Health & Fitness Journal
of Canada

Volume 12 December 30, 2019 Number 4

NARRATIVE REVIEW

What is the best diet to recommend when treating obesity? Part 1. Optimal eating patterns, sugar, and salt content.

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Abstract

Background. The objective of this narrative review is to examine empirical data on the optimal type of diet for individuals with established obesity who are being treated by an exercise-centred weight reduction programme. The first section of the review examines the influence of eating patterns and differences in the sugar and salt content of foods upon weight maintenance. A second section considers the choice between high-carbohydrate, high-fat and high-protein diets, and a third section explores issues of water and fibre intake, along with other possible dietary options for those attempting to reduce their weight. **Methods.** Information obtained from Ovid/Medline, PubMed and Google Scholar through to August 2019 has been supplemented by a search of the author's extensive personal files. **Results**. A person's immediate energy intake increases with the portion-size of foods that are offered, apparently without change of satiety, and the individual seems to make an incomplete subsequent adjustment for any resultant excess of food consumption. Epidemiological studies suggest that sweetness has some effect in increasing food intake, with heavier body weights being found in those who consume large amounts of sweetened foods or drinks, but in short-term experiments subjects compensate at least partially for the energy content of sweetened drinks and foods by reducing their food intake at a subsequent meal. The salt content of food also has some effect on appetite; more tests are needed looking at the salt content of fast foods, but in normal home cooking the appetite-stimulating effect of salt seems less than was once thought. In cross-sectional analyses, the practice of skipping breakfast and the frequent consumption of "fast" foods are often associated with difficulties of weight control, but this is probably because those with poor dietary habits have a limited interest in adopting any aspect of a healthy lifestyle. Fast foods have had little apparent influence on obesity in randomized controlled trials. Likewise, the practice of frequent snacking shows little relationship to obesity once allowance has been made for associated television watching and a low level of habitual physical activity. Cross-sectional comparisons suggest that the risk of obesity is lower in those who take more frequent meals per day, but again this could be an artifact of reverse causation, with obese individuals reducing the frequency of their meals in an attempt to lose weight. **Conclusions.** Public health measures to reduce the portion size and/or energy density of foods seem warranted. A small tax seems an effective method of reducing the consumption of sweetened drinks, but large changes in the salt content of food seem to have little impact upon the palatability of food. Many variations of eating habits have shown cross-sectional associations with problems of weight control, but it remains difficult to disentangle the influence of co-variates such as habitual physical activity, socio-economic status, and overall interest in a healthy lifestyle. Nevertheless, smaller portion sizes, a reduction of sugar and salt intake, and frequent regular meals seem good nutritional recommendations for those who are seeking to reduce their body weight. **Health & Fitness Journal of Canada 2019;12(4):15-57.**

https://doi.org/10.14288/hfjc.v12i4.285

Keywords: Fast Foods, Meal Frequency, Portion Size, Saltiness, Sweetness.

Introduction

Previous reviews published in this journal have concluded that dieting plays only a limited role in the long-term prevention of fat accumulation (Shephard, 2019 a, 2019 b). For health professionals who are concerned with the prevention of obesity in their clients, it thus makes more sense to encourage them to adopt a physically active lifestyle, a positive initiative that confers many health advantages in addition to reducing the risk of fat accumulation. A depressing programme that focuses upon dietary prohibitions seems unlikely to achieve any substantial or lasting health benefits (Shephard, 2019a, 2019b). However, the situation changes once a client has accumulated an excess of body fat. A severe restriction of food intake then achieves a greater reduction of body mass than that resulting from participation in an exercise programme without dietary restriction (Shephard, 2020). Nevertheless, if the intent is to reduce a client's weight substantially, an optimal response, both in terms of fat loss and the conservation of lean tissue, is obtained from a combination of moderate dieting and exercise therapy (Shephard, 2020).

The question arises what dietary recommendations can best complement a moderate exercise programme in clients who are seeking to reduce their body mass? The present review seeks answers to this issue. It is structured in three parts. The first section of the article examines the influence of eating patterns and the sugar and salt content of foods upon weight regulation. The second section considers the choice between diets high in carbohydrate, fat and protein, and the third section explores issues of water and fibre content, along with other possible dietary options.

A substantial change of eating behaviour occurred in North America from the late 1970s to the mid-1990s. During this period, the proportion of food eaten away from home increased greatly, and at the same time there were large increases in the fraction of energy obtained from salty snacks, soft drinks and pizza and large decreases in the energy obtained from milk, pork and beef (Nielsen, Riz, & Popkin, 2002). These changes are often alleged to have contributed substantially to the recent obesity epidemic, and they could also have reduced the overall quality of the diet for many North Americans. Cross-sectional comparisons abound, but there have been few formal randomized controlled evaluations of the impact of dietary change upon the prevalence of obesity. Specific issues to be considered in this regard include potential influences upon weight control of portion size, the sweetness and salt content of foods, the practice of skipping breakfast, a preference for fast foods, repeated snacking, and changes in the frequency of main meals.

The influence of portion size, and the sugar and salt content of food upon energy intake

Some nutritionists have accused the food industry of fostering obesity through a progressive and deliberate increase in the portion sizes and the energy content of both pre-prepared meals and servings at fast food restaurants (Aimiron-Rog, Tsiountsioura, & Lewis 2015; Livingstone & Pourshahidi, 2014; Nielsen & Popkin, 2003; Young & Nestle, 2002) (Table 1), and by marketing food products with an ever-increasing content of refined sugar and salt (Mozaffarian, Hao, & Rimm, 2011; Nielsen & Popkin, 2004; Pan & Hu 2011; Wang, Bleich , & Gortmaker, 2008).

Table 1: Typical changes in the portion size and energy content of food items served at U.S. fast-food restaurants and cinemas over the period from 1996 to 2016. Based on data from the web-site "Business Insider" (https://www.businessinsider.com/how-meals-have-grown-since-1996-portion-size-health-food-2016-4).

Food item	1996		2016		Increase in energy content (%)
	Size	Energy content (kJ)	Size	Energy content (kJ)	
Bagel	7.6 cm	0.58	15.2 cm	2.33	402
Muffin	42.6 g	0.87	113.5 g	2.08	240
Cheeseburger (average size)		1.39		2.45	176
Fries	68.1 g	0.87	195.8 g	2.54	282
Theatre popcorn	5 cups	1.12	1 tub	2.62	234
Soda	192 mL	0.65	591.4 mL	1.04	160

Certainly, such changes in nutritional practice have been substantial, and they have occurred in parallel with the recent obesity epidemic (Shephard, 2018), but a causal relationship has yet to be established.

In considering the health impact of secular changes in the portion size, sugar and salt content of foods, we will look at empirical data evaluating their influence upon daily energy intake, the mechanisms underlying any observed changes in appetite, and the potential public health implications of these findings.

Impact of changes in portion size upon food intake. It has proven difficult to establish a conclusive relationship between the secular growth in portion sizes and a resulting increase of food intake under free-living conditions. However, laboratory trials have shown that at least in the short-term, both young children (aged > 3 years) and adults consume more energy as portion sizes are increased (Ello-Martin, Ledikwe, & Rolls, 2005).

Empirical data. Four-year-old children ate 25% more if they were given an entrée that was twice their age-appropriate size (Orlet Fisher, Rolls, & Birch, 2003). Adults also estimated that they would serve and eat more food at any given sitting if it was presented to them in larger packages (Wansink, 1996). Rolls, Morris, and Roe (2002) observed that if portions were large, this increased the immediate food intake of adults, irrespective of the mode of serving or of subject characteristics. In one example, the increase was 30%, or 0.68 MJ per meal, and in another trial a change from 6-inch to 12-inch diameter sandwiches increased the immediate food intake by 31%, or 0.67 MJ in women and by 56%, or 1.49 MJ in men) (Rolls et al., 2004a) (Table 2). Likewise, observations in a cafeteria demonstrated that in a situation where pasta servings of differing size were priced similarly, the larger portions increased energy intake by 43% (Diliberti, Bordi, Conklin, Roe, & Rolls, 2004).

It remains to be proven how far the eating of a larger portion at any given meal modifies the longer-term energy intake of subjects, but some evidence suggests that compensation is incomplete. One trial found that there was little compensatory reduction of food intake

Table 2: Influence of sandwich size on immediate food intake in men and women. Based on data of Rolls, Roe, Meengs, & Wall (2004a).				
Sandwich size (inches)	Men (n = 38)		Women (n = 37)	
	Energy intake (mJ)	Percent eaten	Energy intake (mJ)	Percent eaten
6	2.64	95	2.14	77
8	3.34	89	2.50	66
10	3.82	82	2.58	53
12	4.12	76	2.80	59

over the ensuing two days (Rolls, Roe, & Meengs, 2006), and another study at a university cafeteria (Freedman & Brochado, 2010) found a decrease both in the consumption per individual diner and plate wastage when the content of individual bags of French fries was reduced progressively from 88 g to 44 g over a period of 3 weeks (Table 3).

Underlying mechanisms. Those participating in the various trials of portion size did not indicate any increase in feelings of "fullness" when they were given larger helping of food, suggesting that normal satiety signals were in some way over-ridden by a change in the size of servings. Possibly, humans have an inherent "unit bias," preferring to eat an entire portion of something, irrespective of its size (Geier, Rozin, & Doros, 2006). Children may have been conditioned to "clean their plates," and adults may be reluctant to waste food that they have already paid for. The American Cancer Research Institute noted that 69% of US adults reported eating their entire entrées in restaurants, irrespective of the size of the serving that they were given. Even the deliberate introduction of a stale taste did not limit an increase in the consumption of popcorn when cinema-goers were given a large rather than a small box of this snack (Wansink & Kim., 2005).

On the other hand, satiety could be achieved with a much smaller energy intake if meals were offered as low energy density servings of items such as fruit, salads and soups (Kral, Roe, & Rolls, 2004; Rolls, Roe, & Meengs, 2004b).

Potential public health counter-measures. Given evidence that portion size influences immediate food intake with at best only a partial subsequent adjustment of food consumption, a decrease of portion size seems a valuable public health measure. However, attempts to educate the public about the desirability of eating smaller portions of food have to date had limited success

Table 3: Influence of a progressive reduction in the size of French-fry bags in a university dining facility upon consumption and plate wastage. Based on data of Freedman & Brochado (2010).			
Week	Portion size (g)	Consumption per diner (g)	Plate waste (kg/day)
1	88	74.3	6.17
2	73	71.4	5.10
3	58	53.0	4.98
4	44	52.2	4.24

(Young & Nestle, 1995). Thus, preventive efforts could most effectively be concentrated on encouraging food manufacturers and distributors to offer individual portions of a more appropriate size (Ditschuneit & Flechtner-Mors, 2001; Noakes, Foster, Keogh, & Clifton, 2004; Wing & Jeffery, 2001) with an associated reduction in the energy density of the products that they are selling (Bell, Castellanos, Pelkman, Thorwart, & Rolls, 1998; Bell & Rolls, 2001; Stubbs, Johnstone, Hasbron, & Reid, 1998). A reduction of energy density seems a particularly promising approach; one trial found that over a 6-mointh period, the consumption of low energy density foods gave a 40% greater weight loss than that seen in subjects assigned to a traditional low fat diet (Ello-Martin, Roe, & Rolls, 2004).

Refined sugar content and food intake. Sweet foods have hedonic value, and the choice of foods tends to be influenced by perceptions of their sweetness. Many authors have argued that an excessive sugar content of foods contributes to over-eating and obesity, but this is less clearly established.

Contrary to the view of many epidemiologists, Anderson (1995) maintained that a high sugar and carbohydrate consumption were associated with leanness rather than obesity, and that the subsequent intake of food intake showed a compensatory decrease in response to the ingestion of 50 g or more of sugar. One factor predisposing to an association between the consumption of sugars and leanness could be the popularity of sugar-containing drinks among endurance athletes. Anderson further noted that in several surveys, the self-reported consumption of sugar was inversely related to an individual's risk of obesity, although this could simply in part the fallibility of such self-reports. He finally pointed to the absence of any differences in either sweetness detection threshold or sweetness preference in obese individuals (Grinker, Gropman-Rubin, & Bose, 1986).

Reports concerning the immediate impact of sweetness upon food intake remain conflicting. Rogers and Blundell (1989) observed that the consumption of saccharine-sweetened yogurt increased a person's hunger and food intake, whereas Drewnowski et al. (1994) found that the lunch-time intake of food was uninfluenced by its sweetness.

Empirical data. In a multiple regression analysis of data for 12,153 adults and children, Cox, Hendrie, Rebuli, & Barnes (2018) found that fatty mouth feel, saltiness and sweetness together accounted for some 56% of the variance in a person's immediate energy intake, but that the contributions of the sensations of sweetness and saltiness to the regression analysis were rather small relative to the fatty mouth feeling, with respective beta-weightings of 0.49, 0.16, and 0.14.

Longitudinal epidemiological data in general have demonstrated that the regular consumption of sweetened beverages is associated with the accumulation of body fat (Laverty, Magee. Montero, Saxena, & Millett, 2015; Morenga, Mallard, & Mann, 2012). A review of 30 trials and 38 cohort studies conducted through December 2011 found 5 reports of adults on *ad libitum* diets where a reduction in sugar intake for periods of 10 weeks to 8 months was associated with an average 0.80 kg decrease in body mass relative to controls. Conversely, in 10 studies, an increase of sugar intake, mostly over periods of 8 weeks or less, was associated with an 0.75 kg increase of body mass (Morenga et al., 2012). Eleven cohort studies also noted a positive association between reported sugar intake and obesity, as compared with only one study that saw a negative relationship.

Moreover, over a one-year follow-up the risk that children would become overweight or obese was increased 55% in those with the highest intake of sweetened beverages (Morenga et al., 2012), although the advice of health professionals to reduce the consumption of either sweetened drinks or all forms of sugar generally had little effect upon the dietary choices of the children. An analysis of secular trends in soft drink consumption across 75 countries pointed to the increased risk in adults, with a 20% increase in average soft-drink consumption between 1997 and 2014, and an associated 4.8% increase in the number of overweight adults for each 1% increase in soft drink consumption (Basu, McKee, Galea, & Stuckler, 2013).

However, individual short-term experiments have shown a less clear relationship between an individual's sweetened drink consumption and energy intake. King, Appleton, Rogers, & Blundell (1999) argued that compensation for the energy content of a sugary drink was particularly complete following a bout of vigorous aerobic exercise (50 minutes of activity at 70% of maximal oxygen intake). Their 16 subjects drank water, a sugar-containing drink or an artificially sweetened drink, and their intake of a test meal was subsequently monitored. Ingestion of the test meal relative to those drinking the aspartame beverage was reduced by an amount that almost exactly matched the energy content of the sweetened drink, to give a similar total energy intake; however, the sample size was insufficient to give a clear answer, since the intake of the test meal was also reduced simply by drinking water (Table 4).

Lawton, Delargy, Smith, Hamilton, & Blundell (1998) examined the consumption of snacks in 36 normal-weight habitual snackers. The subjects were offered four snack options, high versus low-fat and sweet versus non-sweet. The largest snack energy intake was seen with the high-fat-sweet combination (3.21 MJ/day), and the lowest intake with the low-fat-unsweetened option (1.63 MJ/day). However, the main impact of eating the snacks was upon the percentage of fat that was consumed; none of the snack options had any great longer-term impact upon the total energy intake (snacks plus other forms of food) over the 2 days of monitoring.

Lavin, French, & Read (1997) examined

Table 4: Energy intake from a test meal after aerobic exercise and the drinking of either water, a sugar-containing drink, or an artificially sweetened drink. Based on data of King (1999).

Variable	Water	Sugar drink	Aspartame drink
Exercise energy expenditure (MJ)	2.44	2.46	2.42
Weight of drink (kg)	0.46	0.58	0.62
Energy from drink (MJ)	0	0.97	0.05
Test meal intake (MJ)	5.68	5.57	6.36
Drink + Meal (MJ)	5.68	6.54	6.41

the effects of three drinks (carbonated mineral water, sucrose-sweetened lemonade, and aspartame-sweetened lemonade) upon appetite and energy intake in 14 women who were classed as moderately restrained eaters. Reported appetite ratings did not differ between the 3 drink options, but food intake was greater after drinking the aspartame-sweetened lemonade than after the sucrose-sweetened drink (where a decrease in other food intake compensated completely for the energy content of the drink). Over two days of monitoring, the total energy intakes were 19.8 MJ (water), 18.8 MJ (sucrose drink) and 22.5 MJ (aspartame-sweetened drink).

Maersk et al. (2012) compared changes in appetite and energy intake following the ingestion of 4 beverages (semi-skimmed milk, sugar-sweetened and aspartame-sweetened colas, and water) in 24 obese adults. The skimmed milk option induced greater feelings of fullness and reduced feelings of hunger relative to the regular cola. The energy intake over a 4-hour period was greater after the milk and regular cola than after the diet cola or water, due largely to the substantial energy content of the first two drinks (0.95, 0.90 MJ), with respective totals of 5.60, 5.73, 5.00 and 4.79 MJ.

Mattes (1990) conducted an experiment where the taste and energy content of cereal dishes were closely matched, and a half of their 24 subjects were aware of what they were being served. Over 5 days, neither sugar- nor aspartame-sweetened cereal significantly affected reports of hunger, energy intake or the subsequent selection of other foods relative to a dish of unsweetened cereal, although the individual's total energy intake was affected by beliefs about the energy content of the cereal that they were given.

Piernas, Tate, Wang, & Popkin (2013) examined whether dietary choices and energy intakes were altered when a substantial group of 210 adults replaced energy-containing beverages with either water or diet drinks for a period of 6 months. Both water and the diet beverages reduced the intake of energy, both in the form of drinks (by 0.20 and 0.43 MJ/day) and also as food (by 0.34 and 0.43 MJ/day). However, no evidence was found that aspartame stimulated a desire for sweet foods or beverages.

Raben, Vasilaras, Møller, & Astrup (2002) compared the influence of a substantial intake of sucrose or artificial sweeteners in a sample of 41 overweight men and women. Those receiving the sucrose supplements (to 28% sucrose, 1.6 MJ/day) gained a substantial amount of weight (~1.5 kg) over the 10-week trial, whereas those receiving the artificial sweeteners showed a small decline in body mass. A further analysis of this same data set (Sørensen, Vasilaras, Astrup, & Raben, 2014) confirmed that the gain of weight in those receiving the sucrose supplements was due to an increased daily energy intake rather than a decrease of energy expenditure, and this group of subjects also reported higher ratings for the prospect of future food consumption.

Reid, Hammersley, & Duffy (2010) added sugar (1.8 MJ/day) or aspartame drinks to the diet of 53 overweight women for 4 weeks. There were no changes of mood or hunger, and the women in this study appear to have compensated for the added sucrose by reducing their voluntary food intake.

Van Wymelbeke, Béridot-Thérond, de la Guéronnière, and Fantino (2004) compared responses between 2 L of a sugar containing drink (with an energy content of 3.3 MJ), and an artificially-sweetened drink, both flavoured with essences of either orange or raspberry. The sugar-containing drink induced a positive energy balance, and there was no adaptive reduction in the intake of other foods over daily administration of the drink for one month.

Woodend and Anderson (2001) compared the appetite-suppressing properties of sugasucrose with that of safflower oil in normal weight young men, looking at analogue-ratings of appetite for the following hour, and measuring food intake at one hour. The sucrose produced a dose-dependent decrease of appetite, and the largest dose (1.25 MJ) decreased food intake by 1.13 MJ relative to a water control, whereas the largest dose of safflower oil only reduced food intake by 0.48 MJ.

Four of the 10 short-term reports that are cited thus show sugar content as increasing total daily energy intake. However, a recent systematic review (Thornhill, Charlton, Probst, & Neale, 2019) concluded that sugar consumption in general did not increase the subsequent energy intake of overweight and obese individuals (9 studies). Nor did it influence satiety (12 studies) or ghrelin levels (4 studies), although there was some increase of leptin levels (3 studies). A European workshop held in 2017 (Wittekind et al., 2018) also found no evidence that sweetness increased immediate dietary intake.

Underlying mechanisms. Many studies have focused on the potential adverse effects of sweetened beverages. There have been suggestions that compensatory satiety and regulatory mechanisms are less effective when an excess of energy is ingested in liquid form (DiMeglio & Mattes, 2000), a finding that this laboratory confirmed in a meta-analysis of 42 studies (Mattes, 1996). Possibly, the mastication of food may augment feelings of satiety. Furthermore, fluids tend to empty from the stomach more rapidly than solids, thus limiting the input from gastric and duodenal satiety sensors. Cognitive influences may also be involved.

Sweet-tasting foods seem able to overwhelm normal regulatory mechanisms (Erlanson-Albertson, 2005). The sweetness of food may encourage over-eating by changing levels of dopamine, serotonin and endogenous opioids (Bellisle & Drewnowski, 2007). Sweetness also modulates cortisol reactivity, thus tending to relieve stress (Epel, Lapidus, McEwen, & Brownell, 2001). Further, the fructose component of sugars may increase blood levels of uric acid ((Johnson et al., 2009), a substance that has been identified as an important and independent predictor of obesity (Johnson et al., 2007). Fructose appears to increase the deposition of fat in the liver and viscera, independently of any increase in body mass (Silbernagel et al., 2011).

Potential public health counter-measures. The preferred sweetness of foods is largely a matter of habit, and after consuming dishes with a low sugar content for some months, a person may perceive very sweet foods as too sweet. In terms of practical commercial regulatory measures, one report estimated that the introduction of a cap-and-trade policy for the sweetening of beverages could reduce the prevalence of obesity by about 2.4% over 20 years (Basu & Lewis, 2014). Others have suggested that a penny per ounce tax on the sugar content of beverages might provide a sufficient incentive to reduce consumer demand for sweetened beverages by as much as 24% (Andreyava, Chaloupka, & Brownell, 2011). One year after the implementation of a sugar tax in a relatively wealthy Californian county, a significant decrease in the sales of sweetened beverages was observed (Silver et al., 2017).

Some artificial sweeteners, such as aspartame, have a sweetening power that is 100-200 times greater than that of sucrose. The replacement of refined sugar by such artificial sweeteners was thus thought to be a simple method of reducing energy intake in those who were overweight. This approach greatly reduces the energy density of soft drinks, but it has a much smaller effect on the energy density of solid foods. In practice, artificial sweeteners do not necessarily reduce the excessive consumption of soft drinks, nor do they always reverse the associated accumulation of body fat. Indeed, some investigators have suggested their very sweetness stimulates expectations of food, thus increasing rather than decreasing energy intake and obesity (Bellisle & Drewnowski, 2007). One large-scale epidemiologic study of 13,170 British children (Table 5) found that increases of BMI and body fat content between 7 and 11 years of age were correlated with the consumption of both naturally and artificially sweetened beverages at the age of 11 years (Laverty et al., 2015). In contrast, smaller randomized controlled trials have suggested that the use of artificial sweeteners can lead to a modest decrease of body mass (De La Hunty, Gibson, & Ashwell, 2006). A recent review (Rogers, 2018) noted that there have been 3 potential criticisms of the use of artificial sweeteners, all of which (in the opinion of the reviewer) have now been disproven: (1) they disrupt the learned control of energy intake, creating a "sweetness confusion," (2) the exposure to sweetness increases the desire for sweetened foods, and (3) a person's knowledge that their energy intake has been reduced by the use of artificial sweeteners may encourage their subsequent compensatory over-eating.

Table 5: Influence of daily consumption of naturally or artificially-sweetened drinks on gains of BMI between ages 7 and 11 years. Based on data of Laverty et al. (2015)

Type of drink consumed	Gain of BMI (kg/m^2)	Gain of body fat (%)
Natural sugar	0.22	0.57
Artificial sweetener	0.17	0.35

Summary. Despite repeated demonstration of epidemiological correlations between weight gain and the consumption of sweetened soft drinks, such an association is less clearly seen with short-term experimental modifications of diet. The lack of effect in experimental trials do not seem to be due to the testing of specific sub-groups of the population, since investigators have examined responses in both overweight and normal weight subjects. Possibly, compensation for the sugar content of beverages by a reduction in the intake of other types of food is less than perfect, and although little effect can be seen in short-term trials, over a period of several years a small imbalance is sufficient to cause a person to become obese. In many of the experimental trials, the amount of sugar intake has also been blinded by the use of control trials with artificial sweeteners, and this could have masked a cognitive response that can occur when a person knowingly ingests sugar on a frequent basis. However, the most likely explanation of the paradox seems an

Table 6: Secular trend in the salt intake of U.S. men and women aged 20-74 years, as seen in successive NHANES surveys. Based on the data of Briefel & Johnson (2004).

	Daily salt intake (mg)			
Survey Years	1971-74	1976-80	1988-94	1999-2000
Men	2780	3486	4288	4127
Women	1774	2278	2939	3002

impact of covariates in the epidemiological studies. Those who choose to avoid drinking sweetened soft drinks on a regular basis are a healthy segment of the general population, individuals who regulate many aspects of their food intake more carefully than the average person.

Salt content and intake of food. There has been a progressive increase of average daily salt intake among North Americans over the past few decades, due mainly to an increased salting of prepared cooked foods in an attempt to enhance their flavour (Table 6). The main adverse health effect of this change seems to have been an increase in the prevalence of hypertension rather than an increased prevalence of obesity. Nevertheless, there is some evidence that a rising salt intake could have contributed to the current epidemic of obesity.

A young child's liking for salty foods seems to be a learned behaviour, but once such learning has occurred the addition of salt to a meal increases the consumption of food (Liem, 2017). There seems a slight interaction between the temperature of a soup and its perceived saltiness; untrained observers rated chicken broth as less salty when it was served at 70° C or 80° C than when it was served at 40-60° C (Kim, Samant, Seo, & Seo, 2015).

Empirical data. Bolhuis, Lakemond, de Wijk, Luning, and de Graaf (2011, 2012) examined the impact of salt content on the volume of a creamy tomato soup ingested by 53 young normal weight males. Each subject was offered soup below and above a saltiness that they perceived as the most pleasant for them. Under a*d-libitum* conditions, soup ingestion was 9% lower for a high than for a low salt content. A longer oro-sensory experience also reduced soup intake, suggesting the advantage to dieters of eating slowly.

Cox, Perry, Moore, Vallis, & Mela (1999) compared 41 lean and 35 obese adults in terms of their food preferences, using 4-day weighed dietary records. There were no large sensory or hedonic differences in food choices, but those who were obese did seem to prefer salty/savoury items with a higher energy density.

Lucas, Riddell, Liem, Whitelock, and Keast (2011) served hashed-brown potatoes with salt concentrations ranging from 40 to 220 mg/100g. In a laboratory setting, the 220 mg serving was best liked, and this liking was correlated with its perceived salt content. However, when a meal was eaten in a normal dining room, the sodium content had no influence upon either the liking or consumption of the potatoes.

Rannou et al. (2018) assessed the acceptability of white and French breads of differing salt content (18 or 12g per loaf, 1.10 or 0.74% of dry weight) in 39 adults and 100 children aged 6-11 years. Differences in salt content were perceived by the adults, but not by the children. The children expressed a somewhat greater preference for the saltier breads, but this had no significant influence on their consumption.

Tourila-Ollikainen, Salovaara, & Kurkela (1985) examined the influence of the saltiness of both bread (over the range 0.8-2.0%) and butter (over the range 0-2.2%) on liking and consumption in 89 subjects. Bread spread with a high-salt butter was best-liked, but preferences for bread varied less with its saltiness. Over a 6-week period when low salt bread (1.0-1.2%) was being served, the offering of normally salted bread (1.5-2.0%) increased consumption. Thus, in only one of the 5 studies cited did salt content appear to have a positive effect upon food consumption. However, more trials are needed looking at "fast foods," where the salt content is particularly high.

Underlying mechanisms. The intensity of saltiness of a food apparently has a small effect on satiation, with a lower *ad libitum* intake of a high-salt than of a low-salt soup (Bolhuis et al., 2012). Possibly, an excessive salt content reduces the size of individual mouthfuls, thus increasing overall satiety for a given volume. Smaller mouthfuls could also affect the influence of food temperatures on perceived saltiness.

Public health implications. Recommendations for reducing the salt content of soup have ranged from 7 to 50% in different countries, but current research suggests that the salt content of many liquid and solid foods could be reduced substantially without having any great impact upon subjective preferences. Gonçalves et al. (2014) tested the effects of reducing the salt content of a vegetable soup by 30%. Elderly subjects who were living in a nursing home did not perceive any change in the saltiness of the soup, and neither they nor children who were attending a pre-school programme expressed any difference in perceived liking of the soup after the salt content had been reduced. It seems that quite large reductions in salt content have little impact upon the palatability of foods, and it is thus unlikely that any governmental regulation of the salt content of foods would contribute greatly to the control of obesity.

Other characteristics of food. There remains scope for careful exploration of many other sensory and non-sensory characteristics of food that could influence eating patterns; issues to be examined include appearance, taste, smell and texture (McKrickerd & Forde, 2016; Sørensen, Møller, Flint, Martens, & Raben, 2003). For many sensory features, palatability increases progressively with the intensity of the stimulus; it then reaches a peak, and declines if the intensity of stimulation is further increased (the Wundt effect). Food intake may also be modified by non-sensory factors, such as beliefs about the health value of a particular item (Pohjanheimo, 2010). There seems a specificity to satiety mechanisms, and food intake is greater if a variety of dishes are offered (Rolls et al., 1981; Sørensen et al., 2003).

Influence of the timing of meals on food intake

Those seeking to control their body weight have adopted various tactics in terms of altering the timing of their meals. Some dieters have decided to skip breakfast, taking only two large meals per day rather than eating several smaller meals, and others have sought to avoid the purchase of fast foods or snacking between meals. There have been many cross-sectional studies of each of these practices, and some associations with obesity have been described, but it has been less clear whether a particular dietary pattern was the cause of fat accumulation, or whether it was simply serving as a marker of some other feature of the person's lifestyle (Chen et al., 2014; Keski-Rahkonen, Kaprio, Rissanen, Virkkunen, & Rose, 2003, Reeves et al., 2013).

Skipping breakfast

Failing to eat breakfast may occur deliberately, in an attempt to reduce body weight, but it may also reflect failure of the children and/or the parents to wake in adequate time for school or work, and (in some North American urban studies) household poverty. We will look at the frequency of skipping breakfast, and at systematic reviews and individual studies of the impact of this behaviour upon body mass and other aspects of long-term health.

Frequency of skipping breakfast. Brugman, Mulmeester, Spee-Van der Wekke, and Verloove-Vanhorick, (1998) studied 4377 Dutch children and adolescents aged 4-15 years. During the primary school years, only 5% of these students skipped breakfast, but in secondary school the percentage had increased to 13%, with a 73% greater risk of skipping breakfast in girls than in boys. Figures were similar for Australian adolescents, with 12% of 13-year-old students skipping breakfast (Shaw, 1998).

In North America, an analysis of NHANES data from 1971-74 to 2009-2010 showed that in women aged 20-74 years, the fraction of daily energy needs derived from snacks increased from 18% to 23%, and trends for men were similar (Kant & Graubard, 2015). In terms of reversing these trends, Giovannini et al. (2008) argued the importance of parents modeling breakfast habits for their offspring from an early age, teaching good patterns of dietary behaviour that could persist into adult life.

Systematic reviews. Irrespective of the motivations of either children or adults who skip breakfast, many systematic reviews have pointed to positive cross-sectional associations between the eating of breakfast in any form, the consumption of ready-to-eat-cereals and the likelihood of conserving both a healthy body weight and other markers of good overall health.

De La Hunty and Ashwell (2007) saw such relationships in 4 studies of children and 5 studies of adults. However, they thought it likely that undetected lifestyle covariates were responsible, since they found no evidence that the breakfast eaters exercised more or had a lower total daily energy intake than those who skipped the first meal of the day. In a more exhaustive meta-analysis of 88 observational studies (many in children or adolescents rather than in adults), Brown, Bohan-Brown, & Allison (2013) found that the pooled odds ratio for obesity was 1.55 in those who did not eat breakfast. However, the authors of this report noted that a funnel plot suggested some bias towards a publication of papers linking obesity and the skipping of breakfast, and they further underlined that many of the published reports had wrongly implied that a causal relationship had been established. Another review (Rampersaud, Pereira, Girard, Adams, & Metzl, 2005) also found that many of 16 studies of children and adolescents had reported an association between skipping breakfast and being overweight; the breakfast eaters tended to eat more than the "skippers," but (probably because they also tended to have a higher daily energy expenditure), they were less likely to be overweight. A further systematic review, based on data for European children (Szajewskia & Ruszczyński, 2010) once again found that in 13 of 16 studies, mainly observational, eating breakfast was associated with protection against becoming overweight. In contrast, two reviews that were restricted to randomized controlled trials concluded that habitually skipping breakfast did not have any large impact on body mass (Dhurandhar, 2016; McCrory, 2014), although there was some suggestion in the data that missing breakfast might have a detrimental effect upon insulin sensitivity (Dhurandhar, 2016). In support of this last suggestion, Mekary, Giovannucci, Willett, van Dam, and Hu (2012) concluded that skipping breakfast was associated with an increased risk of type diabetes mellitus in adult men.

Several reports have linked the skipping of breakfast to other types of adverse health behaviour. A survey of 310 grade 10 students in southern Ontario (Cohen, Evers, Manske, & Bercovitz, 2003) found that as few as 49% of boys and 36% of girls ate breakfast regularly. In this sample, the regular eating of breakfast was associated with a greater level of habitual physical activity and a reduced likelihood of smoking. In girls, the skipping of breakfast was associated with a fear of gaining weight. A further study of 44,861 Canadian children in grades 9-12 (Patte & Leatherdale, 2017) found that skipping breakfast was related to alcohol use and binge drinking. In a sample of 877 British adolescents, Corder et al. (2011) found no association between skipping breakfast and accelerometer measurements of habitual physical activity in boys, but the girls who skipped breakfast were physically less active than their peers, particularly during the mornings. Eating breakfast regularly was also associated with better school attendance, a greater memory capacity and higher school grades (Rampersaud et al., 2005).

Individual studies. Focusing upon individual reports (Table 7), the immediate response to the skipping of breakfast appears to differ between individuals who normally eat breakfast and those who habitually skip this meal. Thus, Thomas, Higgins, Bessesen, McNair, and Cornier (2015) found that the adverse changes in insulin and free fatty acid concentrations induced by missing the first meal of the day were greater in those who normally ate breakfast than in those who did not. The effects of eating breakfast are also often confounded with the influence of an increased fibre intake, since cereal is a typical component of breakfast in most North American households.

Affenito et al. (2005) reviewed data for 2379 U.S. girls initially aged 9-10 years who were followed for 10 years. The proportion of the sample that ate breakfast regularly decreased as the students progressed through adolescence. Regular breakfast eating was positively correlated with the child's calcium and fibre intake, and it was also negatively correlated with BMI (although the relationship with BMI disappeared after data were co-varied for inter-individual differences in habitual physical activity and energy intake).

Table. 7: The influence of eating breakfast upon the maintenance of a healthy body weight.			
Author	**Subjects**	**Findings**	**Comments**
Affenito et al. (2005)	2379 U.S. girls initially aged 9-190 yr, followed 10 yr	Eating breakfast positively associated with calcium and fibre intake, neg. association with BMI	Relation to BMI disappears after co-varying for activity & energy intake
Albertson et al. (2003)	2000 US households, children4-12 yr	Children with top tertile of cereal servings had lower BMI(16.7 kg/m^2) vs. lowest tertile (19.3 kg/m^2)	Top tertile also ate less fat, greater intake of many micro-nutrients
Astbury et al. (2011)	12 healthy young men, normally breakfast eaters	Missing of breakfast- 150 min later, fullness reduced, appetite increased, food intake increased ¡7%	
Barr et al. (2016)	12,337 Canadian adults	No relationship between breakfast eating and BMI or overweight/obesity	Representative sample
Barton et al. (2005)	2379 girls aged 9-19 yr	Girls eating cereal breakfast on 3/3 days had lower BMI than those skipping breakfast	Similar trend for girls eating breakfast on 3/3 days vs. those who did not
Bellisle et al. (1998)	339 French children aged 7-12 yr	Obese children ate less breakfast, mate meals later in day	Is obesity associated with disturbed metabolic or behavioral cycles?
Berkey et al. (2003)	14,000 children initially aged 9-14 yr, 3 yr follow-up	Overweight children who skipped breakfast sometimes reduced BMI, but not true for those with initially normal BMI	
Betts et al. (2014)	33 lean adults aged 21-60 yr	No breakfast for 6 weeks- no change of weight or body fat, but less morning physical activity matching lower food intake	Randomized controlled trial
Cho et al. (2003)	16,000 US adults aged > 18yr	Cereal or quick bread breakfast eaters had lower BMI than those skipping breakfast	Breakfast skippers had lower daily energy intake
Chowdhury et al. (2016)	23 obese adults aged 21-60 yr	No breakfast for 6 weeks- no change of body weight or body fat, but less morning physical activity matching lower food intake	Randomized controlled trial
Clayton et al. (2015)	10 young men (breakfast eaters)	No breakfast reduces energy intake for day by 19%, 4.5% less work performed in evening exercise test	Subjects served as own controls
Fayat-Moore et al. (2016)	4487 Australian children aged 2 - 16 yr	Association seen between skipping breakfast and being overweight	Breakfast also gave more calcium and folate and less fat intake
Kosti et al. (2008)	2008 Greek children aged 12-17 yr	Consumption of breakfast cereal associated with lower BMI in both boys and girls	
Leidy & Racki (H. J. Leidy & A. M. 2010)	13 adolescents	High protein breakfast reduces appetite and energy intake at lunch vs. skipping or low protein breakfast	Breakfast increased satiety
Levitsky & Pacanowski (2013)	24 normal weight young adults	Skipping breakfast leads to 0.58 MJ greater lunch vs. 2.6 MJ carbohydrate breakfast.	Day's compensation for missing meal 1.7 MJ incomplete
Schlundt et al (1992)	52 moderately obese women	Eating breakfast increased weight loss during dieting programme by 1.7-2.7 kg	Reduced impulsive snacking
Song et al. (2005)	4218 US men & women > 19 yr	For women, odds of BMI >25 kg/m^2 0.76 in breakfast eaters, 0.70 for cereal eaters	No effect in men
Yoshimura et al. (2017)	20 young women, habitual breakfast eaters	Skipping breakfast increased lunch energy intake 0.54 MJ, reduced daily energy expenditure 0.23 MJ	Compensation did not exceed missed breakfast (2.3 MJ)

Albertson, Anderson, Crockett, and Goebel (2003) collected 14-day food records from 2000 US households, relating the BMI of children aged 4-12 years to their breakfast consumption of ready-to-eat cereals. Across all age groups, children who were in the top tertile of cereal consumption had a lower BMI than those who were in the lowest tertile, the average values for the two groups being a BMI of 16.7 versus 19.3 kg/m^2. Children in the top tertile also had a lower fat intake, and a greater intake of many micronutrients. Albertson et al. (2003) further suggested that the top tertile of cereal eaters had a greater calcium intake than their peers. Astbury, Taylor, and Macdonald (2011) found that in those who normally ate breakfast, 150 minutes after missing this, meal fullness ratings were lower, and the desire to eat and hunger ratings were greater than if a normal breakfast had been eaten. Moreover, the energy intake from a subsequent *ad-libitum* test meal was increased by 17%. Others, also, have noted a compensatory increase of food intake if breakfast is missed (Bellisle, Rolland-Cachera, Deheeger, & Guilloud-Bataille, 1988; Leidy & E. M. Racki, 2010; Nicklas, O'Neil, & Berenson, 1998).

Barr, DiFrancesco, and Fulgoni (2016) looked at the consumption of breakfast and its composition in a nationally representative sample of 12,377 adults participating in the Canadian Community Health Survey 2.2. This study found no consistent association between either breakfast or cereal consumption and the prevalence of overweight and obesity in survey participants.

Barton et al. (2005) studied the relationship between breakfast eating and BMI in 2379 girls aged 9-19 years. Those eating cereal on all 3 of the 3 test days had a lower BMI than those skipping breakfast, and a similar trend was seen for those who ate any type of breakfast on 3/3 days versus those who skipped breakfast. However, in terms of BMI, no benefit was seen from eating breakfast intermittently. The authors of this report suggested that consistent cereal eating my have served as a marker for a consistent intake of nutrient-rich foods and/or the following of a generally health lifestyle.

Bellisle et al. (1988) found an association between eating a smaller than normal breakfast and obesity in a sample of 338 French children aged 7-12 years. Obese students also ate more than their peers at lunch and at supper, and the authors of this report suggested that obesity may have arisen because of a disturbance of normal metabolic or behavioral rhythms.

Berkey et al. (2003) followed a sample of 14,000 U.S. children initially aged 9-14 years for 3 years. In those who were initially overweight, skipping breakfast was sometimes associated with a decrease of BMI over the 3 years, but this type of response was not seen in those who were initially of normal weight.

Betts et al. (2014) carried out a small-scale randomized controlled trial to test whether the relationship between skipping breakfast and obesity was causal. Thirty-three lean adults aged 21-60 years were assigned to either a 2.9 MJ breakfast or fasting until the noon hour for a period of 6 weeks. Tissue changes were assessed with dual x-ray absorptiometry, and no eventual inter-group differences of body mass or adiposity were observed. However, those eating breakfast regularly were physically more active than their peers during the mornings, spending 1.84 MJ/day of additional energy and largely compensating for their greater energy intake.

Chowdhury et al. (2016) completed a further randomized controlled trial on a group of 23 obese adults, maintaining a similar difference of morning routine between the two groups of subjects, and as in the lean individuals, they found that the eating of breakfast led to a greater level of physical activity in the mornings, although no significant inter-group differences of body weight or body fat content developed over the 6-week period of observation.

Cho et al. (2003) made a cross-sectional analysis of data from the NHANES III survey. In a sample of over 16,000 adults aged >18 years, those who ate cereals or quick breads for breakfast had a lower BMI than those who skipped breakfast, although people in the latter category reported a lower total daily energy intake.

Clayton et al. (2015) had 10 lean young men, habitual breakfast eaters, omit breakfast for one day. They tended to eat more for both lunch and supper on the day of the experiment, but nevertheless there was an overall 19% decrease in their energy intake for the day in question. At 5 p.m., they also performed 4.5% less total work during a voluntarily limited cycle ergometer test relative to their performance on a day when they had eaten a normal breakfast (300 vs. 314 kJ).

A cross-sectional analysis of data for 4487 Australian children aged 2-16 years (Fayat-Moore et al., 2016) found an association between skipping breakfast and being overweight, with the consumption of breakfast cereal showing a particularly marked association with protection against being overweight. Breakfast consumers also had a greater intake of calcium and folate, and a lower consumption of fat.

Kosti et al. (2008) examined the effects of a cereal breakfast in 2008 Greek children aged 12-17 years. Relative to their peers, they had a lower BMI, and were less likely to be obese.

Leidy and Racki (2010) compared the effects of a normal (18 g) and a protein rich (48 g) breakfast in 13 adolescents who normally skipped the first meal of the day. The normal meal did not modify appetite relative to skipping breakfast, but the high protein meal reduced appetite, and led to a lower energy intake at lunch-time. However, the energy intake for the entire day did not differ between treatments.

Levitsky and Pacanowski (2013) tested the effects of a carbohydrate breakfast (2.6 MJ) versus skipping breakfast in 24 normal weight young adults. On skipping breakfast, an 0.58 MJ larger lunch was selected, but compensation was incomplete, with a 1.7 MJ lesser food intake by the end of the day.

Schlundt et al. (1992) looked at the impact of eating breakfast in a randomized trial with 52 moderately obese women who were seeking to reduce their weight. The same total amount of food was ingested, whether it was taken as two or three meals per day, but over a 12-week trial those eating breakfast lost 1.7-2.7 kg more weight than those skipping breakfast.

Song et al. (2005) analyzed data for 4218 men and women aged >19 years who participated in the NHANES survey of 1999-2000. They observed that in women, the odds of a BMI >2k kg/m^2 were 0.76 for all who ate breakfast, and 0.70 for those who ate ready-to-eat breakfast cereals. However, no such association was seen in men. No reason was suggested for this sex difference.

Wyatt et al. (2002) noted that 96% of successful weight loss maintainers in the

National Weight Control Registry ate a normal breakfast.

Yoshimura et al. (2017) examined the effects of skipping breakfast in 20 young women who were normally breakfast eaters. When breakfast was omitted, the energy intake was increased by 0.54 MJ at lunch, and the daily physical activity was reduced by 0.23 MJ, but neither of these compensations fully adjusted for the loss of a 2.3 MJ breakfast.

Summary. In summary, cross-sectional analyses generally point to an association between the eating of breakfast (and particularly the eating of cereal) and protection against obesity. However, such a relationship is not seen in randomized controlled trials, suggesting that some unmeasured lifestyle covariate of breakfast eating is involved.

Obesity and the purchase of fast foods

We will look briefly at the characteristics of fast food and its place in North American diets before considering empirical evidence of its effects upon the risk of obesity.

Characteristics of fast foods. Fast food is purchased primarily by individuals who are unwilling or unable to wait for a meal to be prepared individually. In some cases, the meal is pre-cooked and simply reheated in a microwave oven, and in other cases mass-produced ingredients are deep-fried or grilled rapidly while a customer is in-line, and the food is then packaged either to be eaten hurriedly in the shop or taken home. One of the earliest fast foods meals was the English package of "fish and chips;" this has been available in London since the 1860s. It comprises a greasy serving of deep fried cod and a large helping of chipped potatoes, usually wrapped in newspaper, and it remains popular supper item in the United Kingdom to this day. More recent fast food offerings, such as the hamburgers and fried chicken of North America, tend to have a high content of saturated fat (often with undesirable levels of industrially-produced trans-fatty acids), sugar, salt and energy content.

The fat, sugar and salt content and the high energy density of most fast foods suggests that their regular consumption would predispose to the development of obesity. Prentice and Jebb (2003) underlined the high energy density of typical fast foods and pre-cooked supermarket meals. Values as high as 1.1-1.6 MJ/100g were noted, as compared with 0.45 MJ/100g in the food eaten by primitive societies, and the 0.67 MJ/100g found in traditional home-cooked British diets. Prentice and Jebb (2003) argued that such high energy densities tended to over-ride normal human appetite control mechanisms (which are based more on the bulk of food consumed than on its energy content). Thus, the total daily energy intake rose in close relationship to the energy density of the food that was eaten, a point further underlined by Stender, Dyerberg, and Astrup (2007).

There are many other nutritional arguments against the regular consumption of fast foods. In particular, Isganaitis and Lustig (2005) argued that the composition of fast food favoured the development of central insulin resistance, and Paeratakul et al. (2003) emphasized the adverse effect of fast food upon the overall daily intakes of key nutrients.

Twin-based studies suggest that the household environment experienced as an adolescent account for 8-10% of inter-individual differences in a person's consumption of fast foods (Nelson,

Table 8: Relationships between purchase of "fast foods" and obesity.

Author	Sample	Findings
Anderson et al. 2011)	4311 Michigan adults	Obesity correlated with frequency of eating fast food (24% if <1/wk, 33% if > 3/wk)
Andreyava et al. (2011)	11,820 U.S. children followed from kindergarten to Grade 8	Fast-food advertising association with obesity in overweight and obese children only
Bes-Rastrollo et al. (2006)	7194 adults, mean age 41 yr followed 28.5 months	Proxy of fast food (hamburgers, sausages, pizza) associated with greater weight gain
Boutelle et al. (2006)	902 middle-school & high-school adolescents	Fast-food purchases associated with weight status of parents but not of adolescents
Bowman et al. (2004)	6212 children aged 4-19 yr	Consumption of fast food gave poorer diet
Chou et al. (2005)	Estimate from previously published associations	Banning TV advertising of fast food would reduce obesity 11% if aged 3-11 yr, 12% if aged 12-18 yr.
Currie et al. (2009)	3 million US Grade 9 students, 3 million pregnant women	For adolescents, fast-food outlet within 0.1 miles increases prevalence of obesity 5.2%; for pregnant women, gain >20 kg if outlet within 0.5 miles
Davis and Carpenter (2009)	500,000 Californian adolescents	Fast-food outlet with 0.5 miles associated with 6% increase of overweight, 7% increase of obesity
Duffey et al. (2007)	3394 young adults followed 3 yr	Fast food intake linked to obesity cross-sectionally
Ebbeling et al. (2004)	26 overweight, 28 lean adolescents aged 13-17 yr	Overweight eat more fast food (7.69 vs. 6.07 MJ). fail to compensate by 1.70 MJ
Francis et al. (2009)	1185 Jamaicans aged 15-19 years	Odds of obesity 1.84 in those eating fast-food >3/wk
French et al. (2000)	891 women aged 20-45 yr	Use of fast-foods associated with higher energy & fat intake & greater body mass
Jeffery et al. (2006)	1033 Minnesota residents	Obesity unrelated to fast-food restaurant within 2-mile radius, but frequency of eating fast food was related to obesity.
Maddock (2004)	Obesity rates for 50 US States	Rates correlated with residents per fast-food restaurant and the square miles per fast-food restaurant.
Mohammadbeigi et al. (2018)	300 Iranian university students	Fast food consumption in past month related to waist/hip ratio (odds ratio 1.46), but not to BMI
Niemeier et al. (2006)	9919 adolescents followed 5 yr	Skipping breakfast and fast food consumption associated with weight gain
Pereira et al. (2005)	15-yr study of 3031 adults, initially aged 18-30 yr	Base-line intake of fast-foods related to weight gain & increased in insulin resistance
Rouhani et al. (2012)	140 adolescent Iranian girls	40% of top quartile of fast-food consumption overweight, 0% overweight in lowest quartile.
Schröder et al. (2007)	1491 Spanish men, 1563 women	BMI associated with fast food consumption in g/d and MJ/d
Thompson et al. (2006)	101 girls aged 8-12 yr followed to age 11 yr & 19 yr	Frequency of fast food at baseline positively associated with BMI z-score

Gordon-Larsen, North, & Adair, 2006). Studies by the U.S. Centers for Disease Control suggest that more than one in three Americans eat fast food on any given day; the typical fast-food eater is young, Afro-American, and with an above-average income.

Impact of fast foods upon weight control. Many reports suggest an adverse effect of fast food upon weight control

(Bowman, Gortmaker, Ebbeling, Pereira, & Ludwig, 2004; French, L. Harnack, & R. W. Jeffery, 2000; Paeratakul, Ferdinand, Champagne, Ryan, & Bray, 2003; Pereira et al., 2005 ; Prentice & Jebb, 2003) (Table 8). However, clear conclusions of causality are hampered by the use of cross-sectional designs, with many potentially influential intervening co-variates.

A review by Rosenbeck (2008) examined 16 studies, including 3 experimental investigations (2 feeding trials and one trial with some aspects of controlled randomization) (Ebbeling et al., 2004,2007; French et al., 2000). All of these reports, including the 3 experimental investigations, pointed to an association between the eating of fast foods, an increased daily energy intake, and resulting obesity.

Looking at individual studies, Anderson et al. (2011) analyzed data from the Michigan Behavioral Risk Factor survey of 2005. At that time, 80% of Michigan adults visited fast-food restaurants at least once per month, and 28% went more regularly (>twice per week). The prevalence of obesity increased with the frequency of eating at such establishments, from 24% among those eating there less than once per week to 33% if a fast-food outlet was patronized more than 3 times per week.

Andreyava et al. (2011) followed a nationally representative sample of 11,820 U.S. children from their enrolment in kindergarten (in 1998) till they reached grade 8 (2007). Their consumption of fast food ranged widely, from none during the last 7 days (28% of the sample) to daily (12% of study participants). The cumulative exposure of children to 100 television advertisements for fast food increased their consumption of such products by 1.1%. There was no detectable link between exposure to such television advertisements and average body weight, but the watching of fast food advertising was associated with BMI in overweight and obese children who were at or above the 85th percentile of the BMI recommended for their age.

A review of data for 902 middle- and high-school students and their parents (Boutelle et al., 2006) found that the purchase fast foods on a regular basis (at least 5 times per week) was associated with the frequent consumption of salty snacks and a low weekly intake of vegetables and milk. The parents of families consuming fast-foods regularly had a higher mean BMI than their peers, and were also more likely to be obese, but in this sample the adolescents themselves showed no associations between fast food consumption and obesity.

Bes-Rastrollo et al. (2006) followed a substantial population of 7194 Mediterranean adults drawn from Spain and the Canary Islands for a period of 28.5 months. The average initial age of the group was 41 years. A food frequency questionnaire was completed, with the eating of hamburgers, sausages and pizza considered as a proxy of "fast food" consumption. Such a diet was associated with a faster than average weight gain over the study period (a multi-variate odds ratio of 1.21).

Bowman et al. (2004) presented results for 6312 U.S. children aged 4-18 years. As many as 30% of this sample consumed some type of fast food on a typical day. This specific sub-group had a higher total daily energy intake (0.78 MJ/day) than their peers, consuming more sugar, carbohydrates and fat, eating less fruit and vegetables, and potentially increasing their risk of obesity.

Based on recently reported correlations between fast food advertising on TV and obesity, Chou et al. (2005) estimated that a ban on such advertising in the U.S. would reduce obesity by 10% in children aged 3-11 years, and by 12% in those aged 12-18 years. In Scandinavian countries (Sweden, Norway and Finland) such advertising is indeed now prohibited, in keeping with a recommendation from the World Health Organisation.

Currie et al. (2009) examined relationships between the proximity of fast-food restaurants and obesity in a sample of 3 million U.S. children and 3 million pregnant women. If a fast-food outlet was located within a tenth of a mile of a school, the prevalence of obesity in ninth-grade adolescents was 5.2% above the regional average, and if pregnant women lived within a half-mile of a fast food restaurant, they showed a weight gain >20 kilos during their pregnancy.

Davis and Carpenter (2009) also analyzed the relationship between distance separating schools from a fast food restaurants and obesity in a group of more than 500,000 Californian adolescents. The presence of a fast food outlet within 0.5 miles was associated with a 6% increase in the prevalence of overweight and a 7% increase in the prevalence of obesity, after controlling the data for several covariates, including ethnicity, town size and habitual physical activity.

Duffey et al. (2007) compared the effects of eating fast food with that of dining at a more formal restaurant in a 3-year study of 3394 young adults in the U.S.. In both cross-sectional and longitudinal analyses, fast food consumption was associated with a greater current weight and a greater gain over the 3 years than that seen in the restaurant diners.

Ebbeling et al. (2004) examined the extent of dietary compensation for eating a large fast food meal in 26 overweight and 28 lean adolescents living in the Boston area. The overweight students ate more of an *ad-libitum* laboratory serving of fast food than their peers (7.69 versus 6.07 MJ), and unlike the lean students they failed to compensate for their excessive intake later in the day, so that their total energy intake was increased by 1.70 MJ on the day that the fast food was offered to them. Overweight students also ate more than lean students under free-living conditions on days when the eating of fast-food was allowed. Moreover, it was not possible to manipulate the over-eating associated with the consumption of fast food by altering portion size or encouraging slower eating; it seemed that the inherent characteristics of fast food (a low fibre content, a high palatability, a high energy density and a high sugar content) predisposed to rapid and excessive eating (Ebbeling et al., 2007).

Francis et al. (2009) examined the correlates of obesity and a large waist circumference in 1185 Jamaican students aged 15-19 years. The odds of being overweight in those eating fast food more than 3 times per week was 1.84 greater than that of their peers who ate less fast food.

French et al. (2000) reported data for 891 women aged 20-45 years who were followed for 3 years. A half of this group received encouragement to eat more healthily. Some 21% of their sample ate fast food more than 3 times per week. The consumption of one such meal was associated with an increased intake of energy (0.23 MJ/day) and fat (0.6%/day). The frequent eaters of fast food also showed a greater 3-year gain in body mass (0.7 kg) relative to their peers, and changes in the frequency of eating at fast food restaurants induced corresponding changes in the body mass of study participants.

Contrary to other findings regarding the close proximity of a fast food outlet and diet, a survey of 1033 Minnesota residents (Jeffery et al., 2006) failed to find an association between the presence of such establishments within a 2-mile radius of study participants' homes and the likelihood of eating fast food. Richardson, Boone-Heinonen, Popkin, and Gordon-Larsen (2011) also failed to find an association between the availability of fast-food restaurant chain outlets within a 3 km radius and the weekly frequency of patronizing fast-food outlets by young adults. In the study of Jeffery et al. (2006), the frequency of patronizing fast food establishments was nevertheless associated with a higher BMI, the eating of less vegetables, and a lower level of habitual physical activity.

Maddock (2004) established significant correlations between the state-wide prevalence of obesity and both the number of residents per fast-food restaurant and the square miles served by each fast food restaurant. The failure of Jeffery et al. (2006) and of Richardson et al. (2011) to find such associations probably reflects the use of a broader definition of proximity than in studies where a relationship was seen.

Mohammadbeigi et al. (2018) looked at the relationship of fast food consumption to both general and abdominal obesity in a sample of 300 Iranian university students. Some 34% of the students had eaten at least one form of fast-food (which in their definition included sandwiches) during the previous week, and 72% had done so during the previous month. A relationship was established between the eating of fast food at least once in the past month and an index of abdominal obesity (the waist-hip ratio) (an odds ratio of 1.46), but the monthly eating of fast food showed no association with overall obesity, as indicated by the BMI (an odds ratio of 0.87).

Niemeier et al. (2006) examined data for successive waves of 9919 participants in the US adolescent health survey. Over a 5-year interval, there were increases in both the number of individuals skipping breakfast and the average number of days per week that fast food was eaten, and both practices were associated with a greater than average increases in body mass.

Pereira et al. (2005) conducted a 15-year study on 3031 U.S. adults initially aged 18-30 years. The initial frequency of fast food consumption and subsequent increases in fast food consumption were both associated with weight gain and the development of insulin resistance over the course of the study, after adjusting data for various covariates including age, level of education, smoking, alcohol consumption, habitual physical activity and television watching. Over the 15 years of observation, those visiting fast food establishments more than twice per week had a 4.5 kg greater increase of body mass, and a doubling of the increase in insulin resistance relative to their peers.

Rouhani et al. (2012) conducted a cross-sectional study of 140 Iranian adolescent girls. In this study, fast foods comprised convenience or prepared foods such as hamburger, sausage, cheeseburger, hot dogs, fish, poultry, and pizzas. Some 40% of students in the top quartile of fast food consumption (> 215 g/week) were overweight, compared with 0% in the lowest quartile (<52 g/week).

Schröder et al. (2007) collected data on a representative Spanish Mediterranean population of 1491 men and 1563 women aged 25-74 years. The consumption of fast food, (particularly more than once per week, and whether measured in grams per day or kJ per day) was associated with a poorer overall quality of nutrition, a greater energy intake, a higher BMI, and an increased risk of being obese.

Thompson et al. (2006) recruited 101 girls initially aged 8-12 years. They were followed to the age of 11-19 years. Frequent fast-food consumption (twice per week versus once or less) was associated with a substantial positive change in the BMI z-score over the period of observation.

Summary. In summary, almost all of 20 reports from various locations world-wide have shown an association between the patronizing of fast-food restaurants, an increased food intake, and an increased risk of obesity, but it remains difficult to establish how far socio-economic and lifestyle variables have contributed to the strength of this association. Although difficult to organize, the need is for randomized controlled studies of this question.

Snacking between meals and obesity

We will look here at trends in snack consumption in North America, the potential health consequences of increased snacking, and possible public health measures to reduce such a trend before documenting empirical findings on the relationship between snacking and obesity.

Trends in snack consumption. Snacks could include healthy items such as celery sticks, but less desirable commercial products have now become an ubiquitous feature of the North American retail landscape. Farley, Baker, Futrell, & Rice (2010) found that 41% of stores carried candy, sweetened soft drinks and/or salty snacks such as pretzels among their merchandise.

US National surveys have shown a marked increase in the average number of eating and snacking occasions taken by the average person between the late 1970s and the 1990s (Briefel & Johnson, 2004). The practice of free feeding rather than spaced and pre-scheduled meal times for infants has been suggested as one possible cause of this trend (Erlanson-Albertsson & Zetterström, 2005).

Zizza, Siega-Riz, and Popkin (2001) found the prevalence of snacking in adults aged 19-29 years had increased from 77% to 84% between 1977-78 and 1994-96, with snacking occasions growing from 1.7 to 1.9 times per day, the energy ingested with each snack rising from 1.03 to 1.31 MJ, the energy density of snacks growing from 4.37 to 5.49 kJ/g, and their contribution to daily energy intake rising from 20% to 23%.

Popkin and Duffey (2010) confirmed these various trends in an analysis of representative data for U.S. children and adults between 1977-78 and 2003-2006. They found that during this interval the average, time between episodes of eating had decreased by an hour in both children and adults, with final values of 3.0 and 3.5 hours, respectively. A study during the early 2000s estimated that up to 30% of a person's daily energy intake was being obtained through snacks (Briefel & Johnson, 2004), making a reduced consumption of such foods a potent target in efforts at weight reduction.

Potential health consequences. Snacking between meals has the potential to influence not only body weight, but also nutritional balance, because of the increased frequency of eating and the poor nutritional composition of most snacks. Many such foods are high in energy content, but low in nutrients. Nevertheless, some investigators have argued that certain types of snack can increase satiety, thereby reducing the intake of food at the next meal, and helping with the process of weight loss. In particular, positive value has been ascribed to snacks that are rich in protein and/or fibre, such as nuts, yogurt and prunes (Njike, Smith, Shuval, Edshteyn, Kalantari & Yaroch,, 2015).

Divergent conclusions have been reached about the health consequences of snacking because investigators have not always defined the nature of snacks (Gregori, Foltran, Ghidina, & Berchialla, 2011), nor have they allowed for the usual association between snacking and low levels of habitual physical activity. Often, snacking occurs when watching television, and food intake may then receive immediate reinforcement from advertising (Halford, Gillespie, Brown, Pontin, & Dovey, 2004). Moreover, television viewers often pay little attention to the quantity of food that they are consuming, particularly when they are engrossed in an interesting programme. Finally, some studies have examined effects in healthy individuals (where snacking can show a favourable association with effective weight control), and others have focused upon obese populations (where snacking is usually associated with an increased prevalence of obesity) (Bellisle, 2014).

Potential public health measures. In terms of reducing the consumption of undesirable commercial snacks, a study of 39 children (Goldfield & Epstein, 2002) demonstrated that when behavioural incentives were equal, commercial snacks were usually chosen in preference to fruit and vegetables. However, if incentives such as access to pleasant sedentary pursuits were made conditional upon choosing the fruit and vegetables, these became the preferred foods.

The use of chewing gum may also reduce the desire for snacks and sweets (Hetherington & Boyland, 2007). In a sample of 60 young adults, the provision of chewing gum reduced hunger in the 3 hours following lunch, and the intake of snacks was reduced marginally, from 0.44 to 0.40 MJ compared with a "no gum" condition.

Empirical data. A number of reports have examined the associations of snacking with obesity (Table 9). Bo et al. (2014) reported findings in 400 Italian children aged 11-13 years. They noted that the prevalence of overweight and obesity rose progressively with the percentage of the daily energy intake that a child obtained from snacking. Classing the intake of students as <15%, 15-20%, and >20%, respective prevalence of obesity were 10.4%, 14.4% and 20.5%. Estimates of the daily frequency of snacking and of the habit of snacking during the evening were also associated with an increased likelihood of developing obesity.

Colles et al. (2007) focused specifically upon children affected by the night eating syndrome, finding that this problem was more common in boys than in girls. It was

Table 9: Studies examining possible relationships between the habit of snacking and obesity.

Author	Sample	Finings	Comments
Bo et al. (2014)	400 Italian children, aged 11-13 years	Prevalence of overweight/obesity rose with % energy from snacks	Frequency of snacking and snacking in evening also related to obesity
Colles et al. (2007)	Bariatric surgery and weight loss groups, and general public	Night-eating syndrome associated with obesity	More common in boys than in girls
Field et al. (2004)	14,977 children aged 9-14 yr	Snack foods not important predictor of weight gain	Snacks had low nutritional value
Francis et al. (2003)	173 girls at 5, 7 and 9 yr	Girls who watched TV ate more snacks, consumed more fat, gained BMI over 4 yrs	Problems exacerbated by parental obesity
Keast et al. (2010)	Representative sample 5811 adolescents aged 12-18 yr	After co-varying for phys. activity, snackers less likely to become obese than peers	
McDonald et al. (2009)	3075 children aged 5-12 yr in Bogota, Colombia	Prevalence of excess weight 1.9 times greater if eating fast food once/wk. vs. none	Excess wt. also associated with maternal obesity & higher SES status
Nederkoorn et al. (2010)	74 normal weight Dutch female undergraduates followed 1 yr	Greatest weight gain with preference for snacks & weakest response inhibition	Average weight gain only 0.4 kg over year
Phillips et al. (2004)	196 girls aged 8-12 yr, followed to 4 yr post-menarche	Gains in BMI z-score little relation to snacking, except perhaps soft drink intake	Snacking associated with TV viewing
Ricketts (1997)	89 children aged 9-12 yr	Wt gain concentrated in children preferring high fat snacks	

associated with obesity, binge-eating and various psychological problems,

particularly depression.

Based on a 3-year study of 8203 girls and 6774 boys initially aged 9-14 years, all normal weight children of women involved in the Nurses Health Study, Field et al. (2004) concluded that although many snack foods had a low nutritional value, they were not an important independent predictor of weight gain in children and adolescents, after controlling the data for habitual physical activity and dieting status.

Francis et al. (2003) studied 173 girls at 5, 7 and 9 years of age. They noted that those who watched more television also consumed more snacks and had a higher fat intake, leading to an increase in their BMI over the 4 years of observation. Such associations were seen whether the families were obese or not, but problems were exacerbated by parental obesity.

Keast et al. (2010) classified a representative sample of 5811 U.S.

adolescents aged 12-18 years by the number of snacks eaten per day and by the contribution that these snacks made to their total daily energy intake. Physical activity was included as a covariate in a multivariate analysis. The data then showed that relative to adolescents who avoided snacking, the snackers were less rather than more likely to be overweight or obese, and were less likely to show abdominal obesity. The respective odds of overall and abdominal obesity ranged from 0.60 to 0.43 and 0.36 to 0.61 for those eating 2 snacks/day relative to those eating >4 snacks/day.

McDonald et al. (2009) studied 3075 children aged 5-12 years who were living in the city of Bogotá, Colombia; 11.1% of this sample was overweight and 1.8% was obese. An excess body mass was associated with a higher socio-economic status, maternal obesity and a snacking dietary pattern. The prevalence of excess weight was 1.93 times higher in those eating items such as hamburgers and hot-dogs at least once per week relative to children who avoided such foods.

Nederkoorn et al. (2010) evaluated weight gain in 74 female Dutch undergraduate students, initially of normal weight, over a one-year period. The average weight gain in this group was small (0.4 kg over the year). The greatest increase of BMI tended to be shown by those with the weakest response inhibition and a preference for snacks, although in a multiple regression analysis, beta-coefficients for these two characteristics were not statistically significant.

Phillips et al. (2004) followed 196 initially non-obese pre-menarcheal girls aged 8-12 years until 4 years post menarche. In this sample, an average of 2.3 servings per day of energy-rich snacks provided the children with 15.7% of their daily energy intake. Snacking was related to television viewing, but (with the possible exception of the consumption of soft drinks) any gains in BMI z-score over the 4 years bore no relationship to snacking.

Ricketts (1997) examined the preference for high- versus low-fat snacks in 88 children aged 9-12 years. Children who preferred the high-fat snacks had a higher energy intake than their peers, and triceps skin-fold thicknesses and BMI values were linked to a preference for the high-fat snacks.

Summary. Although a number of reports have found an association between snacking and weight gain, where allowance has been made for associated television watching and low levels of habitual physical activity, the association has been less evident. The main objection to most snacks seems to be their poor nutritional value, rather than their causation of weight gain.

Influence of number and timing of daily meals upon obesity

A final aspect of eating patterns that the dieter should consider is the ideal number and timing of daily meals. Skipping breakfast (above) is one possible variant of normal behaviour, but others have chosen to alter both the frequency and the timing of meals in an attempt to reduce the risk of obesity. One early report by Stunkard (1959) pointed to three characteristics of food consumption that he thought were typical of an obese person: night eating followed by morning anorexia, episodes of binge eating, and the absence of satiation after eating.

In animal studies, a reduction in the number of daily meals reduces body fat content and increases longevity, but findings on the health implications of meal frequency in humans are less certain (Mattson, 2005), in part because there have been few randomized controlled trials of this issue. One immediate variable confounding the cross-sectional study of meal frequency in humans is a substantial association between the extent of television viewing, the number of meals eaten and the amount of food consumed per day. The watching of television is commonly associated with snacking, particularly if the programme that is watched includes advertisements for food and drink. Thus, a study of 78 university undergraduates (Stroebele & de Castro, 2004) found that the number of meals eaten per day averaged 3.53 when food was eaten while watching television, as compared with 2.76 per day when the television was switched off.

We will look now at the findings from several systematic reviews and a number of individual empirical investigations.

Systematic reviews. A systematic review by Bellisle et al. (1997) found a number of papers that showed an inverse relationship between the frequency of meals and the prevalence of obesity in adults. However, the authors of this review concluded that the observed association could be an artifact, reflecting such factors as a reverse causation from dietary changes implemented by those who were already obese in an attempt to correct their weight gain.

There is no consistent evidence that dividing a meal into several packages alters the thermic effect of feeding, and the 24-hour energy expenditure does not seem to differ between people who nibble and those who gorge. Moreover, the extent of weight-loss when following a hypo-energetic regimen does not seem to be changed by altering meal frequency. If there are any differences associated with nibbling relative to gorging, these likely reflect simply differences in the individual's total food intake.

A second review focused on analyses in children and adolescents (Koletzko & Toschke, 2010). It found 5 relevant studies, all cross-sectional in type. In 3 of these, an increased meal frequency was associated with a reduced risk of obesity; moreover, the remaining 2 studies showed a similar but non-significant trend. An attenuation of endocrine responses by more frequent meals was suggested as one possible underlying mechanism, although the authors of this review acknowledged that the existence of a causal relationship had not been established.

A further meta-analysis of data for children and adolescents was completed by Kaisari, Yannakoulia, & Panagiotakos (2013). They included 10 cross-sectional analyses and one case-control study, covering a total sample of 18,849 children. Making a comparison between children with the highest and the lowest eating frequencies, they concluded that an odds ratio of 0.78 favoured ta lower body mass status in the most frequent eaters, with the association being seen more strongly in boys than in girls.

A more recent systematic review by Raynor et al. (2015) found no effect of eating frequency on food consumption in 8 of 13 reports, and no effect upon body fat content in 11 of 17 studies.

Individual empirical data. The findings from individual studies are summarized in Table 10. Cross-sectional data from a representative sample of 1655 Spanish adults aged 18-64 years (Aparicio et al., 2017) indicated that central obesity (as assessed in terms of the weight/height ratio) was less prevalent in those taking 4 or more meals per day (including mid-morning and mid-afternoon snacks providing some 15% of daily energy requirements) than in those who omitted mid-morning and afternoon snacks. Aparicio et al. (2017) suggested a lesser increase of fasting insulin values as a possible mechanism of benefit from more frequent eating. On average, the female members of this sample showed better eating patterns than the men, skipping fewer meals, taking more time over their meals, eating more fruit, vegetables and

Table 10: Influence of meal frequency upon obesity, as seen in cross-sectional studies.

Author	Sample	Findings	Comments
Aparicio et al. (2017)	1655 representative Spanish adults aged 18-64 yr	Weight/height ratio less in those taking 4 or more meals/day	lesser increase of fasting insulin if more meals. Women generally ate better than men
Berg et al. (2009)	3610 Swedish women aged 25-74 yr	Obesity threshold 30 kg/m^2	Obese women had odds ratios of skipping breakfast (1.41), omitting lunch (1.31), eating at night (1.62)
Bertéus Forslund et al. (2002)	83 obese Swedish women aged ~50 yr	Obese 6.1 meals/day, norms 5.2 meals/day	Obese also ate later in day and at night
Jååskkelåinen et al. (2013)	6247 Finnish 16-year-old adolescents	Logistic analysis shows odds of central obesity 0.41 (boys), 0.63 (girls) with 5 meals/day vs. 3 meals or less	Also favourable triglycerides, LDL cholesterol, blood pressure; low abdominal obesity (boys only)
Jennings et al. (2012)	1700 children aged 9-10 yr	One meal/day greater than average of 4.3/d: body mass -2.4%, BMI z-score -33%, waist circumf. -0.6%	Healthy weight also associated with greater habitual physical activity
Ma et al. (2003)	499 US adults aged 20-70 yr	Risk of obesity 0.55 if eating 4 or more meals/day	
Mota et al. (2008)	886 Portuguese adolescents aged 13-15 yr	Odds overweight/obesity 0.36 (boys), 0.51 (girls) if eat 4 meals/d vs. 3 or less	
Murakami and Livingstone (2015)	18,965 US adults aged > 20 yr	After adjusting for energy intake high vs. low frequency obesity odds 1.54 (M), 1.45 (F)	Unadjusted odds favoured high meal frequency,
Nicklas et al. (2003)	1562 10-year-old children	Weak and varied relationship	Only nutritional data from 24-hour dietary record
Ritchie (2012)	2372 US girls, initially 9-10 yr	10 yr follow-up- low meal frequency linked to BMI, waist circumf.	Association persisted after multivariate adjustments for lifestyle and socio-econ. factors
Toschke et al. (2005)	4370 German children aged 5-6 yr	Odds of obesity 0.71 (4 meals/d), 0.51 (5 or more meals/d)	Could not explain relationship by socio-economic or lifestyle variables
Zhang et al. (2018)	2290 Chinese adults aged 29-74 yr	Meal frequency unrelated to obesity	

cereals, and ingesting more energy in the morning than in the evening.

Berg et al. (2009) compared eating habits within a sample of 3610 Swedish women aged 25-74 years, distinguishing those with a BMI >30 kg/m^2 from those falling below this threshold. The obese women were more likely to report skipping breakfast (odds ratio 1.41), omitting lunch (odds ratio 1.31) and eating at night (odds ratio 1.62). They were also more likely to report taking large portion sizes during their main meals. There was no reported increase of total daily energy intake in the obese, although the authors cautioned that this may have been missed because of the tendency of the obese to under-report their food consumption.

A study of 83 obese Swedish women aged ~50 years (Bertéus Forslund, Lindroos, Sjöström, & Lissner, 2002) used a new questionnaire to evaluate meal frequency. In contrast to most previous reports, the findings with this new instrument suggested that the obese ate 6.1 meals per day (including light meals and snacks), as compared with 5.2 meals per day in a Swedish reference population. The new questionnaire indicated that women who were obese consumed all types of meals and snacks (excluding drinks) more frequently than women of normal body mass. The obese also tended to eat later in the day (afternoon, evening and night) when compared with women of normal body weight.

Logistic regressions were used to assess associations between obesity and meal patterns in a cohort of 6247 Finnish 16-year-old adolescents (Jååskkelåinen et al., 2013). After adjusting for potential adverse effects of early life influences, a five meal per day eating pattern (3 main meals and afternoon and evening snacks) was robustly associated with a reduced odds of central obesity (an odds ratio of 0.41 in boys, and 0.63 in girls) and was also linked to a lesser likelihood of abdominal obesity in boys (odds ratio 0.32) but not in girls. Further, frequent feeding was associated with favourable levels of triglycerides and LDL cholesterol, and a reduced likelihood of hypertension.

Jennings et al. (2012) reviewed data for 1700 children aged 9-10 years. They noted that after adjusting their results for an under-reporting of energy intake and habitual physical activity, an increase of one meal per day over the group average of 4,3 times per day was associated with favourable differences in body mass (-2.4%), BMI z-score (-33%) and waist circumference (-0.6%). An increased eating frequency was also associated with greater habitual physical activity in healthy weight but not in obese children.

Ma et al. (2003) examined relationships between meal frequency and the risk of obesity in 499 healthy U.S. adults aged 20-70 years. The risk was 0.55 in those eating four or meals per day relative to those eating 3 meals per day or less. Skipping breakfast seemed a particularly unwise practice, being associated with an odds ratio of 4.5 for obesity.

Mota et al. (2008) examined meal frequency in 886 Portuguese adolescents aged 13 -15 years. The proportion of overweight students was higher in those eating less than 3 meals per day, and the eating of at least 4 meals per day was associated with a reduced risk of being overweight or obese both in boys (odds ratio 0.36) and in girls (odds ratio 0.51) relative to those students who ate 3 meals or less per day.

Murakami and Livingstone (2015) analyzed cross-sectional data on meal frequency in 18,965 US adults aged >20 years who had participated in the NHANES 2003-2012 surveys. As in other reports, unadjusted data showed inverse or null associations between meal frequency and obesity, but after statistical adjustment for the ratio of energy intake to the estimated (but not measured) daily energy requirements, meal frequency was positively correlated with obesity. On comparing the highest versus the lowest meal frequency, the respective odds ratios for obesity were 1.54 in men and1.45 in women.

Nicklas et al. (2003) attempted to relate eating patterns to body mass in 1562 10-year-old children who were involved in the Bogalusa Heart Study. The only information on food intake was from a single day's dietary recall record, and perhaps for this reason associations with eating patterns were weak and varied with ethnic group.

Ritchie (2012) looked prospectively at the development of obesity in 2372 US girls, collecting data at the ages of 9-10 and 19-20 years. Low initial snack and total eating frequencies were associated with greater increases in BMI and waist circumferences over the 10-year interval. This effect persisted after adjusting data for baseline adiposity, race, level of parental education, habitual physical activity, television and video viewing, total energy intake and deliberate dieting with a view to reducing body mass.

In a study of 4370 German children aged 5-6 years, Toschke et al. (2005) established a consistent inverse cross-sectional relationship between the prevalence of obesity and the typical number of meals taken per day, with obesity odds ratios of 0.71 for 4 meals/day, and 0.51 for 5 or more meals per day. Multiple regression analyses demonstrated that the observed differences could not be explained by any of a wide range of lifestyle and socio-demographic factors, and the authors of this report suggested that an increased response of insulin and other regulatory hormones to larger but less frequent meals might be involved. A further paper from the same research group reported essentially similar findings (Toschke, Thorsteinsdottir, von Kries, & GME Study, 2009).

Data for 2290 Chinese adults aged 29-74 years (Zhang et al., 2018) failed to find any association between meal frequency and obesity after the data had been adjusted for socio-demographic and lifestyle variables. This analysis differed from many of the other reports in its classification of eating patterns. Comparisons were drawn between thrice daily eaters, night or all-day snackers, and irregular eaters). Findings were also adjusted for more covariates than in some studies.

Zimmerman, Johnson, & Brunsteom (2018) examined the effects of what was described as "chaotic" eating. They found no association between an individual's BMI and an irregular timing of meals.

Summary. In summary, most authors have found an inverse association between meal frequency and the risk of obesity at all ages from young childhood to older adults. All studies have been cross-sectional in type, but attempts to find lifestyle or socio-economic covariates that would explain the inverse association have been unsuccessful. Nevertheless, many of the reports cited have failed to ask about attempts to lose weight, and there thus remains a risk of reverse causation, with a low meal frequency being adopted by those who are currently obese and are attempting to reduce their body weight.

Discussion and conclusions

Young women frequently limit their intake of food in an attempt to become or to remain unusually thin. Such measures are particularly likely to be taken to excess by certain categories of athlete such as gymnasts and ballet dancers; they lead to anorexia nervosa (a syndrome first described by William Gull, in 1873 (Gull, 1997) and the female athletic triad (Gordon & LeBoff, 2014; Szmukler, Slade, Harris, Benton, & Russell, 2013). However, such practices have little relevance to members of the general population who are seeking to prevent or to correct established obesity by a combination of regular exercise and changes in their eating patterns. In the general population, initial reserves of fat are more than adequate, and changes in eating patterns are a potentially useful and important complement to programmes of exercise and dietary restriction. Practical options include reductions in portion size, decreases in the sweetness and saltiness of foods, avoiding the practice of skipping breakfast, reducing the intake of fast foods and snacks, and altering the daily frequency of main meals.

The immediate food intake of a person normally increases if he or she is offered a larger portion size; in childhood, this is probably because well-bred youngsters have been conditioned to always "clean their plates," and in adults who are visiting restaurants there may be a reluctance to waste food that has been purchased at a relatively high price. A longer-term adverse influence of large portions upon overall energy balance may be suspected, but it has yet to be demonstrated conclusively in free-living subjects. Some people seem to have an ability to make at least partial compensation for an excessively large meal. Nevertheless, it is probable that many people do not, and given the difficulty in educating the public about the wisdom of eating less, sensible public health measures would seem to encourage a reduction of portion sizes by food manufacturers and restaurateurs, and/or a decrease in the energy density of their wares.

Epidemiological studies have suggested that increases in the sweetness of food and snacks can encourage over-eating, but in short-term experiments subjects have often compensated for an immediate high sugar intake by reducing their subsequent consumption of other foods. Possibly, small errors in compensation remain, and although difficult to detect in short-term experiments, their impact can accumulate, giving rise to obesity if repeated many times over the course of several years. The salt content of food has less effect on appetite than was once thought, but nevertheless an excessive salt intake is undesirable, since it predisposes to hypertension. Certainly, there are unlikely to be adverse health effects if measures are taken to reduce the sugar and salt content of foods, and again such a change would seem an appropriate public health goal, likely with some beneficial consequences.

The habit of skipping breakfast is associated cross-sectionally with weight gain and problems in dieting, but it is difficult to determine how far covariates such as socio-economic class, the overall interest of a family in a healthy lifestyle and fibre intake are responsible for this finding, rather than the missing of breakfast itself. Cross-sectional analyses generally suggest that the regular eating of breakfast (particularly if it includes cereal) protects against obesity. However, no such a relationship is seen in randomized controlled trials, suggesting that lifestyle covariates are largely responsible for the observed association.

Many cross-sectional reports point to associations between the proximity of fast-food outlets and/or the frequency of eating fast-food and the development of obesity, but again there are strong intervening influences of socio-economic class and family lifestyle, and there are as yet few experimental studies pointing to the causality of this relationship.

The habit of frequent snacking shows an apparent relationship with the development of obesity, but much of this association disappears if due allowance is made for associated television watching and a low level of habitual physical activity among frequent snackers.

The taking of frequent meals (four or five per day) is associated with a reduced risk of obesity, but this could be an artifact of reversed causation, with those who are currently overweight or obese attempting to correct for this problem by reducing the frequency of their meals.

The issues reviewed here seem fundamental to advising the person who wishes to control and/or reduce their body weight, and it is disappointing that as yet so few concrete answers can be provided about optimal eating patterns. It is easy to seek inferences from cross-sectional associations, but conclusions from such research are severely limited by the difficulty in making appropriate allowance for important covariates. Evidence-based recommendations must await completion of the more difficult task of undertaking an adequate number of long-term randomized controlled trials.

Acknowledgements

The author acknowledges no funding relationships or other conflicts of interest.

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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