Literature Review

Setting the Record Straight – the role of carbohydrates in weight control

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Executive Summary

The effect of carbohydrate intake on metabolism and in the causation of overweight and obesity is a contentious area. The following statements do, however, reflect current knowledge:

1. The prevalence of overweight and obesity is increasing worldwide.

2. There is a genetic predisposition for obesity, which is evident when there is excess energy intake or a reduction in physical activity.

3. Two aspects of dietary intake appear to be important. - the total energy intake and the amount of fat in the diet.

4. There is no epidemiological evidence to suggest that high carbohydrate intakes are associated with increased prevalence of overweight and obesity, whilst there is some evidence to suggest that high fat intake, particularly because of increased energy intake, is associated with an increased prevalence of overweight and obesity.

5. The body is able to compensate, to some extent, for higher carbohydrate intake, but not for high fat intake. Increased carbohydrate intake produces an increase in carbohydrate oxidation in the body, whilst increased fat intake, particularly in the obese or post-obese, does not produce an increase in fat oxidation.

6. It is easier for the body to turn dietary fat into body fat than it is to turn dietary carbohydrate into body fat. Current scientific evidence supports the view that humans do not manufacture fat from other dietary components, rather they store the excess fat from the diet. In part this is due to the fact that protein, carbohydrate and alcohol are metabolised first, satisfying most of our energy needs, with fat providing some of our energy needs but mostly being stored as body fat.

7. Carbohydrates generally have a more satisfying effect on appetite than fat, and foods containing carbohydrate tend to be less energy dense. In contrast, foods containing fat tend to be more energy dense and promote over-consumption.

8. Carbohydrate intake is not associated with increased prevalence of Type II Diabetes or cardiovascular disease.

Background to the Review

For almost two decades Australians have been encouraged to eat more breads, cereals, fruits and vegetables for better health:
The Dietary Guidelines for Australians, of which there are eight, (1) - considered 'to represent the best consensus of scientific knowledge and public health advice currently available' – recommend '*Eat plenty of breads and cereals (preferably whole-grain), vegetables (including legumes) and fruits'.*
These recommendations are based on available evidence from epidemiological and clinical studies which show that diets high in plant foods – pulses, whole-grains, fruits and vegetables – are associated with a lower incidence of coronary heart disease and various cancers.

Eating more foods made from grains and pulses, together with more fruits and vegetables and less saturated fat, is widely recognised as a positive step towards better health. Foods like bread, cereals, noodles, pasta and beans provide the foundation for meals that are healthy and low in saturated fat, offering variety, convenience and great taste.
A healthy diet for adults should include a minimum of four serves of 'breads and cereals' each day (1 serve is 2 slices of bread, about $1^{1}/_{3}$ cups of breakfast cereal or one cup of cooked pasta/noodles/rice) (2).
Australians are making some changes to their diets, but for many people – especially women - there remains a gap between recommendations and practice. It appears from recent consumer research studies that the continuing misconception that high carbohydrate foods such as bread are 'fattening', may be partly responsible.
The potential benefits of a diet high in carbohydrates (especially starch and dietary fibre) for a healthy digestive system are well recognised. Consumer awareness of the potential benefits of carbohydrates in maintaining a healthy body weight and promoting weight loss is considerably lower.
To better understand the role of carbohydrate in weight control, Professor Ian Caterson has reviewed the current scientific literature. A summary of this review, prepared by Trish Griffiths, follows.

Introduction:

The prevalence of overweight and obesity is increasing throughout the world. While there may be, in some cases, a genetic component, the general increase in prevalence could be expected to be due to an environmental change since there has not been time for a major genetic change. What is this environmental change? Many people see the carbohydrates they eat as the cause for overweight and obesity. Is this general perception correct?
This review examines the available facts to see if carbohydrates (such as are found in grains and pulses, and simple sugars), are the cause of overweight and obesity.
The aims of this review therefore are:

1. To determine whether carbohydrates cause increased fat storage.

2. To determine if carbohydrate intake effects weight loss or weight maintenance.

This review deals specifically with energy intake and the components of that energy intake. It is acknowledged that these are not the only "problems" in the development of overweight and obesity - lack of physical activity also plays a major role. This review does not aim to address physical activity nor its effects on energy intake. A recent review of this latter topic is available in "Acting on Australia's Weight" [3].
Throughout this review, except where mentioned specifically, the term "carbohydrate(s)" refers to the carbohydrates found in grains and pulses (mostly starch and dietary fibre) and the term "sugar" refers to simple sugars (usually sucrose).
Note: Overweight and obesity are classified in terms of Body Mass Index (BMI = weight(Kg)/ height^2 (m)). A BMI of $\geq$ 30 is classified as obese, overweight is usually considered to be a BMI of 25-30. These values are arbitrary cut-off points along the spectrum of morbidity and mortality risk related to BMI.

Overweight and Obesity

Overweight and obesity occur when energy intake exceeds energy expenditure. It was once thought this was simply due to overindulgence in food, but it is now recognised that a complex mix of food intake, physical activity and genetics is involved [4]. Since fat and carbohydrates are the major energy sources in the diet it is not surprising that both have been extensively investigated in relation to the development of overweight and obesity.
Weight gain can result from a minor imbalance of energy intake over an extended period of time. In such instances, weight gain will be gradual and eventually weight will reach a new equilibrium (set point). Alternatively, it can be due to major imbalances in intake in short, but regular bursts. Energy balance can oscillate from meal to meal, day to day, week to week without major changes in body composition, demonstrating the human body's remarkable capacity for adjusting intake and expenditure. Important physiological mechanisms act to maintain a stable weight and body composition. These are extremely sensitive but seem to be more sensitive in resisting underweight than overweight [5].
In countries where food is in abundance it appears to be difficult for people to maintain an energy intake consistently below the body's energy requirements for any length of time. The causes of over-consumption, which are still controversial, are discussed to some extent throughout this paper.

The 'Size' of the Problem in Australia

Overweight and obesity have been increasing in both the developed and developing countries over the past couple of decades. In Australia, two out of every three men and one in two women are overweight or obese [20]. Preliminary studies in children show that the prevalence of overweight or obesity could be greater than 20% [3, 22].

The Cause of the Problem

Three factors - energy intake (diet), energy output (physical activity) and genetic predisposition are important in the development of overweight and obesity.

- ***Diet*** (energy intake) Two components of diet appear to be important:

  the total amount of energy eaten - if energy intake exceeds energy requirements, weight gain will occur, no matter what the composition of the diet.

  the composition of the diet - diets high in fat (no matter what type of fat this is) are associated with weight gain. This may be due to the fact that high fat foods tend to induce over-consumption (by increasing energy density, by creating a pleasant sensation in the mouth [13], or by a reduced metabolic response to fats).

- ***Activity*** (energy output): Despite the fact that populations around the world report eating less energy and fat [20], the prevalence of overweight and obesity continues to increase. It appears that a decrease in daily activity, at work and at leisure, is now a major cause of overweight and obesity [3, 21].

- ***Genes:*** Four single gene defects causing human obesity have been reported to date. These gene defects are associated with massive obesity and hypogonadism.

The Effect of Diet Composition

Metabolism of Macro-nutrients (Nutrient Partitioning)

The four macro-nutrients in our diet are carbohydrate, protein, fat and alcohol. Following digestion of food, these macro-nutrients will be either used for energy (oxidised) or stored. The human body oxidizes (metabolises) these 'fuels' in a preferential order (called an oxidation hierarchy) with alcohol being used first, followed by carbohydrate and protein, with fat being used last [4, 6]. The body's major storage tissue is adipose tissue (body fat).

This order of oxidation is dependent in part on the whether the macro-nutrient can be stored by the body. There is no capacity to store alcohol, which is, in fact, a toxin and must be removed. The body does this by oxidation. The storage capacity for protein and carbohydrates is limited, but the body has virtually unlimited ability to store fat in adipose tissue. Proteins have a specific function within the body and protein balance can be maintained over a wide range of intakes. Carbohydrate balance can be maintained through storage as glycogen (approximately 700g for an adult male [7]) or through oxidation. If carbohydrate is eaten in excess of energy requirements, a progressive increase in carbohydrate oxidation results [8]. In other words, the more carbohydrate eaten, the more the body uses. On the other hand, fat overfeeding has minimal effect on fat oxidation and much fat eaten is stored [9, 10]. Interestingly, lean subjects do appear to increase fat oxidation to some extent with an increased intake of fat, but obese subjects and women who have been obese previously [11] don't show the same increase [12]. This may be a genetic effect or an effect of obesity itself. This reduced induction of fat oxidation serves to perpetuate the obese state.

In situations where both carbohydrate and energy are eaten in excess, carbohydrate can be converted to fat, although this is energetically expensive. Such production of fat from carbohydrate is rare on a usual diet, but not impossible [14]. Production of fat from carbohydrate requires some 23% of the energy ingested compared with 3% of the energy intake when dietary fat is stored as fat. Typically, increased carbohydrate oxidation leads to a reduction in fat oxidation, which in turn results in increased fat storage. [8, 13, 15]. Fat synthesis from carbohydrate does occur in re-feeding after starvation or anorexia nervosa.

Do different diets of different composition lead to increased or decreased metabolic energy expenditure?
Many people who try to lose weight restrict or control their intake ("diet"). People who do this on a regular basis are called 'restrained eaters'. Paradoxically, restrained eaters are more likely to have a higher BMI than non-restrained eaters [16]. Restrained eaters were found to have significantly *lower* 24-hour metabolic energy expenditure on a high or a medium fat diet than on a low fat diet ie they are less likely to use up the energy they are eating. The reduction in energy expenditure was not seen in the unrestrained eaters. Therefore a high carbohydrate /low fat diet, which causes increased energy expenditure and has less energy than a high fat diet, may be beneficial for weight loss, particularly in restrained eaters [17].

The relation to fat intake

Population studies show variable correlation between fat intake and body weight. Animal and clinical studies do show, however, that fat intakes as well as total energy intakes are strongly associated with excess weight [4]. This is particularly so in individuals who have a predisposition to obesity (for example people who have a family history of obesity [19]). In Japan, the incidence of overweight and obesity has increased since the mid-1970s, co-incident with an increase in the proportion of fat in the diet. Fat intake in Japan in 1995 was 26.4% of intake, an increase from 8.7% in 1955 and 22.3% in 1975. Carbohydrate intake has decreased from 78% of the diet to 57.6% over the same period. There has been no change in reported total energy intake over the time.
Dietary fat intake has a synergistic effect when combined with a sedentary lifestyle. Weight has been found to be significantly dependent on dietary fat intake among sedentary women but not among active women [23]. Although there has been a decrease in fat intake it is not enough to match the decline in activity and hence fat intake could still be part of the explanation of the rise in prevalence of overweight and obesity.
Diets high in fat and low in carbohydrate have been positively correlated with body fat [24,25] and BMI [26] in both men and women. High fat/ low carbohydrate diets increase body weight whereas low fat /high carbohydrate diets do not show a similar effect [25]. The fat content of the diet appears to have an effect on body fat as a function of its effect on energy intake. That is, if an individual consumes a diet high in fat there is a greater likelihood of excess energy intake, leading to a positive imbalance in energy and weight gain. It has been suggested that not only total fat intake, but also the fat:carbohydrate ratio of the diet is correlated with body weight (in particular with body fat) [25, 26].
National surveys in England have shown a trend towards a fattier diet. In particular there has been a shift in the fat:carbohydrate energy ratio. In the 1940's, each kilojoule (kJ) of carbohydrate was accompanied by 0.6 kJ of fat, but by the 1990's this had risen to 0.9 kJ of fat, an increase of 50% [27]. Although the actual amount of fat and total energy eaten has decreased, it is possible the change in composition of the diet (an increase in the fat:carbohydrate ratio) combined with a decrease in activity, has contributed to the increased prevalence of overweight and obesity.
The change in fat:carbohydrate ratio - commonly called the "fat carbohydrate see-saw phenomena" - predicts that as the fat content of the diet increases the carbohydrate content of the diet decreases and vice versa. This phenomenon has been demonstrated in children [28], teenagers and young adults [29], and adults aged 19-55 [26]. From these studies it can be concluded that a high carbohydrate diet is positively associated with 1) decreased fat intake, 2) decreased energy intake and 3) decreased BMI or body weight.
Studies investigating the diets of obese people have shown a preference for high fat foods. Preference for carbohydrate-rich foods, low in fat was not a standard feature of obesity but preference for major foods which contained fat seemed to be characteristic. [2, 30]. This preference for high fat foods suggests that fat plays a greater role in the development of overweight and obesity than carbohydrate. Fat has a particularly pleasant mouth feel as well as being easy to chew and swallow. It is therefore not surprising that it is readily consumed. It also has a higher energy content per gram compared to carbohydrate, which makes it easier to meet and exceed energy requirements.

The relationship to carbohydrate intake

There are several major sources of carbohydrate in the diet - fruit and vegetables, breads and cereals, grains and pulses, milk and milk products, biscuits and cakes. Because some of these foods also contain more than one major macro-nutrient, - milk, milk products and pulses contain protein cakes and biscuits contain fat, and micro-nutrients such as vitamins and minerals found in fruit and vegetables - they are often not suitable to use in experimental studies. Sugar, consisting only of carbohydrate, is an appropriate medium to use when testing the effects of carbohydrate per se on eating, appetite and weight gain.
No relationship has been found between per capita sugar consumption of a nation and the incidence of overweight and obesity in the population [31], although differing amounts of sugar are consumed in

different countries. US data indicate that sugar as a proportion of total energy intake has been decreasing over last 30 years on an individual level, but in the UK the figure is said to be increasing [27]. North American data suggest starch intake has increased but because total energy intake has decreased, it is likely that true starch intake has shown little change and in fact may be decreasing. Food patterns of obese individuals do not indicate that their sugar intake is higher than that of normal weight individuals. Hill and Prentice [32].review the relationship between sucrose, carbohydrate and fat with BMI. In all cases where a significant effect was found, the relationship for carbohydrate and obesity was inverse (ie greater carbohydrate intake, less obesity) whereas the relationship for fat was direct (more fat, more obesity).

Weight loss studies, comparing high carbohydrate /energy restricted diets with *ad libitum* carbohydrate /fat restricted diets have shown that groups on either diet lose weight. Energy restricted diets have been shown to result in twice the weight loss of the *ad libitum* group, although the *ad libitum* group had reduced energy intake from baseline. However, at 9-12 months follow up there was no longer a significant difference in weight between the groups. This evidence adds to the current picture that fat is a major cause of excess weight. Although energy intake is important in fat / weight balance, a decrease in energy intake can be achieved on an *ad libitum* carbohydrate diet when fat is restricted [17]. Similar results were found in a study with obese people [33]. The *ad libitum*, low fat / high carbohydrate diet wasn't as good as the energy restricted diet in terms of amount of weight loss, but was superior for weight maintenance. People in the *ad libitum* high carbohydrate group were more compliant, found the diet more palatable and reported a greater reduction in binge eating, a condition which often accompanies obesity [33].

The above evidence suggests strongly that fat intake plays a critical role in the development of overweight and obesity. High fat foods encourage increased energy intake and are associated with increased fat stores and obesity in epidemiological studies [4]. On the other hand, carbohydrate does not play a direct role in the production of obesity. In fact it is low carbohydrate intake (or high fat intake) which is associated with obesity. Of course, where energy (as carbohydrate) is consumed in great excess, and despite the increase in the body's metabolism associated with an increase in carbohydrate intake, obesity may result.

Overfeeding studies

Carbohydrate, when eaten in excess, leads to a 10-40% increase in 24-hr energy expenditure compared to a 0-8% increase when excess fat is eaten (17,18). The mechanism of this reduced energy expenditure with excess fat intake is thought to be reduced *diet induced thermogenesis* (DIT). This is the heat produced after a meal and is a result of food consumption as well as increased metabolism. Habitually high carbohydrate eaters (such as vegetarians) have been shown to have an 11% higher resting metabolic rate (RMR) compared with non-vegetarians (43). RMR is responsible for some 60-70% of total energy expenditure. This evidence suggests that individuals on high carbohydrate diets expend more metabolic energy than those on high fat diets making it easier to maintain or lose weight on a high carbohydrate diet.

Overweight/obesity and energy intake

Nutrition surveys from both the UK and Australia have shown that although energy intake has been decreasing, obesity is increasing [20, 27]. If the composition of the diet was a more important determinant of the development of overweight and obesity than energy intake, weight loss could be achieved by varying the composition of diet, while leaving the energy content the same. However, this has not been shown to occur. In one 12-week study [34] and one 6-month study [35] using two hypo-caloric diets (1200Kcal) of either high or low carbohydrate content, no difference in weight loss was detected between the two groups [34]. These studies suggest that differences in macro-nutrient intake do not lead to differences in weight loss for most individuals, when total intake is less than energy requirements. However, when energy intake is above requirements the macro-nutrient composition of the diet may have an effect.

Although epidemiological data support the correlation between BMI and the percentage of energy from fat, such findings do not prove that energy from fat leads to increased BMI. Studies performed to investigate whether changing the fat content of a meal led to changes in BMI (dependent or independent of energy intake) showed that increased daily physical activity could balance energy intake from higher fat consumption when energy density (kJ/g) was allowed to differ (as would occur in normal diets) [27].

Diet and Satiety

Studies have found that under normal free living conditions excess energy is ingested on a high fat, low carbohydrate diet. This increased energy consumption is called passive over-consumption. Individuals seem unaware that they have exceeded their energy requirements. Such passive over-consumption does not seem to occur on low fat, high carbohydrate diets. It is thought that passive over-consumption occurs on the high fat diet because fat is less satisfying than carbohydrate.

There are many theories about the mechanisms underlying appetite satisfaction (satiety). It has been suggested, for example, that it is to do with plasma glucose, liver glycogen concentrations, differing leptin production (leptin is a satiety hormone in rodents [36]) and feelings of distention on the stomach [37, 38]. Studies suggest that when we are born and in our first few years of life, we are very aware of our internal satiety signals and are able to regulate our energy intake closely [39]. Perhaps as we get older external cues dictate or influence our intake to a greater extent, with the result that we easily override internal satiety signals, leading to over-consumption [40]. There is some evidence to suggest that males of normal weight are able to regulate their energy intakes more accurately than females or the obese, thereby decreasing the likelihood of over-consumption (ie they are able to detect their internal satiety signals).

The satisfying effect of carbohydrate on appetite seems to occur above a certain threshold. No effect occurs if the quantity of carbohydrate eaten is too small. [31, 39, 41]. Studies investigating the satiety produced by different foods [40] show that an increase in fat in foods leads to a *decrease* in satiety, whereas an increase in fibre and water lead to an *increase* in satiety. Palatability increases more with fat than with sugar, and decreases with starch and protein. Potato was found to be the most satiating food. The results showed that the bigger the serving size the greater the satiety, (more food in the stomach and distension of the stomach plays a role in satiety), the more satisfied the individuals were after the food, and the less energy was consumed in subsequent meals. Subjects were less likely to feel full or satisfied when food was highly palatable, suggesting that hedonistic aspects of food override satiety signals. Since fat was found to be more palatable and less satiating this could explain the tendency for over consumption of energy from high fat foods [40].

In lean males, low carbohydrate /high fat diets led to greater fat increase than high carbohydrate /low fat diets. When the diets were equal in energy, the passive over-consumption seen in the high fat diet disappeared [27, 42]. When high starch, high sucrose and high fat *ad libitum* diets were compared, similar amounts of energy were consumed on the sucrose and fat diets but energy intake was lower on the starch (carbohydrate) diet. Weight loss occurred on the starch diet but not on the fat or sucrose diet. Perhaps the increased consumption was due to the hedonistic appeal of both the fat and sucrose meals overriding satiety cues [18].

Prentice [27] suggests that most adults have become habituated to consuming a certain quantity of food, measured in terms of weight, bulk or appearance. The apparent lack of compensation for energy is important in terms of overweight and obesity, as it indicates that the adoption of a high carbohydrate/ low fat diet (high in weight / bulk and low in energy) will help people to lose weight. With this diet the increase in the bulk of food eaten will compensate for the reduction in energy density.

Summary

The scientific evidence suggests that a diet high in carbohydrates and low in fat, can help in weight control:

1. Carbohydrates are an important part of a healthy diet. They have less than half the kilojoules of fat and are less likely to be converted into body fat.

2. Considerable scientific evidence argues in favour of a high carbohydrate, low fat diet as the foundation of weight loss and weight maintenance efforts.

3. Replacing fat (especially saturated fat) with carbohydrates can reduce the risk of many diet-related diseases, while getting the positive benefits of energy, appetite satisfaction, fibre and nutrients associated with high carbohydrate diets.

Breads, cereals, pasta, noodles, rice, pulses, fruits and vegetables are all excellent sources of carbohydrates and are readily available in the Australian diet. Eating a wide variety of these foods is an important part of a healthy diet.

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