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Cereal grains, legumes, and weight management: a comprehensive review of the scientific evidence

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Keywords

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PW was responsible for design of the study and preparation of the manuscript. SG and JO were responsible for the literature searches.

Abstract

There is strong evidence that a diet high in wholegrains is associated with lower BMI, waist circumference and risk of being overweight; that a diet high in wholegrains and legumes can help reduce weight gain; and that significant weight loss is achievable with energy controlled diets that are high in cereals and legumes. There is weak evidence that high intakes of refined grains may cause small increases in waist circumference in women. There is no evidence that low carbohydrate diets that restrict cereal intakes offer long term advantages for sustained weight loss. There is insufficient evidence to make clear conclusions about the protective effect of legumes on weight.

Key Words: Cereals; grains; legumes; obesity; weight control

Introduction

Overweight and obesity are key features of the metabolic syndrome and prevention of excessive weight gain is a health priority internationally. An increased consumption of wholegrain foods, like cereals and legumes, may protect against obesity, but there has also been concern expressed that refined grain intake may directly contribute to increases in obesity.[1] It has been noted that high levels of carbohydrate consumption, especially from high glycemic index cereals, is a relatively recent phenomenon in evolutionary terms and attention has been drawn to the correlation between consumption of refined carbohydrate and the increasing prevalence of obesity.[2]

Cereal grains are generally an excellent source of carbohydrate, dietary fiber, protein and are a good source of many B-group vitamins, vitamin E, and a number of minerals – especially iron, zinc, magnesium and phosphorus. In many countries national dietary guidelines recommend plentiful consumption of grain foods as the basis of a healthy diet and increasingly there has been emphasis placed on increasing consumption of wholegrains. One of the key recommendations of the 2005 US Dietary Guidelines is "consume 3 or more ounce-equivalents of wholegrain products per day, with the rest of the recommended grains coming from enriched or wholegrain products. In general, at least half the grains should come from whole grains".[3]

From a consumer point of view, one of the most commonly held popular beliefs about diet is that grains, and the carbohydrates they contain, provide excess energy to the body and are therefore "fattening".[4] At the same time, one of the key benefits that consumers recognise from eating a plant-based diet is the ability to help control body weight.[5] There is therefore a need to assess the evidence about the role of grains in the prevention and management of overweight and obesity, to ensure health messages are evidence based and consistent with the best research available.

Evidence base

While there is strong epidemiological evidence for a beneficial effect of wholegrain and legume consumption on the risk of many chronic diseases, especially cardiovascular disease and diabetes,[6, 7] such evidence does not usually explain the mechanisms of action or necessarily give sufficient guidance to base quantitative or qualitative recommendations. In

the case of grain foods it is unclear to what extent the fiber content, glycemic index, nutrient density or other features (such as impact on gut flora) of the foods are the main causes of these health effects.

Studies that have directly examined the relationship of grain intake to obesity are quite sparse. They fall into three main categories: (1) cross-sectional epidemiological studies that have noted associations between measures of overweight and obesity with either dietary patterns that are higher in grain foods, or actual measures of particular foods; (2) prospective studies that have measured changes in weight over time and examined associations of rates of weight change with diet patterns, and (3) experimental clinical studies, where the intake of grain foods is manipulated.

From an experimental approach, clinical trials are the gold standard in establishing cause and effect relationships that have been potentially identified in epidemiological studies. However, studies that aim to change one of the major components of a diet, like grains, can rarely be conducted in a blind fashion and are always confounded by the inevitable consequent changes to the nutritional profile of the diet as a result: the choice of foods that are replaced can be as important as those that are added. Increasingly nutrition research is moving toward examination of dietary patterns as a whole, rather than specific foods. The Dietary Approaches to Stop Hypertension (DASH) study[8] and the Lyon Diet Heart Study[9] are examples of this approach. However even these studies are relatively rare, and very often the best data to base dietary recommendations is still largely epidemiological in nature – either descriptive cross-sectional studies, or prospective studies examining changes in risk factors over time and correlations with dietary patterns or changes.

Defining the term “wholegrain” presents difficulties in terms of analysing and interpreting all these types of research studies and making dietary recommendations. Several epidemiological studies have defined wholegrain foods as those products that contain ≥25% wholegrain content or bran by weight.[10-12] The United States Food and Drug Administration (FDA) requires foods to contain >51% by weight of wholegrain ingredients in order to make health claims.[13] However neither of these definitions takes into account the structure of the grain, and the glycemic index (GI) of wholegrain foods can vary significantly depending on their degree of intactness. The fact that grain structure and GI are rarely considered in epidemiological studies makes interpretation of the scientific literature imprecise.[7]

Method

This paper reviews existing research regarding the role of cereal grains and legumes in the prevention or management of overweight and obesity and considers how existing dietary recommendations might be modified to take new information into account. We carried out a search for original studies and reviews in the following databases: PubMed, Medline, Scopus, Cinhal and ScienceDirect, from 1980 to 2005. The following search terms were used: cereal, grain, wholegrain, legume, pulse, bread, pasta, rice, wheat, barley, oat, rye, soy, bean, pea, in conjunction with the following terms: obesity, overweight, satiety, BMI, waist. Studies were limited to those published in English, conducted in humans and reporting anthropometric outcome measures. In addition, hand searching of references in identified papers was used to supplement the electronic search. A total of 556 abstracts were identified for review. Of these only 121 were directly relevant to the topic, with most others being excluded because they did not report original data or because they only examined intermediate markers such as energy intake or satiety hormones, rather than direct measures of overweight and obesity. Relevant studies were assessed for scientific quality using the methods and criteria described by the European Heart Network,[14] and studies with a low quality rating were excluded (generally because they lacked control groups or methods were inadequately described or validated). This left a total of 53 eligible studies included in the final review,

Results

Epidemiological Studies

Studies of dietary patterns

Principal component analysis and cluster analysis are two statistical techniques that have become increasingly popular in the examination and description of complex dietary patterns. There are 11 published studies that have reported analysis of dietary intakes that identified patterns with higher levels of cereals and/or legumes. Only one of these, in a subsample of 466 men in the Health Professionals Follow-up Study, found no association between BMI and quintiles of conformance with a prudent diet including higher intakes of wholegrains and legumes.[15] All the others have found such patterns to be associated with lower measures of obesity. The studies include both male and female subjects from a wide range of age groups (8-87 years) and in 12 different countries.

Analysis of the diets of 4999 adults in the Malmö Diet and Cancer Cohort study identified six diet patterns and found that central obesity (waist circumference above reference values of 94cm in men and 80cm in women) was least likely to occur in those consuming patterns dominated by fiber-rich bread (OR 0.79 for women and 0.58 men). There was no evidence of increased risk with diets dominated by white bread, providing 15-18%E.[16] In the UK Women's Cohort Study with 33971 adults, seven clusters of food consumption were identified, three with high cereal levels: *Health conscious* (high bran, wholemeal and pulses), *Low diversity vegetarians* (high wholemeal bread and pulses) and *High diversity vegetarians* (high wholemeal bread, cereals, pasta and rice and pulses).[17] Women with these patterns had significantly lower average BMI values as well as the lowest proportion of obese subjects (5-9% vs 10-12% in the other four clusters). Another UK prospective study (the Isle of Ely study, with 802 adults) identified four diet patterns and found the one with high intakes of rice, pasta and pulses was negatively correlated with waist-to-hip (WHR) ratio.[18]

In the US, factor analysis of dietary data from the Baltimore Longitudinal Study of Aging (BLSA) identified six food patterns among 449 adults aged 30-80y.[19] Subjects consuming a fiber-rich pattern, high in non-white bread, wholegrains, beans and legumes, had the lowest BMI, smallest waist circumference (WC) and the smallest mean annual increase in BMI. In older adults the same pattern was also found. Cluster analysis of the diets of subjects aged 70-

77y in the cross-sectional SENECA baseline study in Europe and the Framingham Heart Study cohort identified five dietary patterns and the two that were significantly associated with the lowest BMI and WC were those highest in grains and legumes, nuts and seeds.[20]

The same relationship was found in a longitudinal survey of 8-year old Australian children; a food pattern with a high consumption of cereals and bread was an independent negative predictor of BMI in multivariate models.[21] Another study that has also reported a relationship with a prudent diet pattern is from the Danish MONICA surveys, showing that diets with more wholegrain cereals are associated with lower BMI.[22] In Brazil, factor analysis of the diets of 2489 adults identified three patterns, including the traditional diet relying mainly on rice and beans.[23] This pattern was associated with a lower risk of overweight or obesity in logistic models adjusted for dieting, age, physical activity and energy expenditure (OR 0.87).

A few studies are more difficult to interpret because of the food group patterns that were identified. One cluster analysis of the diets of 189 US adults aged 66-87y found a high nutrient-density pattern (with higher intakes of cereal, rice, pasta and beans) was associated with a lower risk of overweight and excessive WC; but this same pattern also had a lower intake of bread.[24] A study of two other US data sets – from the Geisinger Rural Aging Study (GRAS) and the Boston Area study – also provide some contradictory results.[25] A 2-cluster analysis of the GRAS data found individuals in a cluster with more breakfast cereal, but less bread, had a lower mean WC (93.5cm vs 97.2; $p<0.05$), and participants in the Boston study with a pattern high in breakfast cereals, milk and fruit had significantly lower BMI (25.9) than those consuming a pattern high in grains, bread and poultry (27.1). The types of breads were not distinguished in these studies.

Because of the different food clusters identified in these studies, and the fact that many do not report details of the amounts of individual foods consumed in each, it is difficult to reach firm conclusions from their results. The great majority of these studies find an association between a prudent dietary pattern with higher levels of cereals and legumes with lower measures of overweight, and therefore support current recommendations to include these foods in a healthy diet. However, these studies do not provide a clear consensus on the role of bread specifically, nor the differing effects of wholegrain versus refined cereals. They also provide no dose-response data about the relationship. Information from cross-sectional studies, with more quantitative estimates of intakes, is needed to address these issues.

Cross-sectional studies

16 studies have examined weight status in relation to consumption of particular grain foods. The largest of these is the Iowa Women's Health study of 34,942 post menopausal women, which used the 127-item food frequency questionnaire (FFQ) from the Nurses Health Study and defined wholegrain foods as those with at least 25% wholegrain or bran by weight.[11, 26] At both baseline and in follow-up surveys, higher grain intake was associated with lower BMI and lower waist-to-hip ratio (WHR). Higher refined grain intake (median 30 serves per week) was associated with a slightly higher WHR (0.836 vs 0.842 in quintiles 1 and 5 respectively), but there was no significant association with BMI.

From diet recalls collected from 9323 participants in the USDA's 1994-96 Continuing Survey of Food Intakes by Individuals, it has been reported that those consuming wholegrain food were less likely to be overweight: only 7% of people consuming at least 3 serves per day of wholegrain foods had a BMI above 25, compared to 69% of non-consumers.[27] The same result was found in a survey of 285 Minnesota 13-year olds. Analysis of tertiles of wholegrain intake found significant inverse associations with BMI (Q3: 21.9 vs Q1: 23.8; p=0.05) and WC (76.8 vs 81.4; p=0.02) after adjustment for age, sex, and race.[28]

Some studies have reported no adverse relationship with refined grain intake. A cross-sectional study with data from the Framingham Offspring Study found subjects in the upper quintile of wholegrain intake (20.5 serves per week) had lower BMI and WHR, whereas there was no association with refined grain intake, up to a median of 38.9 serves per week in the highest quintile.[12] In results from the 1998-99 Portuguese National Health Survey, with over 39000 individual dietary interviews, logistic regression analysis showed bread consumption (which is traditionally mostly refined) was not related to the risk of BMI >30, while consumption of starchy foods (rice/pasta/potatoes) was protective ($p<0.001$).[29]

A cross-sectional study of 827 adults in Tehran examined quartiles of intake of whole and refined grain foods and reported multivariate adjusted odd ratios for obesity and abdominal adiposity.[30] There was no relationship between consumption of either grain type and obesity, but the odds ratio of WC above the recommended limits was 0.90 in the highest quartile of wholegrain intake (p for trend <0.04). The relationship with refined grain intake was not

significant. In a larger sample from the same study, there was also no relationship between energy intake from carbohydrate and BMI.[31]

Baseline data from 13064 adults in the prospective ARIC study of cardiovascular disease, found White Americans in the highest quintile for cereal fiber intake (5.1g/d) had a slight but significantly lower BMI of 26.4 as against 26.8 in those in the lowest quintile of cereal fiber (2.7g/d).[32] However, in the African-American cohort those in the highest quintile for cereal fiber intake had a higher BMI than those in the lowest quintile 29.3 vs 28.7. Similar trends were found for legume fiber. Only one other study has provided data on legume intake. In a study of 9984 adults in Tehran, the risk of being centrally obese in men in the fourth quartile of legume intake (30g/d) was significantly lower than in other quartiles, but the relationship was not found in women.[33]

Most of these studies have examined intakes of cereal or legume foods in general rather than specific types. Six studies have examined the relationship between breakfast cereal consumption and obesity. The largest of these is based on data from 17881 men in the Physicians Health Study.[34] At baseline, men in the lowest category for breakfast cereal consumption were significantly heavier than those in the highest category (BMI 24.8 vs 24.1; $p < 0.0001$). At the 8-year follow-up, men with higher intake of cereals, regardless of grain type, had a significantly lower weight gain, and at 13 years those who consumed at least one serving of wholegrain cereal daily had a significantly lower weight gain than those who rarely or never ate wholegrain cereals (2.28kg compared with 1.87kg; $p < 0.05$).

NHANES survey data from 4218 adults in 1999-2000 also shows that consumers of ready-to-eat breakfast cereal (RTEC) ate significantly less fat and more fiber ($p<0.001$) than non-RTEC consumers for both men and women.[35] There was a significantly lower prevalence of BMI >25 among the female RTEC breakfast eaters (OR = 0.7) and linear regression analyses indicated an inverse association between RTEC consumption and BMI in women, but not in men.

In the National Heart, Lung and Blood Institute Growth and Health Study of 2379 girls aged between 9 and 19 year, after adjusting for energy intake, mean days of eating breakfast cereal (of any kind) was negatively correlated with BMI and risk of being overweight.[36] Younger children show the same relationship. A cross-sectional survey of 603 American children aged

6-12y also found a statistically significant inverse relationship between BMI and frequency of eating RTEC.[37] Only 16% of 7-9 year old children who ate >8 serves per 14 days were overweight, compared to 50% of those who ate ≤3 serves ($p<0.01$).

Similar relationships have been found in European populations. In Cretan adolescents frequency of RTEC intake was associated with significantly lower BMI and WC.[38] In Spanish schoolchildren, it was found that overweight subjects, particularly females, omitted breakfast more frequently and took smaller quantities of cereals than did normal weight subjects.[39]

Many of these cross-sectional studies have limitations based on the use of food frequency questionnaires that sometimes make it difficult to clearly separate whole and refined-grain foods. For example the standard 127-item FFQ from the Nurses Health Study includes amongst wholegrain foods some lower fiber foods such as popcorn, couscous and breakfast cereals with 25% wholegrain content. This may therefore underestimate the protective effects of wholegrain foods which meet the FDA definition of more than 50% by weight. Despite this limitation, these cross-sectional studies are quite consistent in demonstrating that higher intakes of wholegrain cereals and legumes are associated with lower BMI, WC and risk of overweight. While one major study showed a slightly higher WHR (but not BMI) with higher consumption of refined grains, three other studies have not supported this finding.

Longitudinal studies of weight change

Examining how food intakes are associated with changes in body weight may provide even better information on which to base recommendations. It is recognised that for many people returning from overweight to normal weight is difficult to achieve, and in some countries dietary recommendations now put priority on minimising further weight gain rather than losing weight.[40] Table 1 summarises the eight studies of this kind that were identified.

The US Health Professionals Follow-up Study has data on 27082 males, and multivariate linear regression has examined mean weight changes over 8 years against quintiles of wholegrain intake and various fiber types.[41] A strong dose-response relationship was observed, and for every 40g/d increment in wholegrain intake from all foods, weight gain was reduced by 0.49kg. Cereal fiber intake was also inversely associated with weight gain, independent of wholegrain (p for trend <0.001). For every 20g/d increment in cereal fiber, weight gain was reduced by 0.81kg.

The same relationship was seen in the 6-year follow-up of 12569 males in the Multiple Factor Risk Intervention Trial.[42] Those subjects who achieved the greatest weight loss (≥15lb) were those who had the highest intakes of cereals and breads (p=0.002) and those who made the largest increases in percentage energy contribution from breads and cereals (p<0.001). There was no relationship with legume intake, but overall intakes were generally very low. These results are supported in a small study of food selection habits by 36 subjects over 2 years following weight loss.[43] Consumption of high-fiber bread was one of the key sustainable changes in food intake amongst those who were successful in maintaining weight loss.

In large studies including women the same pattern has been reported. In a two year follow-up in the longitudinal EPIC study with 11005 women, consumption of higher levels of cereals (pasta, breakfast cereals, rice) predicted large weight loss of 2kg or more (OR 1.43), but neither bread nor legume consumption was related to weight change.[44] A one year prospective study in 1379 children aged 2-5 years found bread and cereal consumption, but not fiber, significantly predicted weight loss.[45] There was a 0.16 kg lower weight change per year with each additional daily serve of breads and grains.

While these studies have considered cereals and grains in general, three have separately compared the effects of wholegrain and refined cereals, and in each case refined grains were positively associated with weight increases. In the Nurses Health Study, with 74091 health women, the relationship between changes in grain consumption and development of obesity over 12 years was examined.[46] At baseline, women who consumed in the highest quintile of whole grains weighed approximately 0.9kg less than those in the lowest quintile. Higher intake of wholegrains over the 10 years was associated with less average weight gain in the 2-4y interval between assessments (mean increase of 1.58kg in the lowest quintile vs 1.07kg in the highest; p<0.0001). In contrast higher intakes of refined grains were related to weight gain (0.99kg vs 1.65kg, p<0.0001).

Two other studies have used food pattern analysis to provide some evidence on the different effects of wholegrain and refined grains. The BLSA Study followed 449 subjects over 7 years and related five dietary patterns to annual changes in BMI and WC.[47] There was a significantly greater annual increase in WC (but not BMI) among subjects on the White Bread pattern (with the highest grain intake and 15.8% total energy from white bread), compared

with the Healthy Pattern (with only 3.2%E from white bread): 1.32cm vs 0.43cm; $p<0.05$). An analysis of Danish data from the MONICA study examined associations between baseline food intake and subsequent changes in BMI-adjusted WC over 6 years.[48] A higher intake of refined bread (white and rye) was associated with gain in WC in women (0.29cm per quintile), but not in men (where there was a non-significant inverse association). There was no association with wholegrain intake.

Even with these prospective studies, their observational nature hampers straightforward interpretation. Because changes are time dependent, we cannot be certain that changes in diet preceded changes in weight. For example, those who had recently gained weight might increase their intake of grain products when following a lower fat/high fiber diet to lose weight.

The overall results are therefore somewhat inconsistent. Most studies have found an inverse relationship between wholegrain intake and weight gain, but there is still very limited evidence in relation to legume intake. In a few studies, higher intakes of refined grains appear to be associated with increases in WC and BMI in women, but the weight changes, though statistically significant, appear to be relatively minor in absolute terms (<0.7kg over a 12 year period). Furthermore, there have been no studies that have examined the association of high and low GI grain consumption with body weight.

Intervention studies

While such observational studies are useful, they can only indicate associations between diets and health outcomes, rather than provide evidence of causal relationships. Consumption of cereals or legumes may be a marker for other healthy lifestyle practices such as physical activity, smoking avoidance and lower fat and alcohol intakes. While good quality studies attempt to control for some of these factors, they cannot reliably be used to predict outcomes when diet patterns are changed.

A total of 17 intervention studies were found that examined the impact of increased intakes of grains and legumes. Six of these only measured the effects on intermediate measures such as satiety or energy intake; the other 11 directly report changes in weight or WC and these are summarised in Table 2.

Only a few of these studies report a better rate of weight loss when the grain intake of the diet is increased. One small Mexican trial compared a low and a high GI diet, providing 63 vs 55 g respectively of carbohydrate from cereals and legumes.[49] The low GI diet (high in wholegrain bread and beans, and with less white bread and rice), resulted in improved glycemic control and greater weight loss. Three other studies have examined the effect of increasing the RTEC content of the diet, either replacing one evening meal with a cereal-based meal, or as additional snacks.[50-52] All three have reported modest but favourable reductions in weight in the RTEC-supplemented diets, but all have been relatively short-term studies and long term outcomes are uncertain. Nonetheless, these findings support the findings from the National Weight Control Registry that regular breakfast consumption and eating a low-fat high-carbohydrate diet are some of the behaviours of successful weight-loss maintainers.[53]

All of the other studies have demonstrated that a diet with a high cereal content can support weight control, although most do not find a superior rate of weight loss when compared to diets with lower cereal levels. The largest and most recent of these trials compared exercise combined with two 500 kcal hypocaloric diets, where subjects were either instructed to avoid cereals, or to eat at least two meals per day containing fiber-rich wholegrain cereals.[54] Both diet groups lost more weight than subjects only instructed to exercise, but weight loss was not different between the two diet groups.

Another RCT, with 116 overweight subjects who were prescribed two 500 kcal-restricted diets, found a significant decrease in both weight and WC in subjects following diets with 7-8 grain serves/day (including 3-4 serves of wholegrains), compared to a control diet with only one serve of wholegrain per day.[55] However this study did not have an energy restricted control diet and so, while it can be concluded that weight loss is possible following a diet including a total of 7-8 serves of grains, no conclusions can be drawn about the relative efficacy of this dietary pattern.

One study, comparing high protein (HP), high fat (HF) and high carbohydrate (HC) diets, found subjects lost significantly more weight on the HP and HF diets, but that the subjects including at least 6 serves of wholegrains per day on the HC diet still achieved significant reductions in weight and waist circumference.[56] Another comparison of high and low CHO 1200 kcal diets (including 7 vs 4 serves of bread per day respectively) found both led to

significant weight loss, but there was no difference in reduction in BMI between the two approaches.[57]

Other studies with increases in particular cereals have also been carried out. Supplements of 700 kcal of both rye and wheat bread resulted in similar weight loss in one study,[58] but this was in a study with cancer patients that was primarily examining outcomes of cell proliferation and plasma lignans, so the relevance to healthy subjects is unclear. An 8-month trial adding oats to energy restricted diets for overweight healthy men and women found a trend toward reduced hunger in the high oat group, but no difference in effects on weight loss.[59]

There are few intervention studies directly comparing the effects of wholegrains and refined grains. One examined the different effects of a high wholegrain versus refined grain intake (in diets with the same percentage of energy from carbohydrate) on insulin sensitivity in overweight and obese adults.[60] The authors found lower fasting insulin levels and higher satiety ratings with the wholegrain-rich diets, but no difference in weight after a 6-week period. This finding of increased satiety (and sometimes reduced energy intake) with higher cereal intake has been confirmed in several other studies,[61-65] although one study with 10% lupin flour added to bread reported that, although this reduced the GI, it did not affect satiety ratings of the bread or subsequent food intakes after consumption at breakfast.[66]

In summary, there are few well controlled studies that have specifically examined the effect of higher intakes of cereals and legumes on weight reduction or maintenance in the long term, nor compared the effects of refined and wholegrain cereals specifically. It may be that in short term studies, low carbohydrate diets result in greater weight loss, but those that are summarised here provide consistent evidence that weight loss is still achievable in diets that are high in cereals, especially wholegrain.

Mechanisms of action of grain foods

Several of the studies reported here have noted that higher grain intakes are associated with lower total energy intakes.[11] The main postulated mechanism is through the higher fiber content of diets high in wholegrains and legumes. Higher fiber diets can affect energy balance through intrinsic effects (energy density and palatability), hormonal effects (such as gastric

emptying and post-prandial glycemia and insulinemia) and colonic effects (such as the influence of short chain fatty acids on satiety).[67, 68]

While dietary fiber appears strongly associated inversely with body weight and weight gain in epidemiological studies, the effects of different sources of fiber and resistant starch are not well established and not all of the effect of wholegrains may be explained by their fiber content. In the Health Professionals Study, associations between wholegrain and reduced weight gain was attenuated after adjustment for micronutrients like magnesium, and persisted after changes in bran and fiber intakes were accounted for, suggesting additional metabolic effects beyond the effect of the fiber content.[41]

The lower GI values of diets high in wholegrains and legumes may be another important factor.[69] Low GI foods, and wholegrains in particular, are likely to be beneficial through promoting satiety.[70] The intake of wholegrains may also slow starch digestion or absorption, which leads to relatively lower insulin and glucose responses that favour the oxidation and lipolysis of fat rather than its storage. But it needs to be noted that not all wholegrain foods are necessarily low GI (eg, some wholemeal breads) and some refined grain breakfast cereals with added protein have a low GI value, so the effects of wholegrain and glycemic index are not necessarily the same.

Nonetheless, the higher GI of most refined grains may be the possible mechanism whereby refined grains were associated with small increases in waist circumference in some studies. Experimental data indicate that refined grain products, unlike wholegrain products, can induce an increase in fat synthesis in animal feeding trials even when the total energy intake is unchanged and body weight remains constant,[71] so advising people they can eat an unlimited amount of highly refined carbohydrate diet is probably not appropriate.

Along with wholegrains, legumes constitute another food group that has been relatively understudied in the epidemiological context. The current evidence for recommendations about their inclusion in a healthy diet relate to their nutrient content (low in fat, and a good source of soluble fiber and protein), rather than strong evidence for their role in chronic disease prevention. In relation to weight control, it may be that their generally low GI value is the main benefit in weight control which may enhance satiety,[72] although there have been suggestions that alpha-amylase inhibitors in legumes may play a role as well.[73]

Low carbohydrate diets

With the rising rates of overweight and obesity in most of the Western world, there has been a recent growth in diet books promoting low carbohydrate diets, such as the Atkins Diet and the South Beach Diet, with advice to avoid grain products and providing less than 30% from carbohydrate.[74]

Since 2003 six studies of 3-12 months duration have compared conventional and low-carbohydrate diets.[75-80] They have all reported slightly better results with the low-carbohydrate diets, with weight loss differences ranging from 3.8 to 5.8kg over 6 months. However, studies that followed participants for longer found the difference lost significance after 12 months.[81] The mechanism of action of low carbohydrate diets still seems to be solely via decreased energy intake. This probably results from the greater satiety or monotony of the food choices and not any special metabolic effect, such as ketosis. When energy and protein intake is kept the same, there is no difference in weight loss when very low carbohydrate and low fat diets are compared.[82]

There are data suggesting that diets high in carbohydrate are more satiating than diets high in fat and that voluntary energy intake is likely to be lower with high carbohydrate than high fat diets.[83] Furthermore, surveys of people who are successful at long term maintenance of substantial weight loss show that they follow high-carbohydrate, low-fat diets.[84] In recent evidence-based practice guidelines, the Australian National Health and Medical Research Council cautioned against the use of low carbohydrate diets and has concluded that a low-fat diet with increased activity is still the best approach for obesity management.[85]

Conclusions

The findings reported here are generally consistent with other studies which have concluded that grains and legumes are protective against heart disease and diabetes and are consistent with public health dietary recommendations to make bread and cereals the foundation of a healthy diet and to emphasise wholegrain in this context. The risk of obesity may be reduced by replacing refined cereal sources with more wholegrain, high-fiber, and low GI grain foods, but further randomised trials are necessary to determine the absolute effect of such interventions and to guide new product development. Moreover, the causes of obesity are multifactorial and the outcomes from manipulations of diet alone are likely to be influenced not only by patterns of activity but also by genetic factors that may determine how a person responds.[86]

In the published observational studies, the highest quintiles of wholegrain intakes that are associated with lowest risk of obesity are at levels equal to 3 serves per day. In the US, the average intakes of wholegrains is less than one serving a day and less than 10 percent of Americans consume the recommended three servings per day,[87] so there is substantial opportunity to improve the grain and legume intake of most people. Unfortunately there are also substantial barriers to increasing the consumption of wholegrain and legume foods,[88] including traditional preferences for refined product, limited availability in supermarkets and foodservice settings, unfamiliarity with cooking techniques and confusion in product labelling.

Our knowledge of the relationship between grains and obesity is still incomplete and at the recent Whole Grain and Health summit at the University of Minnesota it was recommended that further research is needed into: (1) the link between wholegrains and health, (2) development of innovative products, (3) effective communication with consumers about wholegrain foods. Nonetheless, the totality of evidence available from research to date shows that there is little evidence that a high consumption of grains increases the risk of obesity and does provide strong support for continuing messages to the public that a diet high in wholegrain cereals and legumes will support good overall health and is likely to help maintain a healthy weight.

Summary points

There is good evidence from both epidemiological and intervention studies that (1) a diet high in wholegrains is associated with lower BMI, waist circumference and risk of being overweight, (2) a diet high in wholegrains and legumes can help reduce weight gain and (3) significant weight loss is achievable with energy controlled diets that are high in cereals and legumes.

There is weak evidence that high intakes of refined grains may cause small increases in waist circumference in women. There is no evidence that low carbohydrate diets that restrict cereal intakes offer long term advantages for sustained weight loss. There is insufficient evidence to make clear conclusions about the protective effect of legumes on weight. The levels reported in most epidemiological studies are too low to demonstrate clear effects and there have been no clinical trials examining the effect of increased legume intake on longer term weight status.

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Table 1. Prospective observational studies investigating the effect of cereals or legumes on changes of weight or waist circumference

Author	Subjects	Study design	Outcomes measured	Key results
Stamler & Dolecek (1997) [42]	12569 males in the Multiple Risk Factor Intervention Trial (with baseline mean BMI 27.7)	Weight and BMI measured annually for 6 years comparing a special intervention (SI) group with usual care (UC). The SI group was initially counseled in 10 weekly group session to modify diets to reduce total and saturated fat, cholesterol and alcohol and to increase polyunsaturated fats Regression analyses assessed relations between food group intakes and weight change.	BMI; Weight loss	In both groups weight loss was associated with increased or higher percentages of energy from total carbohydrate and fiber intake and, for SI men, higher percentages of energy from starch. Subjects who achieved the greatest weight loss (≥6.8kg) had the highest energy intakes from breads and cereals and the highest 6 year increases in bread and cereals intake (3.5%E); those who gained weight had the lowest overall intakes and the smallest increases ($p<0.001$).
Schultz et al (2002) [44]	11005 women and 6364 men in the EPIC-Potsdam cohort (all non-smokers)	Large multi-centre European cohort study. 2 year changes in measured weight and diet assessed by FFQ. Differences in mean food group intake across weight changes were tested using ANOVA.	Weight change	Among women, large weight loss (>2kg/y) was significantly predicted by higher intakes of cereals (pasta, rice breakfast cereals) with an odds ratio of 1.43 ($p<0.05$) but was unrelated to bread or legume intake. Among men there were no significant associations.
Liu et al (2003) [46]	74091 females in the Nurses' Health Study	The US cohort has been followed every two years since 1976 using a validated FFQ and self-reported weight. Data is presented from 1984-96. Multiple regression analysis examined relationships with wholegrain and refined grain intakes.	Weight; BMI; OR of developing BMI≥30	At baseline, the mean weight of women in the highest quintile of wholegrain intake was 0.9kg less than those in the lowest quintile ($p<0.0001$). The odds ratio for developing obesity over 12 years was 0.81 in the highest quintile of wholegrains ($p=0.0002$) and 1.18 for refined grains ($p<0.0001$).

Koh-Banerjee et al (2004) [41]	27082 men aged 40-75 years at baseline in the Health Professionals Follow-up Study	Longitudinal prospective study over 8 years (1986-1994). Self-reported weights, and validated FFQ administered in 1986, 1990 and 1994. Multivariate linear regression used to examine changes in grain intake and weight.	Weight	An increase in WG intake was inversely associated with long-term weight gain ($p<0001$). For every 40g/d increment in WG weight gain was reduced by 0.49kg. Association with WG persisted after accounting for changes in bran and fiber intakes.
Newby et al (2003a) [45]	1379 healthy children in North Dakota aged 2-5 years	One year prospective study with dietary and anthropometric data collected at 2 visits 6-12 months apart. Linear regression used to examine associations between weight change and food group intake.	Weight; Food group servings	A 0.19kg lower weight gain per year was observed with each additional serving of breads and grains – including rice, pasta and breakfast cereals ($p<0.001$). Total fat and fiber was not related to weight change.
Newby et al (2003b) [47]	449 healthy subjects aged 30-80 years in the Baltimore Longitudinal Study of Aging	7 year follow-up from 1984-1991. Heights and weights were measured bi-annually. Dietary intakes were measured with 7-day records at entry. Cluster analysis was used to define five dietary patterns	BMI; WC	Mean annual change in WC was more than 3 times as great for subjects in the "white-bread" cluster (1.32cm) as for those in the "healthy" cluster which included the highest levels of WG cereals and legumes (0.43cm) ($p<0.05$).
Halkjaer et al (2004) [48]	1200 women and 1236 men aged 30-60 years in the MONICA1 study in Denmark	Height and weights were measured and a 26-item FFQ administered in 1982, 1987 and 1993. Multiple regression analysis examined associations of weight change and intakes of 10 food groups.	BMI; WC	A high intake of refined bread was associated with 6-year increase in WC for women, even after adjustment of BMI ($r=0.29$; $p<0.05$). WG intake was associated (but not significantly) with decreased WC.
Borg et al (2004) [43]	36 obese men 35-50y in a RCT to reduce weight with a very low calorie and exercise.	31 month follow up with dietary assessment by a 4 day food diary and classification of 15 food groups used in counselling, including high-fiber breads (to be increased) and other grain products (to be used moderately)	Weight; Three Factor Eating Questionnaire	Increased consumption of high-fiber bread was one of the best maintained behaviour changes and was correlated with food restraint scores ($r=36$; $p=0.03$).

BMI, body mass index; WC, waist circumference; WG, wholegrain; FFQ, food frequency questionnaire; OR, odds ratio; RCT, randomised controlled trial

Table 2. Intervention studies that have investigated the effect of cereals or legumes on weight or waist circumference

Author	Subjects	Study design	Diet	Outcomes measured	Key results
Melanson et al (2006)[54]	180 overweight and obese adults	RCT with two 12-week phases (counselling and monitoring)	1) 500 kcal hypocaloric plus exercise (avoiding cereals) 2) Hypocaloric fiber-rich diet with WG plus exercise 3) Exercise only	Weight and BMI	Hypocaloric diet with cereals resulted in higher fiber intake (27.5 vs 17.5g $p<0.001$) than low cereal diet. Weight loss on wholegrain diet (4.7kg; $p<0.001$) was not different from the diet with less cereal.
Azadbakht et al (2005)[55]	116 overweight men and women	6-month RCT with 2 intervention diets and one "eat as usual" control	1) 500 kcal restriction (3serves WG/d) 2) 500 kcal restricted DASH diet (4 serves WG/d)	Weight and WC	Reduced weight (13-16kg) and WC (5-7cm) ($p<0.04$) in the two intervention diets compared to a control
McAuley et al (2005)[56]	96 overweight insulin resistant women	RCT with 8 weeks weight loss and 16 weeks maintenance phases	High Fat (Atkins) diet, High Protein (Zone) diet, and High CHO (at least 6 serves of wholegrain)	BMI and WC	Subjects on the HP and HF diet lost significantly more weight and WC by 24 weeks (6.9kg/8.8cm and 7.1kg/9.8cm; respectively; compared to those on the HC diet (4.7kg/6.9); $p<0.01$.
Waller et al (2004)[50]	62 healthy men and women	4 week RCT	1 cup of breakfast cereal with milk consumed 90min after dinner meal	Weight	No significant difference between groups overall, but high compliance subjects lost more weight (-1.85kg) than non-compliers (-0.39kg) $p=0.06$
Jimenez-Cruz et al (2003)[49]	14 overweight subjects with type 2 diabetes	Randomised 6 week crossover trial	Low and high GI diets. Low GI diet was high in wholegrain bread and beans	Weight and BMI	Reduction of BMI by 0.6 and weight (1.5kg) ($p=0.04$) in low-GI period. No change during high-GI period.
Bylund et al (2003)[58]	18 men with prostate cancer	12 week RCT pilot study with added bread	700 kcal rye or wheat soft bread and crispbreads as part of a 30%E fat diet.	Weight	Weight decreased significantly in both groups rye (1.1kg) and wheat (1.5kg)

Pereira et al (2002)[60]	11 diabetic overweight men and women	Randomised controlled cross-ever trial with food provided for two 6–week periods	Wholegrain diet (28g/d dietary fiber) vs Refined grain diet (18g/d fiber). Both 54%E CHO	Body weight	No difference in weight between diets; fasting insulin less on wholegrain and satiety higher
Mattes (2002)[51]	109 overweight mean and women	RCT with 2 week RTEC supplementation phase and 4 week Volumetric diet phase, compared to 2 control groups	1 serve RTEC (either Special K or a variety) with skim milk and one serve fruit replacing either lunch or dinner	Weight; Fat mass	Losses of 1.91kg and 1.37kg in the two RTEC groups was mostly in fat mass and significantly greater than control groups ($p<0.05$). No change in control groups
Saltzman et al (2001)[59]	52 healthy men and women, both normal and overweight	8-month RCT	2 energy restricted diets, one with 45g oats/1000kcal.	Weight	Both groups lost weight but no difference with higher oat content
Kirk et al (2000)[52]	22 overweight adults	2 weeks replacing one meal with breakfast cereal, followed by 4 weeks ad lib high carbohydrate regime	Stage 1: 45g RTEC with skim milk Stage 2: encouraged to use RTEC as snack	Weight	Weight loss of 2kg ($p<0.001$) in intervention phase maintained over 4 weeks of high CHO diet
Lean et al (1997)[57]	110 overweight women	6-month RCT outpatients with 12 month follow-up	1200 kcal high carbohydrate diet (58%E: 7 serves of bread/d) vs low carbohydrate (35%E; 4 serves of bread/d)	BMI and WC	6 month reductions in BMI (-2.2) and WC (-5.7cm) on high CHO diet ($p<0.001$) not significantly different to low CHO diet

BMI, body mass index; CHO, carbohydrate; DASH, Dietary Approaches to Stop Hypertension; HC, high carbohydrate; HF, high fat; HP, high protein; GI, glycemic index; RCT, randomised controlled trial; RTEC, ready-to-eat cereal; WC, waist circumference; WG, wholegrain

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