, Sabaté, Beeson and Strahan (1992) provided further data on 31,208 Seventh-Day Adventists who had a high nut consumption; in their sample, the eating of nuts more than 4 times per week reduced the risk of fatal heart attacks to 0.52, and non-fatal heart attacks to 0.49 relative to those who ate nuts less than once per week.

Table 4. Suggested health advantages of a diet rich in nuts.
• Increases satiety, reducing food intake • Reduces risk of cardiovascular disease and sudden death • Reduces risk of diabetes mellitus? • Reduces risk of colo-rectal cancers? • Reduces overall death rate • Provides nutrients, enhancing immune function, countering oxidative stress?

Blomhoff, Carlsen, Andersen and Jacobs (2006) noted an inverse relationship between nut consumption and the overall death rate, with respective risk ratios of 0.89 for those eating nuts once per week, and 0.81 for those eating nuts 1-4 times per week. Much of this benefit was due to a reduced risk of cardiovascular and coronary heart disease, as discussed above. Blomhoff et al. (2006) suggested that further research should be conducted to assess the possible contribution of antioxidants to the nut-related decrease in overall mortality. Garg, Blake, Wills and Clayton (2007) subsequently provided evidence that there was indeed a significant reduction of oxidant stress associated with the eating of macadamia nuts (40-90 g/day) for 4 weeks.

García-Lorda, Megias Rangil and Salas-Salvadó (2003) summarized limited data concerning the effects of nut ingestion upon glucose metabolism. They found that a large intake of almond nuts had no adverse effects on glucose homeostasis or insulin sensitivity, and because of a high unsaturated fat content, nuts could reduce the risk of type 2 diabetes mellitus. Rajaram and Sabaté (2006) substantiated this view; they showed that the eating of nuts not only facilitated weight loss, but also increased insulin sensitivity. Further, a 19-year prospective study of the incidence of diabetes mellitus in 20.224 male physicians found an inverse association between the risk of developing diabetes and nut consumption, although in this study the association disappeared after adjusting the data for other known risk factors (Kochar, Gaziano, & Djoussé, 2010).

In a prospective study of 478,040 European adults, Jenab et al. (2004)

reported findings regarding nut consumption and the risk of developing intestinal tumours. Nut and seed intake had no effect upon this risk in men, but there was some evidence that a substantial nut intake protected against colonic cancers in women.

Empirical data on nut consumption and obesity. As with many of the other possible dietary modifications considered in this review, cross-sectional data have often suggested that the addition of nuts to the diets can help in the process of weight loss, but this has been less evident during randomized, controlled interventions. Many of the prospective trials have aimed at evaluating other health benefits of nut consumption, and their main concern has been to ensure that the high energy content of the nuts did not lead to a gain in body weight, rather than to look for any enhancement of weight regulation. In most interventions, body weight has shown no significant change (Table 5), but we must note also that the sample size has sometimes been quite small and the period of observation too short (3-6 weeks) to detect minor improvements in energy balance (Sabaté, 2003; Vadivel, Kunyanga, & Biesalski, 2012).

Abbey et al. (1994) added 84 g/day of almonds or 64 g/day of walnuts to the diet of 16 healthy men for 3 weeks. No changes of body weight were seen, but the total and HDL cholesterol levels were reduced.

Albert et al. (2002) evaluated cross-sectional data on 21,454 male physicians. Nut intake, graded from "never" to "greater than 2 times per week," was unrelated to body mass.

Almario et al. (2001) looked at the effects of supplying 48 g/day of walnuts to 5 male and 13 female dyslipidaemic adults for 6 weeks. This diet produced no change of body weight over the period of observation, whether superimposed on a habitual or a low fat diet.

Bes-Rastrollo et al. (2007) made a cross-sectional study of 8865 adults over a period of 28 months. During this period, the risk of significant (>5 kg) weight gain in those eating nuts 2 or more times per week was 0.69 relative to other members of their sample, after adjustment of the data for age, sex, smoking, physical activity and other risk factors. Those who ate little or no nuts on average gained 0.42 kg of weight relative to the nut eaters.

Chisholm et al. (1998) used walnuts to replace 20% of the energy intake of 21 hypercholesterolaemic men who were following a low fat diet. Over a 4-week period, there were favourable changes in the cholesterol profile, but no significant changes of body mass.

Colquhoun et al. (1996) carried out a small trial on 7 men and 7 women with hypercholesterolaemia, replacing 20% of their diet with macadamia nuts for a period of 4 weeks. This caused no significant change of body weight.

Durak et al. (1999) added 1g/kg of hazelnuts to the diet of 18 healthy men and 12 healthy women for a period of 4 weeks. This led to a 0.5 kg increase of body mass, although there were also increases in anti-oxidant levels and a reduction of plasma cholesterol.

Edwards et al. (1999) used pistachio nuts to replace 20% of the habitual diet of their subjects (4 men and 6 women with hypercholesterolaemia) for 3 weeks. No change in body weight was observed, but the intervention did lead to decreases in total cholesterol and the LDL/HDH cholesterol ratio.

Garg et al. (2007) took 17 men with hypercholesterolaemia, replacing 15% of their diet by macadamia nuts for 4 weeks.

Their body weight decreased by an average of 0.5 kg in response to this intervention.

Hollis & Mattes (2007) enrolled 20 women in a 10-week programme where they ate 1.44 MJ of almonds per day, a dose judged sufficient to confer cardiovascular benefits. There was no weight gain relative to a corresponding 10-week period when they were following a normal diet, suggesting that the participants had been successful in reducing their intake of other foods to compensate for the energy content of the almonds.

Hyson et al. (2002) persuaded 10 healthy men and 12 healthy women to replace 50% of their diet by almonds or almond oil for 6 weeks. Study participants showed no significant change of body mass over the 6 weeks of observation, but there were decreases in plasma triglycerides, total and LDL cholesterol.

Jenkins, Kendall, Marchie, Parker, Connelly, Qian, et al. (2002) had 15 men and 12 women with hypercholesterolaemia eat 73 g/day of almonds for 4 weeks. No significant change of body mass was seen over this time, but the dietary change led to reductions of cardiac risk factors, particularly a decrease of LDL cholesterol.

Lairon et al. (2005) made a cross-sectional comparison between the intake of total and insoluble fibres and various cardiac risk factors in a sample of 2532 men and 3429 women. Both measures of fibre intake were inversely associated with the subjects' body masses and waist-hip ratios.

Lovejoy et al. (2002) added 100 g/day of almonds to the diet of 10 healthy men and 10 healthy women for 4 weeks. There were small increases of body mass over this time (0.9 kg in the men, 0.3 kg in the women), but nevertheless both total and LDL cholesterol levels were decreased.

Morgan et al. (2002) offered a diet containing 64 g/day of walnuts to 42 men with hypercholesterolaemia. Body weight remained unchanged over 6 weeks of observation, but there were decreases in total and LDL cholesterol levels.

Mozzafarian et al. (2011) evaluated the effects of changes in diet that included an increased consumption of nuts in a large sample of 120,877 adults over follow-up periods as long as 20 years. Increases of body weight were consistently smaller in those individuals who had increased their nut consumption. during this time

Schröder et al. (2004) examined the relationship between adherence to a nut-containing Mediterranean diet and body composition in 1547 men and 1615 women. They concluded that the following of such a diet was inversely associated with obesity.

Spiller et al. (1998) added 100 g/day of almonds to the baseline diet of 13 men and 13 women with hypercholesterolaemia for 4 weeks. No changes of body weight were seen over this time, but there was a reduction of LDL cholesterol with a conservation of HDL cholesterol.

Wien et al. (2003) compared the response of 65 overweight or obese adults who were enrolled in a weight reduction programme to 84 g/day of almonds or an equivalent amount of complex carbohydrates. Over the course of 24 weeks, the weight loss was greater with the almond diet (19.5 kg) than with the complex carbohydrate diet (12.1 kg). Other markers of the metabolic syndrome were also corrected in the nut-eaters over the course of this study.

Zambón et al. (2000) replaced 18% of the energy content of the diet with walnuts in a group of 28 men and 27 women with hypercholesterolaemia.

Table 5. Effects of a high nut intake upon weight management.				
Author	**Sample**	**Dietary intervention**	**Findings**	**Comments**
Abbey, Noakes, Belling and Nestel, (1994)	16 healthy men	84 g/d almonds or 68g/d walnuts for 3 wk	No change of body wt	Total and LDL cholesterol reduced
Albert et al. (2002)	21,454 male physicians	Nut intake, never vs. > 2/wk	No association nut intake & body wt.	
Almario, Vonghavaravat, Wong and Kasim-Karakas (2001)	5 M, 13 F, dyslipidaemic subjects	48 g walnuts/day for 6 wk	No change of body wt over 6 wk	Small LDL cholesterol reduced
Bes-Rastrollo et al. (2007)	8865 adults	Nuts > 2/wk	Risk of wt gain 0.69; if eating no nuts, gained 0.42 kg more wt	937 gained > 5kg over 28 months
Chisholm et al. (1998)	21 hypercholesterolaemic men	20% energy of low fat diet replaced with walnuts for 4 wk	No change of body wt	Favourable changes in cholesterol profile
Coquhoun, Humphries, Moores and Somerset (1996)	7 M, 7 F with hypercholesterolaemia	20% of diet from macadamia nuts for 4 wk	No change of body weight	
Durak et al. (1999)	18 M, 12 F, all healthy	1g/kg of hazelnuts added to diet for 4 wk	Body wt increased 0.5 kg	Antioxidants increased, cholesterol decreased
Edwards, Kwaw, Matud and Kurtz (1999)	4 M, 6 F, hypercholesterolaemic	20% of habitual diet replaced with pistachio for 3 wk	No change of body wt.	Decrease in total cholesterol and LDL/HDL ratio
Garg et al. (2007)	17 M with hypercholesterolaemia	15% of diet replaced by macadamia nuts for 4 wk	Body wt decreased 0.5 kg	
Hollis & Mattes (2007)	20 women	1.44 MJ almonds/day vs. control (crossover design)	No change of body wt	Sufficient dose of almonds to yield CV benefits
Hyson, Schneeman and Davis (2002)	10 M, 12 F, healthy	50% of diet replaced with almonds or almond oil for 6 wk	No change of body wt	Decreased triglycerides, total and LDL cholesterol
Jenkins, Kendall, Marchie, Parker, Connelly, Qian, et al., (2002)	15 M, 12 F with hypercholesterolaemia	73 g/day almonds for 4 wk	No change of body wt	Decreased LDL cholesterol
Lairon et al. (2005)	2532 men, 3429 women	Cross-sectional associations with total and non-soluble fibre intake	Both fibre measures associated with lesser wt and waist-hip ratio	Beneficial effects on other CV risk factors
Lovejoy, Most, Lefevre, Greenway and Rood (2002)	10 M, 10 F, healthy	100g/day almonds for 4 wks	Body wt increased, 0.9 kg M, 0.3 kg F	Decreased total and LDL cholesterol

Table 5 Continued.				
Author	**Sample**	**Dietary intervention**	**Findings**	**Comments**
Morgan et al. (2002)	42 M with hypercholesterolaemia	64 g walnuts/day for 6 wk	Body wt no change	Decreased total and LDL cholesterol
Mozzafarian, Hao, Rimm, Willett and Hu (2011).	120,877 adults. followed for up to 20 yr	Effect of changes in diet, including fibre intake	Increases of weight consistently smaller if fibre intake increased	
Schröder, Marrugat, Vila, Covas and Elosua (2004)	1547 men, 1615 women	Adherence to Mediterranean diet	Inverse association with obesity	
Spiller et al. (1998)	13 M, 13 F with hypercholesterolaemia	100 g/d almonds added to baseline diet for 4 weeks	No change of body wt	Lowers LDL cholesterol
Wien, Sabaté, Iklé, Cole and Kandeel (2003)	65 overweight or obese adults in wt reduction programme	24 wk trial, 84 g/d almonds or complex CHO	19.5 vs. 12.1 kg decrease in wt	Other markers of metabolic syndrome also corrected
Zambón et al. (2000)	28 M, 27 F with hypercholesterolaemia	18% normal diet replaced with walnuts	No change of body wt	Total and LDL cholesterol reduced

No changes of body weight were seen over a 6-week trial, but the total and LDL cholesterol levels were reduced.

Summary. In 4 of the 5 cross-sectional studies cited, body mass was inversely associated with nut consumption. However, there was no change of body mass in 10 of the 14 short-term interventions; in 2 interventions there were small increases of body mass, and in 2 small decreases.

Yogurt.

A high yogurt intake is another dietary option that has been suggested as a means of facilitating weight control. Plainly, this is not an appropriate recommendation for individuals with lactose intolerance, unless a lactose-free yogurt is selected. Possibly, any benefit from yogurt consumption is attributable to a modification of the gastro-intestinal bacterial flora, although mechanisms need to be clarified (Mozaffarian, Hao & Rimm, 2011). Certainly, cross-sectional studies have linked changes in the large intestinal micro-flora to obesity and its correction (Kadooka et al., 2013; Le Chatelier et al., 2013).

Yogurt also increases satiety, particularly if alpha lactalbumin has been added to it (Hursel, van der Zee, & Westerterp-Plantegna, 2010). Chapelot and Payen (2010) compared sensations of satiety after ingesting either 1.2 MJ of yogurt or chocolate bars of similar energy content. Ratings of satiety were taken every 20 minutes. Hunger was less and satiety greater with the yogurt than with the chocolate snack, although the yogurt did not decrease food intake at the next meal. Tsuchiya, Alamiron-Roig, Luch, Guyonnet and Drewnowski (2006), likewise, found that either semi-solid or liquid yogurt had a greater effect on satiety than fruit drinks, but again this did not appear to influence food intake at the next meal.

Douglas, Ortinau, Hoertel and Leidy (2013) claimed that relative to other types of yogurt-based snacks, high protein yogurt delayed eating, reduced the energy consumed at a subsequent meal, and improved heart health (by increasing HDL cholesterol and reducing blood pressure).

Diepvens, Soenen, Steijns, Arnold and Westerterp-Plantenga (2007) reported a higher resting energy expenditure in yogurt-eaters than that seen in their control group, and Delzenne, Neyrinck, Bäckhed and Cani (2011) pointed to differences of intestinal microbiota between lean and obese individuals.

Another potential contribution of yogurt to weight management comes from an increased calcium intake (below). Finally, yoghurt may prove beneficial simply by replacing less healthy components of a person's diet (Panahi & Tremblay, 2016).

We will look briefly at the possible formats of yogurt, and ancillary health benefits of an increase in yogurt consumption before evaluating empirical information concerning yogurt intake and weight management.

Chemical composition and possible formats of yogurt. Yogurt is a food product obtained by the fermentation of denatured milk by a lactobacillus culture. It may be produced from whole, 2%, or skimmed milk); if it is derived from whole milk, it contains about 81% water, 9% protein, 5% fat and 4% carbohydrates. A 100 g portion has an energy content of about 0.4MJ, and contains substantial amounts of vitamin B_{12}, riboflavin and selenium.

In many commercial formats, yogurt is flavoured with fruit juices, and considerable amounts of sugar are added to mask its sour taste. In Greek yogurt, the preparation is strained to remove the whey and much of the liquid. Icelandic yogurt is rich in protein and has a low fat content. It is also possible to prepare yogurt using almond, coconut or soy-milk. If the yogurt is pasteurized, the probiotic content is destroyed, but in other preparations the probiotic content is deliberately increased, for instance by adding selected grains (as in Kefir Yogurt).

Ancillary health benefits of increased yogurt intake. Independently of any favourable effects upon weight management, a number of health benefits have been ascribed to the regular consumption of yogurt (Table 6). It is a rich source of several important nutrients, including calcium, vitamin B_{12}, riboflavin, phosphorus, iodine, magnesium and potassium (Williams, Hooper, Spiro, & Stanner, 2015). It also has a high protein content, and promotes satiety, especially if

Table 6. Suggested health benefits of a substantial yogurt intake.
• Contains important nutrients (calcium, vitamin B_{12}, riboflavin, phosphorus, magnesium, and potassium) • Has a high protein content • Promotes satiety (especially if served as strained yogurt) • If not pasteurized, it contains probiotics that enhance intestinal health, and reduce the risk of constipation • May boost immune function • May protect against osteoporosis (particularly if supplemented by vitamin D)

it is taken in a strained format (Chapelot & Paven, 2010; Tsuchiya et al., 2006). If it is not pasteurized, it contains a wide variety of micro-organisms that enhance intestinal health and reduce the risk of constipation (Aoyagi et al., 2019). It may also boost immune function (Wheeler et al., 1997), protect against osteoporosis (particularly if taken in conjunction with a vitamin D supplement) (Sahni, Tucker, Quach, Casey, & Hannan, 2013), and it reduces the risk of future cardiovascular disease by increasing HDL cholesterol levels and reducing blood pressures (Elias, Wade, & Crichton, 2018).

Meta-analyses of yogurt intake and weight management. The review of Astrup (2014) concluded that in cross-sectional comparisons, the consumption of yogurt and other dairy products was associated with a reduced risk of weight gain and obesity, as well as with a decreased risk of cardiovascular disease. Moreover, these findings were supported "in part" by randomized trials.

Eales et al. (2016) reviewed 22 publications that related the consumption of yogurt to weight outcomes. Six cohort studies and 7 cross-sectional analyses all showed a correlation between the amount of yogurt consumed and success in the regulation of body weight or body composition. However, the interpretation of 7 randomized controlled trials was limited by small sample sizes and short periods of observation; one report demonstrated a significant weight loss from the administration of yogurt, in five studies any changes were non-significant, and one trial was compromised by differences in calcium intake between groups.

Jacques and Wang (2014) reviewed 5 prospective trials and 2 randomized controlled trials that each evaluated the effects of yogurt ingestion. The short-term interventions both showed greater weight losses from the ingestion of yogurt than from a control diet, and this difference was statistically significant in one of the two experiments. Findings from the prospective trials were inconclusive; 2 reports showed a lesser weight gain with yogurt consumption, one lacked statistical power, and a fourth report showed no association between yogurt intake and weight gain. In the final report, benefit was seen in men, but on the other hand the women who received yogurt showed a larger weight gain.

Lanou and Barnard (2008) focused on clinical trials of the effects of dairy products or calcium supplementation. A total of 49 randomized trials were found. Of these, 41 reports showed no effect from the intervention, 2 indicated a weight gain, one a slower rate of weight gain, and 5 a weight loss. They concluded that the intake of dairy products or calcium supplements generally did not facilitate the process of weight regulation.

A literature search by Park and Bae (2015) found 4 good quality randomized trials comparing probiotics with placebo treatments. Despite earlier suggestions that the ingestion of gut microbiota could have a favourable influence upon body mass, these reports indicated no significant influence of probiotics upon body weight.

In summary, there seems as yet no good randomized controlled experiments demonstrating better weight regulation in those eating any of the various types of yogurt. However, there remains a need to study this issue in large samples, with observations continuing over longer periods of time.

Empirical data on yogurt intake and weight management. Individual trials have looked at the influence of various types of yogurt upon weight management. Sometimes, possible benefits from the yogurt have not been separated clearly from effects attributable to an increased intake of calcium and other milk products (Table 7).

Babio et al. (2015) enrolled 1868 men and women aged 55-80 years, initially free of the metabolic syndrome, in a prospective trial. Over an average of 3.2 years, 830 of the group developed the metabolic syndrome. Multivariate hazard calculations showed risk ratios of 0.73 for those ingesting low fat, and 0.78 for those eating whole-fat yogurt. Comparing subjects in the first tertile of yogurt consumption with those in the third tertile, the relative risk of abdominal obesity was 0.74 for those who ate yogurt more frequently.

Bowen, Noakes and Clifton (2005) compared the response of 50 healthy but overweight adults to 12 weeks of energy restriction, using either a high-calcium high-dairy diet or a high mixed protein diet with a moderate calcium content. Over a 12-week period the decreases of body mass (9.7 kg) and fat mass (8.3 kg) were similar for the two treatments.

Delbert et al. (2004) compared the effects of a simple lifestyle education programme with that of a soy/yogurt diet with or without added physical education in a sample of 83 overweight or obese adults. After 6 months, all subjects showed improved glycaemic control and lipid profiles. Both of the soy/yogurt programmes led to an 8.9 kg decrease of body mass, as compared with 6.6 kg in those receiving only lifestyle guidance. However, losses of lean tissue did not differ between groups.

Drapeau et al. (2004) followed 248 volunteers from the Quebec Family Study for 6 years, examining changes in their body composition in relation to various self-selected dietary patterns. Over this period, gains in waist circumference were inversely related to the intake of low fat (<2%) yogurt.

Keast, Hill Gallant, Albertson, Gugger and Holschuh (2015) made a cross-sectional analysis of data for 3786 U.S. children aged 8-18 years who had participated in the NHANES surveys of 2005-2008. The children were asked a simple yes/no question about their yogurt consumption. Only 280 of the 3786 children reported eating yogurt. In this sub-group, body weights and skin-fold thicknesses were more favourable than those for the remainder of the sample.

Lee, Cho, Lee, Kim and Cho (2014) examined cross-sectional associations between the intake of dairy products (yogurt or milk) and overweight/obesity in 7173 Korean adults aged 19-64 years. This group as a whole had a low intake of dairy products. Those taking such items more often than twice per week had a risk ratio of overweight or obesity of 0.63 relative to those taking such food items less than once a month. Benefit from the dairy products seemed to be greater in women than in men.

Madjd et al. (2016) carried out a randomized controlled trial on 89 healthy but obese women who were following an energy-restricted diet. A half of the group was given a probiotic yogurt, and the remainder a conventional low fat yogurt. Over 12 weeks of observation, the weight losses (5.3 vs. 5.1 kg) were very similar for the two cohorts. However, it was suggested that the probiotic yogurt had some advantages over the alternative format in terms of lipid profile and insulin sensitivity.

Table 7. Influence of yogurt ingestion upon body weight regulation.				
Author	**Sample**	**intervention**	**Findings**	**Comments**
Babio et al. (Babio et al., 2015)	1868 men & women aged 55-80 yr	Dietary habits vs. incidence of metabolic syndrome over 3.2 yr	Risk 0.73 for low-fat and 0.78 for whole-fat yogurt	Multivariate adjusted hazard ratios
Bowen et al. (2005)	50 healthy but overweight adults	12 wk energy restriction, high Ca/high dairy. high mixed protein/mod. Ca	No inter-group difference in wt loss.	
Delbert et al. (2004)	83 overweight or obese adults	Lifestyle ed. vs. soy/yogurt diet with or without phys. activ.	Wt loss at 6 months 8.9 kg (soy/yogurt) vs. 6.6 kg (lifestyle)	No inter-group differences of fat free mass
Drapeau et al. (2004)	248 volunteers from Quebec Family Study	Diet vs. 6 yr change in body composition	Changes in waist circumference linked to intake of<2%fat yogurt	
Keast et al. (2015)	3786 US children aged 8-18 yr	Yogurt consumer (yes/no)	Yogurt intake associated with lower body mass and skin-folds	Only 280/3786 chose to eat yogurt
Lee et al. (2014)	7173 Korean adults aged 19-64 yr	Cross-sectional association BMI >25 kg/m^2 and ingestion of dairy products	Yogurt or milk >2/day vs. <1/month, odds ratio of 0.63, overweight or obese	Benefit of dairy products greater in women than men
Madjd et al. (2016)	89 healthy but obese women	Probiotic vs. low fat yogurt over 12 weeks	Both groups showed similar loss of wt (5.3 vs. 5.1 kg).	Probiotics may help lipid profile & insulin sensitivity
Martinez-Gonzalez et al. (2014)	8516 men and women	Yogurt consumption vs. obesity and weight gain over 6.6 yr	High total and whole yogurt (>7 days/wk) reduced risk of obesity (0.80, o.62)	Multivariate risk analysis
Pereira et al. (2002)	3157 adults aged 18-30 yr	Obesity vs. dairy intake over 10-yr follow-up	>35/wk vs. <10/wk risk 0.70 in overweight, 0.75 in normal wt.	Also reduced risk of insulin resistance syndrome
Santiago et al. (2016)	4545 elderly adults at high CV risk	Total, whole-fat & low-fat yogurt and reversion of abd. obesity	Total yogurt not related to abd. obesity, whole fat yogurt inversely associated	Multivariate analysis.
Vergnaud et al. (2008)	2267 middle-aged French adults	6-yr changes in wt. & waist circumf.	In overwt. men, & normal wt women gains of wt and waist circumf. inversely associated with yogurt intake	
Wang et al. (2014)	3440 Framingham offspring study	Gain of body wt. 1991-95 to 2005-08, (12.9 yr) relative to yogurt intake	3 servings/wk had 0.1 kg/yr less wt. gain, 0.13 cm/yr less gain of waist circumf.	Data adjusted for demographic and lifestyle factors

Martinez-Gonzalez et al. (2014) followed a sample of 8516 men and women for an average of 6.6 years, relating their risk of developing obesity to yogurt intake. In a multivariate analysis allowing for age, sex, baseline weight, habitual physical activity, TV watching, smoking, snacking and other potential risk factors, those with a high total and whole-fat yogurt intake (>7 days/wk) had reduced obesity risk ratios (0.80 and 0.62, respectively) relative to the remainder of their sample.

Pereira et al. (2002) followed adults initially aged 18-30 years for 10 years. The risk of obesity was lower in those consuming dairy products >35 times per week compared to those consuming such items 10 or less times per week. The risk ratio was 0.70 for those with an initial BMI >25 kg/m^2, and 0.75 for those who were initially of normal weight. The dairy products were also helpful in protecting against the insulin resistance syndrome.

Santiago et al. (2016) followed 4545 elderly adults at high risk of cardiovascular disease on a yearly basis, relating abdominal obesity to yogurt consumption. Findings were unrelated to the total consumption of yogurt, but a multivariate analysis established an inverse association between abdominal fat and the consumption of whole-fat yogurt.

Vergnaud et al. (2008) examined 2267 middle-aged French adults. Six-year changes in body weight and waist circumference in overweight men were inversely associated with yogurt intake, whereas in women the association was only seen in those who were initially of normal weight. The impact upon body weight was greater for yogurt than for alternative dairy products such as milk, cheese, butter and cream.

Wang et al. (2014) examined data for3440 participants in the Framingham offspring study. Over an average follow-up of 12.9 years, the annual multivariate adjusted gains of body weight and waist circumference were marginally smaller (0.1 kg/yr, 0.13 cm/year) for those eating more than 3 servings of yogurt per week, relative to those taking less than one serving per week.

Summary. Of the studies cited, 3 cross-sectional comparisons and 6 cohort analyses all suggested some advantage of weight management from a high level of yogurt ingestion. There is a dearth of controlled studies, although Delbert et al. (2004) did find a somewhat greater weight loss with a soy/yogurt diet relative to lifestyle advice alone.

Increased calcium intake.

A substantial number of animal experiments have suggested that a low calcium intake increases intracellular calcium levels, thus promoting fat deposition and reducing the body's rate of lipolysis and thermogenesis. In contrast, an increased intake of calcium is held to reverse such trends. Thus, observations in mice have shown that a high calcium intake depresses circulating levels of parathyroid hormone and vitamin D, leading to decreases of intracellular calcium, an inhibition of lipogenesis, an acceleration of both lipolysis and fat oxidation, and a lesser tendency to weight regain following dieting (Schrager, 2005; Shi, Dirienzo, & Zemel, 2001; Sun & Zemel, 2004; Zemel, 2002, 2004; Zemel, Shi, Greer, Dirienzo, & Zemel 2000),

Similar findings have been reported in studies of rats. Metz, Karanja, Torok and McCarron (1988) found a reduction of body fat when rats were fed a diet with a high calcium and sodium content. Bursey, Sharkey and Miller (1989) observed that when the calcium content of the diet was increased from 0.1% to 2.0%, weight gain was reduced in both lean and fatty Zucker rats. Likewise, Papakonstantinou, Flatt, Huth and Harris (2003) noted that animals given a high calcium diet had 29% less carcass fat, apparently due to a reduced intestinal absorption of fat and a greater faecal loss of lipids. Further, some authors have suggested that dairy products are more effective than elemental calcium in promoting such changes (Shi et al., 2001). However, the benefits of a high calcium intake are as yet less clearly established for humans than for small mammals.

In the animal models, one mechanism of benefit seems that the calcium ions bind to fatty acids in the intestine, and that calcium absorption is then limited by the formation of soaps (Christensen, Lorenzen, Svith, Bartels, Melanson, Saris, et al., 2009). Furthermore, a low calcium intake leads to a release of calcitrol (1,25 dihydroxy-vitamin D), and this increases adipocyte Ca^{2+}, with a stimulation of fatty acid synthase (Claycombe, Wang, Jones, Kim, Wilkison, Zemel, et al., 2000; Shi et al., 2001). In humans, also, a suppression of calcitrol by a high intake of yoghurt and other dairy products augments lipolysis, and increases fat oxidation by as much as 30 g/day (Melanson, Donahoo, Dong, Ida, & Zemel, 2005). However, any benefits from an increased calcium intake are closely inter-woven with the response to yogurt and other dairy products.

We will consider the effects of calcium upon human weight regulation in terms of the findings of meta-analyses, as well as the findings seen in cross-sectional and cohort studies, and randomized controlled experiments.

Meta-analyses of calcium intake and weight regulation. A review by Barr (2003) found little evidence that an increase of calcium intake or dairy products was helpful in human weight regulation. She analyzed nine studies where dairy supplements had been provided, and in seven of these no differences of body weight or composition had developed relative to control subjects. In the remaining two trials, the weight gain was greater in those who received the dairy supplement, although it is unclear how far subjects had attempted to compensate for the increased energy intake associated with their dairy products. Barr (2003) also found 17 trials of calcium supplementation, and in 16 of these reports the changes of body weight and body fat content in those receiving the supplements closely matched findings for the controls, with just one study finding a greater weight loss in those who received the supplement. Nevertheless, Barr cautioned that most of the studies were not specifically designed or powered to address the issue of calcium intake versus weight regulation, and further research was thus required.

Davies et al. (2000) repurposed 5 clinical studies (2 cross-sectional, 2 longitudinal, and one a randomized intervention) that were initially focused upon skeletal health, using the resulting data to explore the relationship between calcium intake and body mass. Among a total of 780 subjects, significant negative relationships were demonstrated for all 3 age groups (third, fifth and eighth decades), and it was estimated that a 1000 mg increase of calcium intake equated to an 8 kg smaller gain in body weight, with calcium intake explaining 3% of the variance in body mass.

Heaney, Davies, and Barger-Lux (2002) examined findings from six observational studies and three controlled trials where calcium intake was the dependent variable. They found a consistent effect associating a higher calcium intake with a lower body fat content or body mass, and they suggested that each 300 mg increase of daily calcium intake was equivalent to a 1 kg lower body mass in children, and a 2.5-3.0 kg lower body mass in adults.

In summary, two of the 3 meta-analyses (both based upon a majority of non-randomized trials) demonstrated benefit from calcium supplementation, but the review that encompassed the largest number of papers, focusing upon randomized trials, found little evidence of benefit from an increased intake of either dairy products or calcium supplements.

Empirical data on calcium intake and weight regulation. Empirical studies have evaluated the use of calcium supplements, estimated the calcium content of the diet in relation to body composition, or in some cases simply looked at the quantity of dairy products consumed, using this as a proxy measure of calcium ingestion. Factors influencing the response of body fat stores seem to have included whether a person's calcium intake was sub-optimal before any intervention, the initial obesity of the subjects, and whether there was any associated restriction of total energy intake (Table 8).

There seems to have been a potential for the creation of spurious associations between calcium intake and body mass, due to a substantial proportion of underreporting of overweight status (Fiorito, Ventura, Mitchell, Smiciklas-Wright, & Birch, 2006).

Cross-sectional and cohort studies. Barba et al. (2005) examined cross-sectional relationships between the intake of dairy products and BMI in 884 healthy children. The BMI Z-score was found to be inversely associated with dairy intake after adjusting the data for sex, age, physical activity, birth weight, parental obesity and the parental level of education. The relationship remained significant when data for skimmed milk consumption were added to the dairy product total.

Berkey et al. (2003) followed 12,829 U.S. children initially aged 9-14 years for a period of 3 years. Contrary to the authors' expectations, a classification of milk intake (more than 3 servings per day versus less than 3 servings per day) showed that those who drank more milk gained more body weight over the 3 years. Gains of body weight were also linked to the daily intake of 1% and skimmed milk, as well as to total calcium intake.

Boon et al. (2005) followed some 370 Dutch citizens from the age of 13 through to the age of 36 years. Over this period, the BMI and skin-fold measures of body fat showed a weak inverse correlation with reported calcium intake, although no added advantage was seen in those whose intake exceeded 800 mg/day.

Buchowski et al. (2002) studied lactose intolerance in a group of 50 premenopausal African American women. Both lactose intolerance and a low calcium intake were associated with a greater BMI, with calcium intake (which varied from 100 to 800 mg/day) describing 47% of the variance in BMI.

Bueno et al. (2008) examined 1459 Sao Paulo adults with a relatively low average calcium intake (449 mg/day). The individual calcium intake showed a weak inverse relationship with BMI, after statistical adjustment of the data for age, sex, smoking habits, physical activity, educational attainments, and fibre and fat intake.

Caruth and Skinner (2001) used home interviews to collect 18 days of dietary information on 53 children aged 2 to 96 months. Both a higher intake of calcium and a higher intake of dairy products were associated with a lesser body fat content as determined by dual energy x-ray absorptiometry.

Dicker et al. (2008) related the ingestion of calcium to waist circumference in a sample of 2601 Israelis, with an average calcium intake of about 500 mg/day. In the men,
waist circumference was unrelated to calcium intake, but in the women those with a waist circumference of less than 88 cm had a higher calcium intake than their peers.

Dos Santos et al. (2008) examined relationships between DEXA assessments of trunk fat, insulin resistance and calcium intake in 47 normal and 40 obese post-pubertal adolescents aged ~16.6 years. The daily calcium intake was lower in the obese (585 mg) than in those of normal weight (692 mg), and in the obese group there were also inverse relationships between calcium intake and both trunk fat and insulin resistance.

Jacqmain et al. (2003) made a cross-sectional analysis of data for 470 adults aged 20-65 years who had participated in the Quebec family study. Daily calcium intake was divided into three categories (<600, 800 and >1000 mg), and a low calcium intake was found to be associated with adiposity and an adverse lipid profile. In women, the associations persisted after adjustment of the data for covariates (age, daily energy intake, percentage of dietary fat, protein intake and socio-economic status), but in men the associations were no longer statistically significant after adjusting for inter-individual differences in these factors.

A trial in 120 obese primary school children (Kelishadi et al., 2009) found that the introduction of a dairy-rich diet had significant beneficial effects on body mass index and waist circumference over a 3-year period.

Lin et al. (2000) studied 54 normal weight young women aged 18-31 years, who had been randomly assigned to an exercise programme or to a control group. Changes in body weight and measures of body fat were inversely associated with calcium intake for both of these groups.

In a survey of 10,066 women aged over 45 years, the prime focus of Liu et al. (2005) was the risk of developing the metabolic syndrome. Protection was found in increasing quintiles of calcium and Vitamin D intake. Data were also obtained on BMI, and these showed a highly significant inverse gradation with the individual's intake of calcium and Vitamin C.

Lovejoy et al. (2001) related calcium intake to BMI and body fat content in a group of 149 premenopausal women, finding inverse associations between calcium intake and both of these variables, the relationship being statistically significant in "white", but not in African American women.

Novotny et al. (2004) found that the thickness of the iliac skin-fold was inversely related to calcium intake, physical activity and age in a group of 323 girls aged 9-14 years. One milk serving per day equated to an 0.8 mm decrease in thickness of the iliac skin-fold. However, subcutaneous fat thickness was not correlated with the subjects' non-dairy calcium intake.

Ochner and Lowe (2007) studied 103 overweight or obese women who had been losing weight for a total of 22 weeks. Their calcium intake inversely predicted weight regain during the following 6 to 18 months, but only after covarying the data for individual differences in total energy intake.

Table 8. Effects of calcium supplementation on weight regulation, as seen in cross-sectional and cohort studies				
Author	**Sample**	**Measurement**	**Findings**	**Comments**
Barba, Troiano, Russo, Venezia and Siani (2005)	884 normal children aged 7.5 yr	Milk cons. vs. BMI Z-score	Inverse assoc. after adjusting for sex, age, phys. activ., birth wt, parental wt. & educ.	Association still signif. after including skimmed milk consumption
Berkey, Rockett, Gillman, Field and Colditz (2003)	12,289 U.S. children aged 9-14 yr	>3 servings of milk/day vs. < 3 servings/day	3 yr follow-up, greater milk intake had greater wt. gain	Wt. gain also associated with !%, skim milk and total daily Ca intake
Boon, Koppes, Saris and Van Mechelen (2005)	~ 370 Dutch men & women	Ca intake vs. BMI & skin-folds	23-yr follow-up from age 13 yr Ca intake weak inverse relation to body composition	No added advantage if Ca > 800 mg/d
Buchowski, Semenya and Johnson (2002)	50 premenopausal lactose intolerant women	Ca intake vs. BMI	Lactose intolerance and low Ca intake associated with greater BMI	r^2 for BMI 0.47
Bueno, Cesar, Martini and Fisberg (2008)	1459 Sao Paulo adults, Ca intake 449 mg/d	Ca intake vs. BMI	Ca intake weak inverse correlation with BMI	Data adjusted for age, sex, smoking, phys. activ., educ., fibre & fat
Dicker, Belnic, Goldsmith, and Kaluski (2008)	2601 Israelis	Ca intake vs. waist circumf.	No relationship in men; women with waist <88 cm consumed more Ca	Mean Ca intake ~500 mg/d
Dos Santos, de Pádua Cintra, Fisberg and Martini (2008);	47 normal, 49 obese post-pubertal adolescents aged 16.6 yr	Ca intake vs. obesity (DEXA) and insulin resistance	Lower Ca intake in obese (585 mg/d) than normal wt (692 ng/d)	Ca intake inversely assoc. trunk fat and insulin resistance in obese
Jacqmain, Doucet, Despres, Bouchard and Tremblay,(2003)	470 adults aged 20-65 yr	Comparison Ca <600, 800, >1000 mg/d	Low Ca intake associated with adiposity and adverse lipoprotein profile	Members of Quebec family study
Kelishadi, Zemel, Hashemipour, Hosseini, Mohammadifard, and Poursafa (2009)	120 obese primary school children	Introduction of a dairy rich diet	Over 3 yr, signif. beneficial effects on BMI & waist circumf.	
Lin et al. (2000)	54 normal weight women, aged 18-31 yr	2 yr randomized exercise intervention	Wt and body fat inversely related to calcium intake.	Association seen irrespective of ex. group
Liu et al. (2005)	10,066 healthy women aged >45 yr	Ca & Vit. D intake vs. metabolic syndrome	BMI decreases across quintiles of Ca & Vit. D intake	Intake of Ca & dairy products protects against metabolic syndrome
Lovejoy, Champagne, Smith, de Jonge and Xie (2001)	149 premenopausal women	Calcium intake vs. body fat	BMI and body fat inversely related to Ca intake	Relationship significant in "white" but not in African Americans

Table 8 Continued.

Author	Sample	Measurement	Findings	Comments
Novotny, Daida, Acharya, Grove and Vogt (2004)	323 girls aged 9-14 yr	Ca intake vs. iliac skin-fold	Negative association (but not seen for non-dairy Ca)	1 milk serving/d equals 0.8 mm iliac skin-fold thickness
Ochner and Lowe,(2007)	103 overweight or obese women after 22 wk dieting	Ca intake vs. wt regain at 6 & 18 months	Ca intake predicted wt. regain 6-18 month if controlled for energy intake	
Olivares, Kain, Lera, Pizarro, Vio and Morón (2004)	1701 Chilean children, grades 3-7	BMI vs. diet	Dairy consumption inverse association with obesity	
Pereira et al. (2002)	3157 adults	Dairy food frequency vs. BMI	Higher dairy intake if BMI <25 kg/m^2	High dairy also reduces insulin resistance
Phillips et al. (2003)	178 non-obese girls initially aged 8-12 yr	BMI Z score and body fat vs. dairy intake	Followed to 4 yr post-menarche. unrelated to dairy intake	
Rockett, Berkey, Field and Colditz (2001)	16,882 children aged 9-14 yr	Food frequency questionnaire	Overweight students had slightly smaller intake of dairy products	
Shahar et al.(2010)	322 adults in 2-year wt loss programme	Ca intake tertile and wt loss	2 yr loss -3.3, -3.5, -5.3 kg for tertiles	Higher Vit. D also increased wt loss
Skinner Bounds, Carruth and Ziegler (2003)	52 children aged 8 yr	Ca and polyunsaturated fat intake vs. DEXA	Ca and polyunsaturated fat intake inversely related to body fat	Account for 28-34% variation in body fat

Olivares et al. (2004) made a descriptive analysis of diet in relation to BMI in1701 Chilean schoolchildren from grades 3-7. Dairy consumption showed a consistent inverse association with obesity in a logistic regression analysis of their data set.

Pereira et al. (2002) reported that among 3157 of the adults enrolled in the CARDIA study, dairy intake was significantly greater in those with a BMI of less than 25 kg/m^2. The higher dairy intake was also associated with a lower risk of insulin resistance.

Phillips et al. (2003) followed 178 non-obese girls from an initial age of 8-12 years to 4 years post-menarche. Over this time, neither the BMI Z-score nor the body fat content showed any relationship to the intake of dairy products.

Rockett et al. (2001) made a cross-sectional analysis of food frequencies in 16,882 children aged 9-14 years. Those who were overweight reported eating significantly fewer daily servings of dairy products, although differences were quite small (3.38 versus 3.48 servings/day in the boys, 2.92 versus 3.05 servings/day in the girls).

Shahar al. (2010) evaluated 322 adults who were enrolled in a 2-year weight loss programme. Over this period, the decreases in body mass for the three tertiles of calcium intake were 3.3, 3.5 and 5.3 kg, respectively. Long-term weight loss was also associated with a greater intake of Vitamin D.

Skinner et al. (2003) determined the calcium and polyunsaturated fat intakes of 52 eight-year-old children. Values were inversely correlated with DEXA assessments of body fat in each of 3 statistical models, with these dietary measures accounting for 28-34% of the variation in body fat content.

In summary, 19 of 21 cross-sectional or cohort studies showed an inverse association between calcium or dairy intake and measures of obesity, in one study, there was no effect, and in one the consumption of dairy products was linked to an increase of body mass.

Randomized controlled trials. Bowen et al. (2005) assigned 50 healthy but overweight adults between a high protein diet providing 2400 mg of calcium per day, and an alternative diet providing only 500 mg of calcium per day. Over 12 weeks of dietary restriction and 4 weeks of energy balance, the decreases of body weight (9.7 kg) and body fat (8.3 kg) were similar for the two diets (Table 9).

Caan et al. (2007) tested 36,282 post-menopausal women. They were randomized to groups receiving either 1000 mg of elemental calcium plus 400 units of Vitamin D per day or a placebo treatment. The calcium supplementation group showed a small (0.17 kg) but consistent weight advantage with respect to the placebo group. Particularly in those women with a low initial calcium intake, the calcium supplements led to a 11% decrease in the likelihood of developing either minor or more substantial (>3 kg) weight gain over the next 3 years of observation.

DeJongh et al. (2006) administered a substantial calcium supplement (1000 mg/day) to a half of a sample of pre-school children. No overall association was seen between body mass and calcium intake. However, in those from the lowest tertile (a calcium intake of less than 800 mg/day), the supplement was linked to a smaller gain of fat mass (0.3kg versus 0.9 kg) over the following year, although even in this group fat mass was unrelated to total calcium intake.

Harvey-Berino, Gold, Lauber, and Starinski (2005) enrolled 54 adults in a programme that included a 2.2 MJ/day energy deficit. A half of the group followed a low calcium regimen (500 mg/day), and in the remaining subjects' calcium intake was augmented to 1200-1400 mg/day. The weight loss at 12 months showed no significant inter-treatment difference (9.6 versus 10.8 kg), and fat loss was also similar for the two cohorts (9.0 versus 10.1 kg).

Jensen, Kollerup, Quaade and Sørensen (2001) focused on bone mineral content in 32 obese women who were following a restricted diet (a total energy intake of 4.2 MJ/day). A half of the group was given a calcium supplement (1000 mg/day). The weight loss at 6 months was similar with or without calcium supplementation, but the added calcium did appear to offer some protection against the tendency to bone demineralization (which the authors attributed to a decreased mechanical strain as weight was reduced).

Lorenzen, Mølgaard, Michaelsen and Astrup (2006) divided 100 girls aged ~12 years between a cohort that was given a calcium carbonate supplement (500 mg/day) and those who received a placebo. After one year, the two cohorts did not differ from each other in terms of their body mass or body fat content, although at baseline body fat was inversely correlated with the initial calcium intake of the girls.

The authors of this report speculated that calcium might only exert its effect if forming part of a meal, or possibly it was simply serving as a marker of some other beneficial constituent of dairy products.

Major et al. (2007) followed 63 healthy but overweight or obese women who had reduced their energy intake by 2.9 MJ per day. All had an initial calcium intake of less than 600 mg/day. A half of the sample was given a supplement of 600 mg of calcium and 200 IU of Vitamin D per day. After 15 weeks although there were no inter-cohort differences in weight loss, the calcium supplements enhanced favourable changes in lipids and lipoproteins.

The subjects of Reid et al. (2005) were 1471 normal older women (age ~74 years). A half of the group was given a calcium supplement (1000 mg per day). At the end of 6 months, the two halves of the sample showed an identical weight loss of 0.37 kg, and any effect of the calcium supplement upon blood pressures was small and transient.

Shapses et al. (2004) recruited 100 women to a weight-loss programme. A half of the group received a daily supplement of 1000 mg of calcium, and the remainder a placebo. Over 25 weeks, there were no statistically significant inter-cohort differences in weight loss (7.6 kg versus 6.2 kg) or fat loss (5.5 kg versus 4.5 kg), although there was a possible small trend favouring those receiving the calcium supplement.

Thompson et al. (2005) enrolled 72 obese subjects in a weight loss programme based upon a 2.2 MJ/day energy deficit. Over a period of 48 weeks, there was no significant difference in weight loss (11.8 vs. 10.0 kg) or fat loss (9.0 vs. 7.5 kg) whether the diet contained 1400 mg/day or 800 mg/day of calcium. Morover, no benefit was seen from an increased fibre intake.

Wagner et al. (2007) studied 58 middle-aged adults who were following a diet with a 2.2 MJ/day energy deficit. The group was assigned randomly between cohorts who received a 800 mg calcium supplement (as lactate, phosphate or milk) and a placebo group, After 12 weeks, there was no inter-group difference of weight loss, although those individuals receiving the calcium lactate did show less bone degradation.

In contrast with most of the other randomized controlled trials, Zemel et al. (2004) found that in 32 obese adults who were following a 2.2 MJ/day energy deficit diet, an increase of calcium intake from 400-500 to 1200-1300 mg/day, using either calcium supplements or a high dairy intake augmented weight loss, from 6.4% in the control subjects to 8.6% in those receiving the calcium supplements, and to 10.9% in those given the high dairy intake. Further, there were comparable benefits in terms of fat loss.

Additional observations by the same research group (Zemel et al., 2005) compared responses to 1200 versus 500 mg of calcium per day in 34 obese African Americans who were in a weight maintenance phase. Neither of these diets led to a change in body mass. However, in 29 individuals who were restricting their diet by 2.2 MJ/day, the decrease of body weight and fat mass after 24 weeks were twice as great with the high dairy intake than with the control regimen, and the high dairy diet also led to a better conservation of lean tissue mass.

In summary, 9 of 13 randomized controlled trials showed no significant enhancement of weight regulation by an increased calcium intake (although in 3 of the 9 studies, there was a slight trend favouring individuals who received a

Table 9. Randomized controlled trials evaluating effects of increased calcium intake on the regulation of body weight.				
Author	**Sample**	**Intervention**	**Findings**	**Comments**
Bowen et al. (2005)	50 healthy but overweight adults, 12 wk energy restriction, 4 wk energy balance	High protein diet, 2400 mg vs. 500 mg Ca/d	Loss of wt (9.7 kg) and fat mass (8.3 kg) independent of Ca intake	
Caan et al. (2007)	36,282 post-0menopausal women	Randomized to 1000 mg Ca plus 400 units Vit. D vs. placebo	At 3 yr, women with low initial Ca receiving Ca 11% less likely to show both small and larger weight gains	Benefit seen mainly in women with low initial Ca intakes
DeJongh et al. (2006)	178 preschool children	Random assignment to Ca supplement (1000 mg/d) vs. placebo	Over 1 yr, children with baseline Ca >800 mg/day gained less fat mass (0.3 vs. 0.8 kg) with Ca	No correlation of Ca and body fat in overall sample
Harvey-Berino et al. (2005)	54 subjects on 2.2 MJ/d dietary restriction	500 vs. 1200-1400 mg Ca/day	Wt loss at 12 months showed no signif. inter-group difference (9.6 vs. 10.8 kg)	Fat loss also similar (9.0 vs. 10.1 kg)
Jensen et al. (2001)	30 obese women on low energy diet	Half received 1000 mg/d Ca	No difference of wt loss at 6 months	Ca supplement partly inhibits bone loss
Lorenzen et al. (2006)	100 young girls	50 mg Ca vs. placebo	No effect on body mass or body fat over 1 yr	Initial Ca intake inversely associated with body fat
Major, Alarie, Doré, Phouttama, and Tremblay, (2007)	63 healthy but overweight or obese women, 2.9 MJ/day energy deficit, Ca intake <800 mg/d	600 mg/d Ca + 200 IU Vit. D vs. placebo	At 15 wk no difference in wt loss	Treatment enhanced changes in lipids and lipoproteins
Reid et al. (2005)	1471 normal older women (age ~74 yr)	1000 mg/d Ca vs. placebo	Over 6 months, wt. loss of 0.37 kg with both options	Any hypotensive effect small & transient
Shapses, Heshka and Heymsfield (2004)	100 women	1000 mg Ca vs. placebo	Over 25 weeks, no differences body wt (7.o, 6.2 kg) or fat mass (5.5, 4.5 kg)	
Thompson et al. (2005)	72 obese subjects, daily energy deficit 2.2 MJ	1400 mg vs. 800 mg Ca diet	Over 48 wks, no diff. wt loss (11.8 vs. 10.0 kg) or fat loss (9.0 vs. 7.5 kg)	Dietary fibre or Ca > 800 mg does not help weight loss
Wagner, Kindrick, Hertzler and DiSilvestro (2007)	2.2 MJ diet restriction, 58 middle-aged adults	800 mg Ca supplement as lactate, phosphate or milk vs. placebo	At 12 wk, no difference of wt. loss relative to placebo	Ca lactate reduced bone degradation
Zemel, Thompson, Milstead, Morris, and Campbell (2004)	32 obese adults, energy deficit 2.2 MJ/d	1200-1300 vs. 400-500 mg Ca/d	At 24 wk, High Ca or equivalent dairy increased wt loss to 8.6, 10.9 % vs. 6.4% control	Fat loss showed comparable increase
Zemel, Richards, Milstead and Campbell (2005)	34 obese African Americans wt maintenance	1200 mg vs. 500 mg Ca/d	At 24 wk no change of weight in either group	Wt and fat loss twice as great with high dairy intake; loss of lean mass less with high dairy intake

calcium supplement). Two further trials showed a small but significant advantage to those receiving additional calcium, and only in the two reports of Zemel et al. (2004, 2005) was there a substantial advantaged from calcium supplements.

Other dietary options

Some authors have advocated providing nutritional supplements such as flavonoids and probiotics to counter possible oxidative stress and a depression of immune function during periods of dietary restriction (Walsh, Gleeson, Shephard, Gleeson, Woods, Bishop, et al. 2011),

Flavonoids are mainly obtained from fruit and vegetables, but minimum daily requirements have yet to be clarified.

Diets with an extreme emphasis upon protein or fat can have unintended adverse effects upon health. A high intake of red and processed meat increases the risk of heart disease (Bernstein, Sun, Hu, Stampfer, Manson & Willett, 2010; Mente, de Koning, Shannon, & Anand, 2009), diabetes mellitus (Aune, Ursin, & Veierød, 2009; Pan, Sun, Bernstein, Schulze, Manson, Willett, & Hu, 2011) and colon cancer (Aykan, 2015). A diet that is high in saturated and trans-fat increases oxidant stress (Couillard, Pomerleau, Ruel, Archer, Bergeron, Couture, et al., 2006), predisposes to atherosclerosis (Oh, Hu, Manson, Stampfer, & Willett, 2005) and accelerates aging (Honma, Shinohara, Ho, Kijima, Sugawara, Arai, et al.,2012). However, a large intake of vegetable fat has an opposite effect.

Discussion and conclusions

Most of the dietary options considered in this review seem to have had a remarkably small influence upon the success of either weight loss or weight maintenance programmes. Although individual nutritional initiatives have often appeared to show substantial benefit in cross-sectional analyses, this seems due largely to the influence of covariates, particularly the healthier lifestyle of those willing to accept radical changes in their diet. Nevertheless. more long-term and adequately powered randomized controlled trials are needed before one can exclude most of the potential options that have been discussed in this article. It may prove that the limited response to a given intervention reflects a lack of commitment on the part of those assigned to the experimental group, or too short a period of observation for the small positive trends that have sometimes been observed over the course of a few weeks to accumulate to become a clinically and statistically significant benefit.

However, it does seem that the main factor that will favour success in a weight management plan is not the adoption of some radical diet, but rather a consistent increase of habitual physical activity and scrupulous adherence to a programme of moderate overall dietary restriction.

Causes of the decrease in body mass during dieting. The usual objective of weight management is to decrease the fat content of the body, but many clinicians have equated weight loss directly with a decrease in body fat content. In practice, not all of the weight that is lost is due to a decrease in fat stores.

Ancel Keys noted that the body mass is determined by the sum of 3 components-adipose tissue (G), extracellular fluid (F), and other tissues (N). Furthermore, adipose tissue includes not only pure fat, but also cellular matter (sarcoplasm and connective tissue) and extra-cellular water (Keys & Brozek, 1953). A weight-loss programme usually affects all 3 of these constituents. In healthy, middle-aged men, G typically comprises 62% fat, 24% cell residue, and 14% extracellular water. However, these proportions differ substantially between individual, with the fat component becoming larger in those who are obese. Wishnofsky (1958) reported that in an obese individual G could comprise as much as 87% fat, mainly triglycerides.

Other factors modifying the balance between the energy ingested and body mass include the energy consumed by the thermogenic properties of foodstuffs, a depletion of glycogen reserves during dieting, with the release of associated bound water, a loss of lean tissue during gluconeogenesis, again with the release of associated bound water, and alterations in mineral balance and thus water retention (Table 10). Plainly, several of these factors can be influenced by a person's dietary choices.

Thermogenic effect of foods. Energy is needed to metabolize all types of food, but different nutrients having differing thermogenic effects. Expressed as a fraction of the ingested energy, thermogenesis accounts for 20-30% of the energy released during protein metabolism, 10-30% for alcohol, 5-10% for carbohydrate, and (seemingly contrary to the views of Atkins) only 0-3% for fat (Tappy, 1996).

Depletion of glycogen reserves. Other factors being equal, the body normally stores some 400 g of glycogen in skeletal muscle and a further 100 g in the liver. Further, between 1.5 and 3 g of water is associated with each gram of stored glycogen. These glycogen reserves are quickly depleted by vigorous exercise and/or the introduction of a negative energy balance.

If a subject is only provided with water, liver glycogen levels drop to zero within 12-24 hours of commencing the fast (Heymsfield, Thomas, Nguyen, Peng, Martin, Shen, et al. 2011). Early observations by Benedict (1912) further showed that a total depletion of the body's carbohydrate reserves could occur over a 10-day period of stringent dieting, although normally losses occurred more slowly. The water that is bound to the glycogen molecule is liberated as this process of depletion proceeds. The metabolism of 500 g of stored glycogen can release as much as 2 L of fluid, thus causing a 2 kg decrease of body mass that is unrelated to fat loss during the first 1-2 weeks of rigorous dieting. Potassium ions are also associated with the stored glycogen (about 0.45 mMol of potassium per g of glycogen), and a substantial release of this mineral can upset potassium-based estimates of body composition in dieters (Kreitzman, Coxon, & Szaz, 1992), as well as predisposing to cardiac arrhythmias.

Table 10. Factors contributing to the weight loss observed during dieting.
• Energy intake less than daily energy expenditures • Metabolism of body fat • Energy lost due to thermogenic properties of foodstuffs • Depletion of glycogen reserves, with release of the associated bound water • Loss of lean tissue, with the release of the associated bound water • Alterations in mineral balance and thus water retention • Possible losses of bone mineral

Depletion of fat-free tissue. Severe dieting, particularly if performed without a resistance exercise component, can lead to the breakdown of several kg of lean tissue, as the liver engages in gluconeogenesis in an attempt to sustain blood glucose levels. Ball, Canary and Kyle (1967) noted that if the total energy intake of a person was limited to 3.2 MJ/day, the fat-free mass could decrease by as much as 224 g/day, and with total starvation, the loss rose further, to 576 g/day. Protein molecules have a hydration of around 1.6 g per g of protein (Hall, 2008), so that water loss comprises a substantial part of the decrease in body mass that is seen as a consequence of the metabolism of lean tissue.

Depletion of bone mineral. Bone mineral depletion is well documented during anorexia nervosa, but its contribution to weight loss during clinical dieting is less clearly established (Shapses & Sukumar, 2014). The extent of osteoporosis that occurs in the dieter probably depends in part on the type of diet that is chosen, with an obvious potential to seek protection through a deliberate increase in the intake of dairy products, calcium, Vitamin D and proteins.

Altered mineral balance. A severe dietary restriction can cause substantial changes in the body's mineral balance, with associated alterations in fluid content. Thus Wynn, Abraham and Densem (1985) found that when subjects ingested a liquid formula diet that provided an energy intake of 2.7-3.3 MJ/day, there was a negative sodium balance during the first week, with an associated body fluid loss of 100-500 mL/day. This reflected not only a decreased dietary intake of sodium, but also an attempt to compensate for ketosis, an effect of hypoinsulinaemia on the renal excretion of sodium, and an activation of the renin/angiotensin system (Kamel, Lin, Cheema-Dhadli, Marliss, & Halperin,1998; Kolanowski, 1981).

The potassium losses of dieters closely paralleled their losses of nitrogen, the potassium ions came mainly from the intracellular compartment of the body, reflecting a combination of glycolysis and proteolysis ((Kolanowski, 1977), and amounting to around 300 mMol over the first 7-10 days of dietary restriction.

Relative utilization of carbohydrate and fat. The usual objective of weight regulatory programmes is to maximize the utilization of fat relative to carbohydrate. The ability of the tissues to metabolize fat is enhanced by the adoption of a high fat diet, and is lessened by a high carbohydrate diet. The latter option progressively decreases lipolysis and thus the metabolism of fat (Turcotte, 1999), whereas a high fat intake increases the sympatho-adrenal response to exercise and thus the extent of fat metabolism (Jansson, Hjemdahl, & Kaijser, 1982; Langfort, Pilis, Zarzeczny, Nazar, & Kaciuba-Uśxilko, 1996). But much depends upon the characteristics of any associated exercise programme: the intensity of the effort that is undertaken, the type of activity that is performed, the state of training of the individual, and the timing of recent food intake (Gmada, Marzouki, Haboubi, Tabka, Shephard, & Bouhlel, 2012).

Fat usage increases progressively with the intensity of effort, but it peaks at 50 to 60% of maximal aerobic effort. If the intensity of exercise is further increased, the fraction of energy derived from fat decreases, since vigorous muscle contraction restricts the local blood flow to the active tissues, compromising aerobic metabolism. The local limitation of muscle blood flow is most obvious if only a small fraction of the total musculature is activated during exercise, as when performing a heavy task using the forearms (Shephard, Bouhlel, Vandewalle & Monod, 1988). Local ischaemia is also more likely to occur if the muscles are weak and the person is poorly trained (Achten & Jeukendrup, 2004). Thus, Achten and Jeukendrup observed a peak of fat oxidation at 59-64% of maximal aerobic power in individuals who were well-trained, compared with 47-52% in those who were untrained.

Endurance training progressively increases the potential of muscle to oxidize fat derived from body stores (Achten & Jeukendrup, 2004; Horowitz & Klein, 2000), both by facilitating local muscle blood flow and by increasing the activity of aerobic enzymes in the muscle fibres. Brief periods of fasting or a negative energy balance increase the relative metabolism of fat (Bouhlel, Salhi, Bouhlel, Mdella, Amamou, Zaouali, et al., 2006; Stannard & Thompson, 2008). However, if carbohydrate is ingested within 6 hours of beginning an exercise bout, this reduces the fraction of fat that is metabolized (Achten & Jeukendrup, 2004).

Loss of lean tissue associated with dieting. Some loss of lean tissue seems an almost inevitable consequence of a decrease in body mass. One classical dictum, dating from a period when exercise was not a common feature of dietary programmes, suggested that as much as a quarter of the weight loss achieved by a dieter was likely to be lean tissue (Heymsfield, Gonzalez, Shen, Redman, & Thomas, 2014; Webster, Hesp, & Garrow, 1984; Weinheimer, Sands & Campbell, 2010). Since fat itself contains some lean tissue (above), the metabolism of fat will inevitably cause some reduction of lean tissue. However, the major loss of lean mass during dieting comes from elsewhere in the body, particularly muscle. Such tissue loss has negative health consequences, and it is desirable that it be attenuated as far as possible.

Various precautions can keep the losses of lean tissue below that expected from the 25% rule. The provision of amino acid supplements as a part of a restricted diet is likely to limit the breakdown of tissue protein. It is also generally accepted that dieters lose a smaller amount of lean tissue if exercise (particularly resistance training) is added to a rigorous dietary programme (Avila, Gutierres, Sheehy, Lofgren & Delmonico, 2010; Hunter, Brock, Byrne, Chandler-Laney, Del Corral, & Gower, 2010; Warner, Linden, Liu, Harvey, Thyfault, Whaley-Connell, et al., 2010). Furthermore, the loss of muscle protein during a period of dietary restriction tends to be less in someone who is still obese relative to a person who has already attained a normal body mass and thus has few reserves of fat to draw upon (Thomas, Schoeller, Redman, Martin, Levine & Heymsfield, 2010). Finally, hormonal factors such as levels of tri-iodo-thyronine have a protein-sparing effect (Yang & Van Itallie, 1976), and certain constituents of the diet such as dairy products, calcium, Vitamin D and leucine tend to limit the breakdown of lean tissue relative to stored fat (Phillips & Zemel, 2011).

Influence of exercise programmes on loss of lean tissue in dieters. The inclusion of exercise generally limits the loss of lean tissue associated with a weight control programme. Nevertheless, it is difficult to assess the magnitude of this benefit unless the body fat content is measured directly, since other concomitants of exercise including alterations in glycogen storage, fluid balance and protein turnover also affect the observed decrease in body mass.

An early meta-analysis based on young and middle-aged adults suggested that the 25% loss of fat-free mass anticipated with simple dieting was reduced to 12% if appropriate exercise was added to a dietary programme (Garrow & Summerbell, 1995). Weinheimer, Sands and Campbell (2010) reviewed the response of older individuals, as reported in 52 articles covering observation periods of 9 to 52 weeks (Table 11). Their analysis strongly underlines the conclusion that in terms of both the loss of body fat and the conservation of lean tissue, it is important to supplement the restriction of food intake by a regular exercise programme. Only one of the 16 exercise studies included resistance training, and this study actually showed an increase of lean tissue over the course of the investigation. Nevertheless, many of the studies employing aerobic exercise also conserved lean tissue relative to dieting alone. The process is optimized if participants are also assured an adequate intake of high quality protein (Krieger, Sitren, Daniels & Lamgkamp-Henken, 2006; Mettler, Mitchell, & Tipton, 2010).

Table 11. Distribution of changes in total body mass and lean tissue mass occurring in response to energy restriction, exercise, or a combination of the 2 interventions. Data accumulated by Weinheimer, Sands and Campbell (2010) in a review of 52 reports on older adults, covering observation periods of 9 to 52 weeks.

Variable	Energy restriction alone (% of 36 groups)	Exercise alone (% of 16 groups)	Energy restriction + exercise (% of 36 groups)
Decrease of body mass (kg)			
>10 kg	19%	0%	22%
5-10 kg	75%	6%	67%
<5 kg	6%	94%	11%
Decrease of fat-free mass (kg)			
>3 kg	19%	0%	22%
1.5-3 kg	56%	0%	8%
0-1.5 kg	22%	75%	56%
<0 kg (gain)	3%	25%	14%

Negative health and metabolic consequences of a loss of lean tissue. Phillips and Zemel (2001) argued that when a person was dieting, a loss of lean tissue gave rise to several important negative consequences for health and functional ability. In addition to a loss of muscular strength and a resulting weakness that reduced the individual's willingness to participate in voluntary physical activity, adverse metabolic effects included a decrease of resting metabolic rate, a reduced control of glycaemia, a reduced capacity for lipid oxidation, and a greater propensity to weight regain after completion of the dietary programme.

Muscle mass forms a smaller fraction of the total fat-free mass in the elderly than in younger individuals, and in order to look at the potential adverse effects of dieting in this age group, it is desirable to measure changes in muscle mass specifically rather than to estimate the total loss of fat-free mass. Baumgartner, Wayne, Waters, Janssen, Gallagher, & Morley (2004) arbitrarily defined sarcopaenia as a DEXA estimate of appendicular muscle mass that had fallen 2 standard deviations below the value anticipated for a healthy young adult. Baumgartner et al. (2004) noted that in individuals with sarcopaenic obesity, the odds ratio of reporting 2 or more physical disabilities relative to their peers was increased by a dramatic 8.7 for men, and 12.0 for women. Moreover, the loss of muscle tissue usually preceded their disability, and both the loss of muscle and the continued burden of unresolved obesity contributed to the overall loss of physical function.

The heart is not immune to the loss of lean tissue that occurs during dieting. The progressive depletion of cardiac structural and functional proteins not only reduces myocardial mass, but also predisposes a person to dysrhythmias, cardiac rupture and sudden cardiac death (Heymsfield, Wang, Baumgartner, & Ross, 1997). Altered levels of serum minerals and an increased sensitivity of the myocardium to autonomic stimulation further increase the risk of dysrhythmias (Drott & Lundholm, 1992; Fisler, 1992).

Among other adverse effects of lean tissue loss, the decrease in resting metabolic rate compromises attempts at generating a negative energy balance. Any loss of lean tissue is quite important in this regard, since skeletal muscle is the primary source of resting energy expenditure (Johnstone, Murison, Duncan, Rance, & Speakman, 2005; Schoeller, 2009; Strychar, Lavoie, Messier, Karelis, Doucet, Prud'homme et al., 2009).

Poor responses to a dietary regimen

There are many reasons for a limited fat loss in response to any of the dietary regimens considered in this review. Some reflect methods that the body adopts to compensate for an externally imposed disturbance of energy balance, and others simply reflect poor adherence to the recommended combination of dietary restriction and increased physical activity (as discussed below).

Contributing factors (Table 12) include a reduction of resting metabolism linked to the decreased mass of metabolically active tissue, a decrease in resting metabolism per unit of body tissue, a decrease in the body stores or activity of brown fat, adjustments in the hormonal milieu, decreases in the volume and/or intensity of voluntary leisure activity, and a failure to comply with the prescribed regimen. There remains a need for clear information as to how far the addition of exercise to any type of dietary programme attenuates these problems. Certainly, there is evidence that exercise can minimize the loss of lean tissue mass, and it may also have an arousing effect, counteracting the negative mood changes induced by dieting alone, and encouraging the maintenance of voluntary leisure activity.

Table 12. Possible reasons for a poor response to a weight-loss programme.

- Decrease of resting metabolism because the mass of metabolically active tissue is decreased
- Decrease of resting metabolism per unit of metabolically active tissue
- Decrease in body stores and/or metabolic activity of brown fat
- Adjustments in the hormonal milieu (noradrenaline, insulin, tri-iodothyronine, and leptin concentrations)
- Decrease in the volume and/or intensity of voluntary leisure activity
- Decrease in the energy cost of body displacement
- Failure to comply with the prescribed regimen

Effects of reduced tissue mass. Lean tissue accounts for a large fraction of the body's resting metabolism, and if lean tissue mass is reduced by drastic dieting, there will inevitably be a decrease of resting metabolism that is simply an expression of the smaller lean tissue mass. This was demonstrated in the classical Minnesota starvation experiments (Keys, Brozek, & Henschel, 1950), where a cumulative weight loss of 16.8 kg was associated with an overall 40% decrease of resting metabolism, with 25% of this total being due to lean tissue loss, and only 15% reflecting an adaptive decrease in metabolic rate per unit of tissue.

The lean tissue loss associated with a restriction of total energy intake can be minimized by ensuring an adequate intake of good quality protein and encouraging regular physical activity with a resistance component.

Decrease of resting metabolism per unit of active tissue. If weight loss is attempted through some combination of a reduced food intake and an increase of energy expenditure, then the fat loss may be less than intended because of a decrease in resting metabolism per unit of tissue (Shephard, 2019).

The accurate measurement of resting metabolism is not an easy task, and the magnitude of the decrease in RMR associated with rigorous dieting remains controversial. Some have suggested it is can be as large as 1 MJ/day. The decrease seems less in those who remain obese than in those who have become close to their ideal weight (perhaps because the obese have lost less lean tissue), and the decrease of RMR can sometimes be avoided entirely if the energy deficit is created by exercise rather than by dieting alone (Frey-Hewitt, Vranizan, Dreon, and Wood, 1990). Certainly, the addition of strength training to a dietary programme increases resting metabolic rate (Lemmer, Ivey, Ryan, Martel, Hurlbut, Metter, et al. 2001), largely through an increase in lean tissue mass (Treuth, Hunter, Pichon, Figuera-Colon, R., & Goran, M.I.,1998).

Brown fat, uncoupling proteins and related metabolic adjustments. Studies in genetically obese mice have demonstrated that over-feeding leads to a compensatory increase in the animal's reserves of brown fat, with an enhanced capacity for metabolically uncoupled energy usage in response to catecholamine stimulation (Trayhurn, Jones, McGuckin & Goodbody, 1982).

Brown fat is more obvious in mice than in humans, and it remains uncertain how far such observations are applicable to the treatment of human obesity. Nevertheless, an increase in the body's brown fat content offers a further potential mechanism to ensure a favourable relationship between the energy consumed by the body and the external work that is performed (Del Mar Gonzalez-Barroso, Ricquier, & Cassard-Doulcier, 2000; Lowell & Spiegelman, 2000). Exercise during cold exposure may offer a mechanism encouraging the development of brown fat during weight loss (O'Hara, Allen & Shephard, 1979).

Hormonal adjustments. Weight loss is associated with decreases in the levels of several hormones regulating metabolism. Tremblay, Poehlman, Després, Thériault, Danforth & Bouchard, 1997) coupled a training programme with a 244 MJ/day energy deficit for 93 days. This led to a 5 kg decrease of body mass in their subjects, almost entirely fat, and in response to this intervention they noted reduced circulating levels of noradrenaline and tri-iodothyronine. Likewise, Poehlman, Tremblay, Nadeau, Dussault, Thériault and Bouchard, (1986) observed decreases of insulin levels after 22 days of training with a negative energy balance of 4.2 MJ/day. Doucet, Imbeault, St. Pierre, Alméras, Mauriège, Després et al., (2003) commented further on the impact of altered leptin levels on the energy cost of a standardized treadmill exercise.

Some of these hormonal influences can be modified by dietary controls; for instance, catecholamine levels can be modified both by the intake of dietary sodium and by the catecholamine content of the diet (Nicholls, Kiowski, Zweifler, Julius, Schork, & Greenhouse, 1980).

Altered expenditures on leisure activity. The weight loss from a restricted diet may be less than anticipated because of reductions in the energy cost of performing normal daily activities, and in the volume of voluntary daily physical activity taken outside of any prescribed exercise programme.

Reduced energy cost of daily activities. The energy cost of displacing the body mass is almost inevitably decreased as body mass diminishes, and because movement also tends to become more efficient in a thinner person, the impact may even be greater than the immediate decrease in body mass might suggest.

Lazzer, Boirie, Mountaurier, Vernet, Meyer, and Vermorel (2004) found up to a 22% decrease in the energy cost of walking at the end of a 9 month programme that combined moderate dieting with aerobic training and resistance exercise. At the end of the 9-month intervention, a physical activity programme that had initially required an energy expenditure of 14.8 MJ/day could be performed for only 11.8 MJ/day. Likewise, Doucet et al. (2003) noted that an 11% decrease in body mass was associated with a decrease in the energy cost of treadmill walking, from an initial value of 17.3 kJ/min to 15.5 kJ/min.

The increased mechanical efficiency of movement cannot be countered by any devise of programming other than an increase in the volume of exercise that is prescribed. However, the effects of a decrease in fat mass can be minimized if a combination of dietary and exercise measures that seek to replace much of the fat that has been metabolized by an increased volume of lean tissue.

Adverse psychological changes and a resulting reduction in voluntary physical activity. A rigid restriction of diet can have a negative effect upon mood state, with a resulting reduction in the volume and/or intensity of voluntary physical activity.

Trials in 106 obese and overweight individuals showed adverse changes in cognitive function, the Profile of Mood States, the Beck depression scale and the Spielberger anxiety scale in response to the maintenance of a 4.2 MJ/day diet (Brinkworth, Buckley, Noakes, Clifton & Wilson, 2009). Kerksick, Thomas, Campbell, Taylor, Wilborn, Marcello et al. (2009) noted that the addition of exercise to a dietary programme substantially countered such issues, improving the individual's body image and overall quality of life.

Accurate measurements of diet-related changes in leisure activity are challenging, but Martin, Hellbronn, De Jonge, DeLaney, Volaufova, Anton et al. (2007) compared a 25% dietary restriction (an energy intake of 3.7 MJ/day) with dieting (12.5% energy restriction) plus a planned 12.5% increase in energy expenditure. With dieting alone there was a decrease in the volume of daily physical activity, but this response was largely averted by the addition of exercise to the weight loss regimen.

Poor compliance with the prescribed dietary regimen. Sometimes, subjects have shown less than the expected decrease in body mass simply because they have failed to comply with the prescribed dietary regimen, and this problem has not been detected by the investigator.

Byrne, Wood, Schutz and Hills (2012) checked programme adherence by examining detailed attendance records for exercise classes and weekly consultations, as well as by monitoring urinary acetoacetic acid concentrations. However, few investigators have monitored programme adherence this closely, and often the amounts of food ingested by supposed dieters have been substantially greater than intended.

Adherence to exercise and dietary programmes. Whichever diet is chosen, the key to its effectiveness is creation of the intended energy deficit. Potential methods of assessing client compliance include food intake questionnaires, 3-day records of food intake, diary records of the exercise performed, programme adherence as reported in interviews, careful records of attendance at intervention sessions, determinations of energy intake based on the ingestion of doubly labeled water, and measurements of urinary ketones.

Long-term adherence is disappointingly poor, although there is some evidence that it is enhanced if dieting is supplemented by an element of exercise. Other possible methods of improving adherence include the setting of personal goals, motivational interviews, the provision of positive feedback and the reinforcement of goals that are met by an appropriate system of rewards. Electronic monitoring can play an important role in reducing the clerical burden of recording the details of energy intake and expenditures necessary to effective monitoring (Glanz, Murphy, Moylan, Evensen, & Curb, 2006; Sevick, Piraino, Sereika, Starrett, Bender, Bernadini, et al., 2005).

Attempts to implement excessively severe diets seem particularly likely to discourage adherence (Del Corral, Chandler-Laney, Casazza, Gower, & Hunter, 2009).

Probability of programme success. Successful weight reduction has been defined arbitrarily as an intentional loss of 10% of body weight that is maintained for at least one year (Wing & Phelan, 2005). Wing and Phelan chose the 10% criterion because a decrease in body mass of this magnitude was judged to carry clinically significant benefits in terms of future health.

Adherence to any dietary programme decreases steeply with time, in part because the client tires of feeling perpetually hungry, and in part because the intensity of the reinforcement provided by health professionals often wanes after a few months. In one study of a low fat diet, Acharya, Elci, Sereika, Music, Slyn, Turk and Burke (2009) found a class-session adherence of 56% at 6 months and 44% at 12 months. Half of their group continued to self-monitor at 6 months, but self-monitoring had dropped to 22% by 12 months. Adherence to the prescribed exercise peaked at 6 weeks, but diminished steadily thereafter. Further, only 22% were attaining the prescribed fat loss goal at 3 weeks, and this had dropped to 10% at 1 year. Moreover, the weight loss that was achieved (an average of 9.4% at 6 months) was closely associated with the client's programme adherence, a finding also emphasized by Holiis, Gullion and Stevens (2008).

The probability that an obese person will be successful in maintaining a normal body mass after dieting is extremely low (Kassirer & Angell, 1998). Stunkard and McLaren-Hume (1959) studied 100 obese individuals, finding that 2 years after treatment only 2% of the group had maintained a weight loss > 9.1 kg. Data for 76,704 obese men and 99,791 obese women in the U.K. (Fildes, Charlton, Rudisill, Littlejohns, Prvost, & Gulliford, 2015), likewise, showed that the respective annual probabilities of returning to a normal body mass were only 1 in 210 in men and 1 in 124 in women, and the figures for those with morbid obesity (1 in 1290, 1 in 677) were even more discouraging. Among the morbidly obese, even a 5% decrease in body mass was only achieved by 1 in 8 of the men and 1 in 7 of the women.

Other studies of deliberate weight loss programmes have shown slightly more encouraging results. One report found many subjects had achieved a 7-10 kg reduction of body mass at 6 months, with a continuing loss of >5 kg at one year (Wing & Phelan, 2005), Wing and Phelan followed dieters for 5 years, finding that 13-20% still maintained a 5 kg weight loss (Wing & Phelan, 2005). However, they also noted that only about 10% of clients recovered from even a minor (1-2 kg) relapse in their weight-loss plan. Although 96% of clients remained > 10 kg below their maximum lifetime weight, up to 20% became "weight cyclers," making repeated attempts to shed body fat with little long-term success.

There have been suggestions (Hill, 2004) that such "weight cycling" favours fat accumulation and has even more adverse effects on health than the initial weight gain; probable causes are an overshoot of lipogenic enzymes, triglycerides, and cholesterol levels (Kochan, Karbowska, & Swierczynski, 2006; Sea & Foing, 2000), although research on this topic has been hampered by lack of a clear definition of "weight cycling" (Jeffery, 1996). Blair, Shaten, Brownell, Collins and Lissner (1993) related the variability of an individual's weight to their health over a 3.8-year interval. The risk of all-cause death in the first quartile relative to the 4th quartile of weight variability was 1.64, and cardiovascular deaths and ischemic stroke deaths followed a similar pattern. French, Folsom, Jeffery, Zheng, Mink, & Baxter, (1997) carried out a similar analysis in 33,834 women aged 55-69 years. Over a 6-year follow up, the relative risk from the first to the fourth quarter of weight variability was increased for a number of chronic conditions, including myocardial infarction (2.01), stroke (1.61), diabetes mellitus (1.42), lung cancer (1.72) and hip fractures (1.45).

Practical methods of improving adherence. The U.S. National Weight Control Registry evaluated individuals who had been successful in losing an average of 33 kg, and had maintained this weight loss for at least 5 years. Factors associated with their success included initiation of regular exercise (~1 h/day), and several of the dietary options discussed in this review: adoption of a low calorie low fat diet, eating breakfast regularly, self-monitoring of body weight and maintaining a consistent eating patterns (Wing & Phelan, 2005).

Lemstra, Bird, Nwankwo, Rogers, and Moraros (2016) carried out a meta-analysis of 27 weight-loss programmes, looking at factors that had influenced adherence. The overall adherence rate was 60.5% (70% for <12 months, 53% for >12 months). In their study, the 3 most important variables modifying success were a close supervision of programme attendance (a rate ratio of 1.65 favouring such supervision), interventions that included social support (a rate ratio of 1.29 favouring those receiving social support), and the choice of dieting alone vs. exercise alone (a rate ratio of 1.27 favouring dieting alone versus exercise unsupported by dieting).

Some (but not all) investigators have found the inclusion of exercise classes into a weight-loss programme improved overall adherence to their programme. Del Corral et al. (2009) examined clients who had been prescribed a 3.2 kJ/day diet with or without 3 sessions/week of aerobic or resistance exercise. Despite provision of packaged food allowances and close monitoring by a dietician, adherence to the diet was only around 73%. Nevertheless, all 3 groups showed a 12.1 kg decrease of body mass, taking around 160 days to reach their target body mass index. Completion rates did not differ greatly between programmes, being seen in 35/51 of the diet only group, 46/88 of those prescribed diet plus aerobic exercise, and 61/88 of those treated by diet plus resistance training. Redman, Heilbronn, Martin, Alfonso, Smith, Ravussin, et al. (2007) also found little difference in adherence when dieting (a 25% reduction of food intake) was compared with dieting (a 12.5 % reduction of energy intake) plus exercise (a 12.5% increase of energy expenditures). Both groups showed a similar 10% decrease of body mass over 6 months, and there was little inter-group difference in the loss of lean tissue.

Racette, Schoeller, Kusher and Neil (1995) had obese women engage in diets designed to produce a 1 kg/week decrease of body mass. Some members of the group also undertook thrice weekly 45-minute exercise sessions at 65% of their maximal oxygen intake. Double-labeled water data showed that over a 12-week programme, the exercised group exceeded their prescribed food intake by only 0.7 MJ/day, but overeating was significantly greater (2.3 MJ/d ay) in those following only the dietary restriction protocol.

Kempen, Saris and Westerterp (1995) compared the effects of dieting (an energy intake of 4 MJ/day for 4 weeks, followed by 3.5 MJ/day for 4 weeks) with diet plus moderate exercise in a group of 20 healthy but obese women. The combined treatment induced a greater energy deficit, and a significantly greater fat loss than dieting alone (7.8 vs. 5.5 kg).

Conclusions. Although many dietary tactics have been proposed to enhance the effectiveness of weight loss initiatives, as yet the promise of benefits inferred from cross-sectional analyses of these various options remains to be confirmed by adequately powered and long-term randomized controlled trials. For the present, the best recommendation for the obese individual seems a well-balanced diet with a moderate reduction of energy intake and regular participation in a programme of moderate physical activity that includes elements of both aerobic and resistance exercise.

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Author's Qualifications

The author's qualifications are as follows: Roy J. Shephard, C.M., Ph.D., M.B.B.S., M.D. [Lond.], D.P.E., LL.D., D.Sc., FACSM, FCSEP, FFIMS, FAAPE.

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