Ready-to-eat cereals and the burden of obesity in the context of their nutritional contribution: are all ready-to-eat cereals equally healthy? A systematic review

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A significant increase in the prevalence of obesity has occurred worldwide and the importance of considering the role of diet in the prevention and treatment of obesity is widely acknowledged. A growing body of evidence encourages the consumption of ready-to-eat cereals (RTEC) as part of a healthful diet. Research has shown an inverse association between the consumption of RTEC and the rate of obesity. However, other findings claim that this association was only attributed to the consumption of whole-grain cereals and not the refined-grain ones. Although meta-analyses of clinical trials support the use of a low-glycaemic index diet on weight loss, findings from other studies on the effect of the dietary glycaemic index on body weight have not been consistent. Thus, further research into the role of glycaemic index in the prevention and management of obesity and chronic disease is needed. Moreover, significant differences have been observed in composition among the marketed RTEC. In light of the revealing protective role of whole-grain, fibre-rich, low-energy-dense and low-glycaemic index/glycaemic load foods against obesity, public health professionals could drive their efforts towards the promotion of even more healthier RTEC when issuing advice on weight management. It seems, however, that despite any differences in their composition, the frequent consumption of RTEC due to their nutritional contribution is recommended in moderation and under the current recommendations in the context of a healthy balanced diet.

Ready-to-eat cereals: Obesity: Nutritional status: BMI

Introduction

The epidemic of obesity took off from about 1980 and in almost all countries has been rising inexorably ever since[1]. Overweight and obesity are key features of the metabolic syndrome and the prevention of excessive weight gain is a health priority internationally[2]. Although the beneficial effects of a healthy diet cannot be linked to a single nutrient[3], it has to be emphasised that a high intake of dietary fibre and whole-grain cereals is a central component of a healthy eating pattern[4]. Increased consumption of whole-grain foods, such as cereals and legumes, may protect against obesity, but concern has been expressed that refined-grain intake may directly contribute to increases in obesity[5]. It has been noted that high levels of carbohydrate consumption, especially from high-glycaemic index (GI) cereals, is a relatively recent phenomenon in evolutionary terms and

attention has been drawn to the correlation between the consumption of refined carbohydrate and the increasing prevalence of obesity[6]. Several reports suggest that diets with a high GI or glycaemic load, or are high in refined carbohydrates, increase the risk of obesity[7–9].

On the other hand, research findings in adults, children and adolescents have demonstrated the beneficial role of an increased consumption of ready-to-eat cereals (RTEC) on their nutritional status[10–20]. In many studies, RTEC are called breakfast cereals or fortified breakfast cereals. In the present review, we prefer to use the term 'ready-to-eat cereals' as these cereals are not necessarily eaten only for breakfast.

The aim of the present review was to evaluate whether RTEC are equally healthy and effective against the burden of obesity in the context of their nutritional contribution.

Study selection

In order to achieve the aim of the present review, we conducted iterative searches in two databases, PubMed and Scopus. Selection criteria included original research articles, as well as review papers, meta-analyses, short communications, letters to the editors, and editorials, written in any language with an English abstract. The search period was set between January 1980 and March 2010. Medical subject heading (MeSH) keywords used to assist allocating the studies were: cereals, ready to eat cereals, breakfast, fortified, body mass index, overweight, obesity, nutritional status, and nutrient intake. After allocating the papers, we expanded the searches reviewing the reference lists and authors of 'key' papers. Selection of articles was restricted to those evaluating body size or weight managements in humans (i.e. BMI, weight in kg, or weight in pounds or body fat). Restriction based on the age of the study participants was not used because there is large variability in eligible age groups among studies. For prospective cohort studies, duration of ≥ 6 months was required for inclusion in the present review, to ensure that sufficient follow-up time was provided to effectively evaluate the relationship between RTEC consumption and weight change. For intervention studies, a sample size greater than twenty-five per intervention group was set, although the latter cannot ensure adequate statistical power. Thus, thirty-seven articles were initially allocated and expanded after reviewing the references lists. After reviewing the aim, design and results of the aforementioned papers, twenty-one research studies (i.e. fifteen observational and six clinical trials) that presented original information were selected and discussed here.

Association between consumption of ready-to-eat cereals with obesity/adiposity

Children and adolescents

Albertson et al. [13] suggested that the consumption of RTEC at breakfast should be encouraged as a component of an eating pattern that promotes the maintenance of healthy body weight and nutrient intakes in children. This cross-sectional study was conducted on a sample of 603 children aged 4–12 years. Results showed that there was a statistically significant inverse relationship between BMI and frequency of RTEC consumption ($P < 0.01$) within each age group as well as for the total sample. The main limitation of the study was the fact that the food records, height and weight were self-reported. Findings from another recent cross-sectional study [21] conducted in 700 children aged 10–12 years provide evidence that daily consumption of breakfast and consumption of breakfast cereal as a most frequent choice are inversely associated with the prevalence of overweight or obesity.

Other researchers concluded that the consumption of breakfast cereals was associated with lower BMI levels and lower likelihood of overweight/obesity, in both sexes, in a sample of 2008 schoolchildren adolescents in a cross sectional study [22]. More specifically, the results showed that compared with no or rare consumption, the daily intake or the intake of more than two daily servings of cereals for breakfast was associated with lower BMI levels in boys and girls ($P < 0.01$). Consumption of cereals as a first choice for breakfast was associated with 33 (95 % CI 14, 48) % lower likelihood of overweight/obesity, irrespective of age, sex and physical activity status. Furthermore, another cross-sectional study [10] conducted in a sample of 392 adolescents (183 boys, 209 girls) aged 15 (SD 0.4) years, showed among others that RTEC consumption was inversely related to the obesity indices. Others have reported similar associations [23–25]. In particular, results from a survey conducted in a sample of 2075 British schoolchildren showed that BMI values were lower among frequent breakfast cereal eaters [23]. In addition, Ortega et al. [24] found that intake of cereals at breakfast was significantly higher among normal-weight children aged 9–13 years [24]. Similarly, Vågstrand et al. [25] found that a low intake of breakfast cereals in boys was correlated significantly with a high body fat percentage ($r_s \pm 0.2$) [25].

In addition, the findings from a cross-sectional study conducted by Williams et al. [16] in a sample of 1389 children aged 1–12 years and including African–Americans showed that the consumption of RTEC at breakfast was associated with improved body weight.

It is worth mentioning that the findings from the 10-year longitudinal biracial observational cohort study (National Heart, Lung, and Blood Institute Growth Health Study) [15,26] are in agreement with the aforementioned associations found in cross-sectional studies. In particular, the National Heart, Lung, and Blood Institute Growth Health Study was conducted in a cohort of females between the ages of 9 and 19 years. The ethnically diverse sample consisted of 2379 girls aged 9 and 10 years at baseline. Specifically, the results showed that the consumption of cereal breakfasts as part of an overall healthful lifestyle may play a role in maintaining a healthful BMI [15]. Moreover, Albertson et al. [26] concluded that girls who ate cereal on a greater percentage of days during childhood had lower percentage body fat and total cholesterol, and were more likely to exhibit high levels of physical activity and less television viewing during study year 10 (P values < 0.05) [26].

In addition, research findings from a recently conducted randomised clinical trial in a sample of 660 children aged 8–10 years at study entry showed, among others, that in boys higher RTEC consumption was associated with lower BMI [17].

However, another intervention study [27] conducted in children aimed among others to determine if an increase in RTEC intake is an effective strategy to reduce excess body weight in overweight or at risk of overweight children. Results showed that a strategy to increase RTEC consumption, as a source of carbohydrate, to reduce obesity, is effective only when accompanied by nutrition education (Table 1).

Adults

Research by Cho et al. [28], conducted on a sample of 16 452 individuals and consisting of data from the Third National Health and Nutrition Examination Survey (NHANES III), showed that not only is breakfast consumption important, but also, that the type of breakfast may be an important

Table 1. Summary of the reviewed studies relevant to the associations of ready-to-eat cereal (RTEC) with obesity/adiposity in children and adolescents

Study	Design	Sample	Measurements	Results
Albertson et al. (2003)[13]	Cross-sectional	603 children, aged 4 to 12 years	RTEC, BMI	Children in the upper tertile had lower mean BMI than those in the lowest tertile consistently across all age groups ($P < 0.01$). Additionally, the proportion of children aged 4–12 years who were at risk for overweight/overweight was significantly lower in the upper tertile of cereal consumption ($P < 0.05$)
Gibson & O'Sullivan (1995)[23]	Cross-sectional	2705 schoolchildren, aged 10–15 years	Breakfast cereal consumption patterns, nutrient intakes, BMI	BMI tended to be lower in the frequent breakfast cereal eaters
Kafatos et al. (2005)[10]	Cross-sectional	392 adolescents, aged 15 (SD 0·4) years (183 boys, 209 girls)	RTEC, health and diet indicators	RTEC consumption was inversely related to the obesity indices
Kosti et al. (2008)[22]	Cross-sectional	2008 students, aged 12–17 years (1021 male, 987 female)	RTEC, BMI, dietary habits, physical activity	Consumption of breakfast cereals was associated with 33 (95 % CI 14, 48) % lower likelihood of overweight/obesity
Ortega et al. (1998)[24]	Cross-sectional	200 schoolchildren, aged 9–13 years	Breakfast habits, BMI	Overweight/obese subjects took significantly smaller quantities of cereals than did normal-weight subjects
Panagiotakos et al. (2008)[21]	Cross-sectional	700 children, aged 10–12 years (323 male, 376 female)	BMI, dietary habits, physical activity, type of breakfast	Adjusted OR for breakfast cereal intake for being overweight or obese was 0·54 (95 % CI 0·45, 1·29), while for girls it was 0·41 (95 % CI 0·21, 0·79). Moreover, the OR of overweight/obesity for boys who ate daily breakfast was 0·51 (95 % CI 0·25, 1·05), and for girls was 0·27 (95 % CI 0·12, 0·64), adjusted for physical activity and other potential confounders
Vågstrand et al. (2007)[25]	Cross-sectional	275 girls and 199 boys, aged 16–17 years	Dietary intake, meal frequency, BF	A low intake of breakfast cereals in boys was correlated significantly with a high BF %
Williams et al. (2009)[16]	Cross-sectional	African–American children (n 1389), aged 1–12 years	Nutrient intake/diet quality and weight status by breakfast consumption patterns	The lowest mean BMI ($P <$ or $= 0.05$) and mean waist circumference ($P <$ or $= 0.05$) was found in children aged 1–12 years who consumed RTEC at breakfast compared with other consumption groups
Albertson et al. (2009)[26]	Prospective	2379 girls	Cereal intake, BF %, waist:hip ratio, lipid levels, and physical activity	Girls who ate cereal on a greater percentage of days during childhood had lower BF % and total cholesterol (P values < 0.05)
Barton et al. (2005)[15]	Prospective	2379 girls, aged 9 and 10 years at baseline	Frequency of consumption of breakfast (cereal v. other foods) and cereal, BMI, dietary fat, fibre, Ca, cholesterol, Fe, folic acid, vitamin C and Zn	Days eating cereal was predictive of lower BMI
Albertson et al. (2009)[17]	Randomised, controlled, clinical trial	Children (n 660), aged 8 to 10 years	RTEC intake, nutrient intake, blood lipids, BMI	Except for energy, RTEC consumption was positively associated with all measures of nutrients. In boys, higher RTEC consumption was associated with lower BMI
Rosado et al. (2008)[27]	Randomised controlled clinical trial	147 children (aged 6–12 years) Intervention groups: (a) One serving of 33 (SD 7) g RTEC for breakfast; (b) one serving of 33 ± 7 g RTEC for breakfast and another one for dinner; (c) one serving of 33 (SD 7) g RTEC for breakfast and a nutrition education programme. (d) Non-intervention, control group	Anthropometry, body composition, physical activity and blood lipids, RTEC intake, nutrition education programme	After 12 weeks of intervention, only the children that received 33 ± 7 g RTEC and nutrition education had significantly lower body weight (− 1·01 (95 % CI − 1·69, − 0·34); $P < 0.01$), lower BMI (− 0·95 (95 % CI − 1·71, − 0·20); $P < 0.01$) and lower total body fat (− 0·71 (95 % CI − 1·71, 0·28); $P < 0.05$) compared with the control group

BF, body fatness.

factor in influencing BMI. Eating cereal, whether cooked or ready to eat for breakfast, is associated with a significantly lower BMI in adults, when compared with either skipping breakfast or consuming other types of breakfast.

Other findings showed that RTEC breakfast consumption was associated with a desirable macronutrient profile for preventing obesity, and predicted weight status in women but not in men[29]. The study sample consisted of 4218 men and women aged ≥ 19 years (National Health and Nutrition Examination Survey). Results showed an inverse association between RTEC breakfast consumption and BMI in women.

Moreover, research findings from a prospective study[30] showed that BMI and weight gain were inversely associated with intake of breakfast cereals independently of other risk factors. The study sample consisted of 17 881 US male physicians aged 40–84 years. Results showed that over 8 and 13 years of follow-up, respectively, men who consumed breakfast cereal, regardless of type (whole or refined breakfast cereals), consistently weighed less than those who consumed breakfast cereals less often ($P < 0.01$).

However, some researchers[31,32] reported that this association was only attributed to the consumption of whole-grain cereals and not the refined-grain ones. In particular, Koh-Banerjee et al. [31] conducted a study in a prospective cohort of 27 082 men aged 40–75 years at baseline. Results showed that an increase in whole-grain intake was inversely associated with long-term weight gain ($P < 0.0001$). A dose–response relationship was observed, and for every 40 g/d increment in whole-grain intake, weight gain was reduced by 0.49 kg. No associations were observed between changes in refined-grain intake and body weight. Similarly, in another prospective study[32] in a sample of 74 091 US female nurses aged 38–63 years, the authors concluded that weight gain was inversely associated with the intake of high-fibre, whole-grain foods, but positively related to the intake of refined-grain foods. This indicates the importance of distinguishing whole-grain products from refined-grain products to aid in weight control.

The protective effect of the consumption of RTEC against obesity has also been found in some intervention studies[33–36]. Particularly, findings from an intervention study[33] showed that eating RTEC after the evening meal may attenuate energy intake in night snackers and promote weight loss in compliant individuals. The study sample consisted of overweight/obese adults (aged 18–65 years) with self-reported night-snacking behaviours. Results showed that there was a correlation between the number of days of compliance with post-dinner cereal consumption and weight loss ($r - 0.36$; $P < 0.057$). In summary, the results of this short-term study show that offering a structured post-dinner snack to overweight or obese night snackers reduces post-dinner energy intake and the total daily energy intake and results in weight loss, which is proportional to compliance. Moreover, another intervention study[34] in adults aimed to determine whether RTEC used as a portion-controlled meal replacement promotes weight loss. The authors concluded that RTEC may be used to promote weight loss when consumed as a portion-controlled meal replacement. Provision of a variety of brands does not compromise efficacy. In another randomised controlled clinical trial[35], conducted in 164 eligible overweight and obese adults, the authors tested the effectiveness of three commercially available partial meal replacement products on weight-loss outcomes. The results showed that a variety of RTEC products may be safely and effectively used as meal replacements in weight-loss programmes. Moreover, in the most recently conducted randomised control study[36], conducted in 204 adults, the authors evaluated whether or not a whole-grain, ready-to-eat oat cereal containing viscous fibre, as part of a dietary programme for weight loss, lowers LDL-cholesterol levels and improves other CVD risk markers more than a dietary programme alone. The results showed that consumption of a whole-grain ready-to-eat oat cereal as part of a dietary programme for weight loss had favourable effects on fasting lipid levels and waist circumference (Table 2).

Effects of consumption of ready-to-eat cereals on nutritional status

The strong association between RTEC consumption and vitamin and mineral intakes demonstrated in many studies suggests that RTEC make a major contribution to micronutrient intakes by increasing the intake of fibre, Ca, Fe, folic acid, vitamin C and Zn, and decreasing the intake of fat and cholesterol[10–20]. In particular, children who eat cereals consume significantly less fat and cholesterol[13]. Moreover, in a randomised, controlled, multicentre, clinical trial, the results showed that except for energy, RTEC consumption was positively associated with all measures of nutrients for both sexes[17]. In particular, in boys, higher RTEC consumption was associated with lower total and LDL-cholesterol levels[17]. Since fortified breakfast cereals are consumed with milk it is not possible to separate the dietary effects of the two foods. Those who have a high intake of breakfast cereal almost certainly consume high milk levels[14,22,37] too.

Specifically, in the frame of the National Heart, Lung, and Blood Institute Growth Health Study, in a sample of 2379 adolescent girls, Albertson et al. [37] tried to examine three possible explanations for the documented association between cereal consumption and positive health outcomes. In particular, the major findings were (1) cereal consumed at breakfast provided more fibre, Fe, folic acid and Zn and less fat, Na, sugar, and cholesterol, compared with the nutrients in foods eaten during non-cereal breakfasts. The cereal consumed provided less protein, carbohydrates and Ca, compared with foods consumed during non-cereal breakfasts; (2) eating cereal for breakfast appeared to facilitate milk consumption (leading to increased Ca intake) and to displace fats/sweets, quick breads, soda, and meat/eggs as breakfast foods. Eating cereal at breakfast was associated with increased consumption of fibre and carbohydrates and decreased consumption of fats throughout the day; and (3) greater physical activity was also associated with eating a cereal breakfast. Thus, the increased intakes of nutrients such as Ca and Zn of breakfast cereal eaters which are found in the literature are most likely due to the milk consumed with them, since breakfast cereals are not typically fortified with, or naturally rich in, these nutrients.

Table 2. Summary of the reviewed studies relevant to the associations of ready-to-eat cereals (RTEC) with obesity/adiposity in adults

Study	Design	Sample	Measurements	Results
Cho *et al.* (2003)[28]	Cross-sectional	16 452 individuals, aged > 18 years	Breakfast type, total daily energy intake, BMI	Subjects who ate RTEC had significantly lower BMI compared with skippers and meat and egg eaters ($P \leq 0.01$)
Song *et al.* (2005)[29]	Cross-sectional	Men and women (*n* 4218), aged ≥ 19 years	Breakfast consumption, RTEC, BMI	Inverse association between RTEC breakfast consumption and BMI in women (regression coefficient -0.37; $P < 0.01$)
Bazzano *et al.* (2005)[30]	Prospective	17 881 males, aged 40–84 years	Breakfast cereal intake, weight, height	Compared with men who rarely or never consumed breakfast cereals, those who consumed ≥ one serving breakfast cereals per d were 22 and 12 % less likely to become overweight during follow-up periods of 8 and 13 years (relative risk 0.78 (95 % CI 0.67, 0.91) and 0.88 (95 % CI 0.76, 1.00), respectively)
Koh-Banerjee *et al.* (2004)[31]	Prospective	27 082 men, aged 40–75 years	Lifestyle factors, body weight	An increase in whole-grain intake was inversely associated with long-term weight gain (P for trend < 0.0001). A dose–response relationship was observed, and for every 40 g/d increment in whole-grain intake from all foods, weight gain was reduced by 0.49 kg. Bran that was added to the diet or obtained from fortified-grain foods further reduced the risk of weight gain (P for trend $= 0.01$), and, for every 20 g/d increase in intake, weight gain was reduced by 0.36 kg
Liu *et al.* (2003)[32]	Prospective	74 091 females, aged 38–63 years	Intake of dietary fibre, whole- or refined-grain products, weight gain	Women in the highest quintile of dietary fibre intake had a 49 % lower risk of major weight gain than did women in the highest quintile (OR 0.51 (95 % CI 0.39, 0.67); $P < 0.0001$ for trend)
Maki *et al.* (2010)[36]	Randomised parallel-arm, controlled trial	Overweight and obese adults (*n* 204) Two portions per d of whole-grain ready-to-eat oat cereal (3 g oat β-glucan per d) or energy-matched low-fibre foods (control)	Fasting lipoprotein levels, waist circumference, triceps skinfold thickness, and body weight were measured at baseline and weeks 4, 8, 10 and 12	Consumption of a whole-grain ready-to-eat oat cereal as part of a dietary programme for weight loss had favourable effects on fasting lipid levels and waist circumference which decreased more (-3.3 (SD 0.4) *v.* -1.9 (SD 0).4 cm; $P = 0.012$) with whole-grain ready-to-eat oat cereal
Mattes (2002)[34]	Randomised controlled clinical trial	Group 1 (six males, twenty-two females, mean age 43.0 (SD 1.9) years, single cereal group) Group 2 (three males, twenty-five females, mean age 40.9 (SD 2.3) years, variety group) Group 3 (seven males, nineteen females, mean age 41.6 (SD 2.4) years, non-diet control group) Group 4 (nine males, eighteen females, mean age 38.2 (SD 2.8) years, diet control group)	Body composition was measured and diet records, appetite questionnaires and activity logs were completed	RTEC may be used to promote weight loss when consumed as a portion-controlled meal replacement. Provision of a variety of brands does not compromise efficacy
Wal *et al.* (2007)[35]	Randomised controlled clinical trial	164 eligible overweight and obese adults, aged 18–65 years: Control group (CN) Three intervention groups: 'Cereal substitution plus nutrient bar' (CB) 'Cereal and waffle substitution plus nutrient bar' (CWB) 'Cereal substitution, no nutrient bar' (CR)	Tested the effectiveness of three commercially available partial meal replacement products on weight-loss outcomes	Compared with the CN group, the CB, CWB and CR groups evidenced significantly greater reductions in weight, BMI, waist, hip and thigh measurements, and the CB and CR groups evidenced significantly greater reductions in percentage body fat
Waller *et al.* (2004)[33]	Randomised clinical trial	Fifty-eight males and females between 18 and 65 years of age, twenty-nine in the no-cereal group and twenty-nine in the cereal groups	Post-dinner cereal consumption, weight loss	There was a correlation between number of days of compliance with post-dinner cereal consumption and weight loss (r -0.36; $P < 0.057$)

In addition, whole-grain breakfast cereals, fruits and vegetables are all important dietary sources of antioxidants[38]. Indeed, literature findings showed that whole-wheat- and wheat bran-based ready-to-eat breakfast cereals could be important sources of dietary antioxidants. Phenolic acids from breakfast cereals possess strong antioxidant activity *in vitro* at concentrations that would be obtained from a normal serving of whole-wheat cereal. Current research on the antioxidant activity of wheat phenolics suggests that further research is warranted to determine the potential benefits of these dietary antioxidants[39]. Moreover, several intervention studies showed that breakfast cereals may be of special help with respect to folate status, serum homocysteine levels and thiamin status in overweight/obese young women following energy-restricting diets[40,41] and that breakfast cereals are an important source of non-haeme Fe and could help to improve Fe status, especially in women with poor initial Fe levels[42]. Furthermore, Melanson *et al.*[43], who conducted an intervention study in a sample of 180 obese adults, found that a hypoenergetic diet with fibre-rich whole-grain cereal is effective for improving or maintaining other aspects of dietary quality during weight loss.

On the other hand, Whittaker *et al.*[44] expressed concerns regarding the analysed values of Fe and folic acid in breakfast cereals, which were found to be considerably higher than the labelled values. However, other researchers concluded that concern for excessive nutrient intakes in those individuals consuming fortified cereals, even in children who have smaller safety margins, is unfounded[12,14]. Moreover, there is a trend towards decreasing Na levels in RTEC contents[45]. Indeed, evidence has shown that there was no significant difference in Na intake between RTEC consumers and non-consumers[14].

A recently published paper has raised serious concerns relevant to the important differences observed in nutritional quality between children's cereals and non-children's cereals[46]. It is worth mentioning that, according to the authors' terminology, cereals that are primarily marketed to children (e.g. packaging contained a licensed character or contained an activity directed at children) were classified as children's cereals while cereals that are not marketed to children were classified as non-children's cereals. Specifically, the authors concluded that compared with non-children's cereals, children's cereals were denser in energy, sugar and Na, but were less dense in fibre and protein. In addition, the authors suggested that the majority of children's cereals (66 %) failed to meet US nutrition standards, particularly with respect to sugar content. However, research findings from recently conducted studies[22,26] in children and adolescents showed that cereal intake was associated with a variety of health outcomes (including lower body fat), after statistically adjusting for the sugar content of cereals consumed[26], and that consumption of pre-sweetened breakfast cereals was associated with lower BMI compared with non-pre-sweetened cereals, in both sexes ($P < 0.001$)[22].

Possible explanations for the observed associations

The relationship between the consumption of RTEC with BMI is difficult to explain. Several explanations could be proposed for the association between cereal consumption and body weight. First, RTEC consumption may be a marker for other healthful lifestyle factors[13]. For example, it has been reported[13] that breakfast consumers are less likely to snack during the morning, a habit, which if repeated daily, could lead to overconsumption of energy.

It is possible that consistent cereal eating is a marker for consistent intake of nutrient-rich foods and/or a tendency to consistently follow a generally healthful lifestyle[15]. Indeed, research findings[37] showed that eating cereal at breakfast tends to displace consumption of other breakfast foods (for example, fats/sweets, quick breads, meats/eggs, soda), which have been shown[28,47] to be associated with high BMI.

Second, RTEC is most frequently consumed with milk[14,22,37], which is a good source of dietary Ca. Zemel[48] showed that dietary Ca modulates circulating calcitriol (1,25-dihydroxyvitamin D) levels that in turn regulate intracellular Ca which affects fat metabolism in human adipocytes.

A portion of this additional anti-obesity bioactivity is attributable to the angiotensin-converting enzyme-inhibitory activity of dairy and to the high concentration of branched-chain amino acids which act synergistically with Ca to attenuate adiposity[48]. Thus, it is possible that the proposed mechanism[48] could be a factor in contributing to the better intake regulation of frequent cereal eaters[13].

Furthermore, some studies[33–35] showed that consuming RTEC may contribute to reduced snacking and portion-controlled meal replacement, both of which might be mechanisms connecting RTEC consumption with reduced BMI.

In addition, it is worth mentioning that the findings from recently conducted prospective studies[26,37] in children and adolescents showed that increased cereal intake is related to lifestyle habits such as high levels of physical activity and reduced television viewing, revealing that lifestyle issues might also have to be taken into serious consideration in our attempt to explain why RTEC intake is associated with lower BMI.

Furthermore, Harnack *et al.*[49] has shown that RTEC is an important food source of whole grains which have been found[50,51] to be inversely associated with obesity, and that cereals and cereal products are the main sources of dietary fibre[4] with an undoubtedly positive effect on BMI status[36,52]. Thus, these findings suggest that additional components in whole grains may contribute to favourable metabolic alterations that may reduce long-term weight gain[31], providing another possible explanation of the observed associations.

Indeed, the disruption and removal of the plant cell-wall material (dietary fibre), as occurs with many types of bakery products and breakfast cereals, results in the loss of their original complement of micronutrients, and the starch and sugar components are often made easily digestible[53]. There is evidence that a greater consumption of slow-release carbohydrates is likely to be associated with health benefits[54]. Thus, food processing techniques that retain or introduce characteristics that slow carbohydrate digestion should therefore generally be encouraged[53]. In addition, concentrations of vitamins, minerals, essential fatty acids and phytochemicals that are important in carbohydrate

metabolism are lower in refined grains[55]. RTEC are high in unrefined carbohydrates (albeit, they may be sugar rich and thus higher in unrefined sugar) and are usually fortified with a range of micronutrients, including Fe, thiamin, riboflavin, niacin, vitamin B_6, folic acid, vitamin B_{12} and vitamin D[14]. However, several varieties of RTEC are high in dietary fibre, as they contain whole grains, bran or dried fruit[14].

Thus, the inherent high fibre content of most whole-grain foods may help prevent weight gain by increasing appetite control through producing a delay in carbohydrate absorption[56]. Moreover, multiple enzyme inhibitors that exist in a whole-grains-fibre complex might directly affect metabolic efficiency[55]. This mechanism might serve as another way whereby whole grains could have beneficial effects on body weight[32].

In addition, the investigation of the effect of low-GI/glycaemic load diets in the prevention of obesity could be another possible, although not yet quite clear, mechanism of the observed associations.

There is now a large body of evidence comprising observational prospective cohort studies, randomised controlled trials and mechanistic experiments in animal models that provides robust support for low-GI carbohydrate diets in the prevention of obesity, diabetes and CVD[57].

Carbohydrate foods with a lower GI may assist in weight management via several mechanisms[58]. By reducing insulinaemia, low-GI foods may provide greater access to fatty acids as a source of fuel, promoting greater fat oxidation. Small differences in substrate oxidation have been found to predict long-term weight gain[58].

Another potentially very important line of research with the GI has been its influence on satiety, hunger, energy intake and ultimately obesity. The evidence from short-term studies suggests that low-GI diets increase satiety and decrease hunger compared with high-GI diets[58,59]. The longer-term benefits for energy balance with low-GI diets have been demonstrated in children as part of an obesity programme[60].

However, results from other studies[61–63] provided no evidence to support an effect of a reduced-GI diet on body weight. Thus, findings from studies on the effect of the dietary GI on body weight have not been consistent[63].

Taking into account that modern carbohydrate staples, including potatoes, breads, breakfast cereals and other processed cereal foods have a high GI, even when high in fibre[64], it seems that the controversies observed between low- and high-GI/glycaemic load diets and health effects could not be explained by claims that the GI of the diet *per se* may have specific effects on body weight, and therefore such claims may be misleading[62].

Thus, although a large body of evidence supports the current popularity of low-GI diets, further research into the role of GI in the prevention and management of obesity and chronic disease is needed, since it seems that the associations between RTEC and obesity may be best explained via multiple mechanisms.

Conclusions

Although it is clear and well documented that the consumption of RTEC contributes to a better diet, it should, however, be recognised that the nutritional contribution derived from the unique structural food matrix components found in largely unprocessed foods[53] is indispensable. There is also strong evidence that RTEC has a protective role against obesity. However, future research examining the benefits of cereal consumption should differentiate between cereals that are higher in nutrient density (i.e. non-children's cereals) and those that are lower in nutrient density (i.e. children's cereals)[46]. Moreover, taking into account that, first, several varieties of RTEC are high in dietary fibre, as they may contain whole grains, bran or dried fruit[14], second, the total dietary fibre content of cereals varies from 10 to 15 %, third, the content of soluble fibre varies from 20 % (wheat) to approximately 50 % (oats)[65], and, fourth, breakfast cereals are available in both high- and low-GI versions[66], there are quite significant differences in composition among the marketed RTEC. Thus, the reported benefits of RTEC might be more pronounced among the more nutrient-dense cereals and among the more fibre-rich cereals. So, the need for further research among the different types of RTEC is warranted. Thus, it is recommended that dietary advice for children and adults to increase consumption of RTEC should identify and recommend those cereals with the best nutrient and functional profiles against the burden of obesity.

The independent effect of bran, germ and different types of fibre, such as non-digestible oligosaccharides, on body weight is not known and should be further investigated[67].

With some types of dietary carbohydrates being more protective against the risk of obesity, a future strategy could be applied by public health professionals in issuing advice on even healthier RTEC.

Nevertheless, more studies are needed, especially large-scale, randomised clinical trials. Moreover, food labelling will guide the consumer towards RTEC that are less energy-dense, have higher fibre content and are more compatible with maintaining good health.

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