

Plant foods and plant-based diets: protective against childhood obesity?^{1–3}

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ABSTRACT

The objective of this article is to review the epidemiologic literature examining the role of plant foods and plant-based diets in the prevention of childhood obesity. Available data suggest a protective effect of ready-to-eat cereal on risk of obesity, although prospective studies are still needed. Studies on fruit and vegetables; grains other than cereal; high-protein foods, including beans, legumes, and soy; fiber; and plant-based dietary patterns are inconsistent or generally null. The evidence base is limited, and most studies are fraught with methodologic limitations, including cross-sectional design, inadequate adjustment for potential confounders, and lack of consideration of reporting errors, stage of growth, and genetic influences. Well-designed prospective studies are needed. The lack of evidence showing an association between plant-based diets and childhood obesity does not mean that such diets should not be encouraged. Plant foods are highlighted in the Dietary Guidelines for Americans, and children do not meet the current recommendations for most plant foods. Although the advice to consume a plant-based, low-energy-dense diet is sound, ethical questions arise concerning the relatively high price of these diets in the United States and the way in which such diets are perceived in other parts of the world. Reducing the burden of childhood obesity, eliminating health disparities, and preventing the further spread of the disease around the globe will require not only policy interventions to ensure that plant foods are affordable and accessible to children of all income levels but also awareness of sociocultural norms that affect consumption. *Am J Clin Nutr* 2009;89(suppl):1572S–87S.

INTRODUCTION

Plant foods and plant-based diets, as well as vegetarian diets, are associated with health promotion and disease prevention in adults, as discussed throughout the Fifth International Congress on Vegetarian Nutrition. Little is known, however, about the role of plant-based diets in child health and, more specifically, about their potential role in the prevention of childhood obesity. Small studies of vegetarian children performed in the 1970s and 1980s showed that vegetarian children tended to be lighter and leaner than nonvegetarian children (1–5). Vegetarian diets may be preferable to omnivorous diets because of myriad environmental and ethical reasons, if not because of human health promotion and disease prevention. Yet, the prevalence of vegetarianism among children in the United States is quite low, estimated at 2–3% according to a nationally representative sample of youths aged 8–18 y in 2005 (6). From a public health perspective, it is

therefore important to consider the health benefits of plant foods and plant-based diets rather than to focus only on frank vegetarian diets.

The global burden of childhood obesity is profound, and currently 1 child in 10 is overweight or obese worldwide (7, 8). The prevalence of childhood obesity is highest in the United States, where 33.6% of children aged 2–19 y were overweight or obese in 2003–2004, of whom 17.1% were obese (9). Health disparities are evident: Mexican American children have the greatest burden, with 37.0% overweight or obese, followed by non-Hispanic blacks (35.1%) and non-Hispanic whites (33.5%) (9). Obesity poses a significant threat to the current and future health of children and leads to a broad range of physical and psychosocial health consequences (8, 10, 11). Because of the difficulty in treating obesity, expert committees agree that preventing excess weight gain is the key (12, 13)—indeed, it is the only feasible solution (8)—to stemming the obesity epidemic.

The goal of this article is to discuss the peer-reviewed epidemiologic literature on the association between a plant-based diet and childhood obesity, including fruit and vegetables; grains and cereals; high-protein foods such as beans, legumes, and soy; fiber; and plant-based dietary patterns. Studies on obesity treatment, animal studies, and studies in adults are not included because of space limitations. The article also notes methodologic challenges and directions for future research and concludes by highlighting ethical considerations surrounding dietary advice to consume a plant-based diet in the United States and abroad.

FRUIT AND VEGETABLES

Fruit and vegetables are important sources of fiber and micronutrients, but data from National Health and Nutrition Exami-

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nation Survey 1999–2000 indicate that children consume far less than currently recommended in MyPyramid (14), ranging from 3.4 ± 0.2 total servings/d for girls aged 4–8 y to 4.2 ± 0.3 servings/d for girls aged 14–18 y, with slightly higher intakes among boys for each age group (3.5 ± 0.2 and 4.6 ± 0.3 servings/d, respectively) (15). Fruit and vegetables are low-energy-dense foods that contribute to satiety and satiation; they may also displace other high-energy-dense foods from the diet such as salty snacks or baked goods. Intake of fruit and vegetables increased slightly with rising income among US adults (16).

Fourteen studies examining fruit and vegetable consumption in relation to childhood obesity have been performed to date, including 3 prospective studies, 10 cross-sectional studies, and 1 case-control study (Table 1). Prospective studies do not show a protective association between fruit or vegetable consumption and childhood obesity. Among preschool children aged 2–5 y, consumption of fruit (with or without fruit juice) and vegetables (with or without potatoes) was not significantly related to changes in body mass index (BMI; in kg/m^2) or weight in models adjusted for dietary and nondietary confounders (17). These findings are consistent with a recent report among children of similar age, which also observed no significant associations between BMI z score and fruit (excluding juice), potatoes, carrots, or total vegetables (excluding potatoes and carrots) (18). Likewise, fruit intake (with or without juice) was not significantly associated with change in BMI z score in a prospective study among children aged 9–14 y (19). In that study, Field et al (19) did observe a significant inverse association with vegetables and change in BMI z score; although the association was no longer significant when energy was included in the model, energy is likely a mechanism by which fruit and vegetables exert an effect on body weight.

With a few exceptions (20–22), most cross-sectional and descriptive studies do not show a protective association between fruit and vegetable consumption and obesity in children, or findings were inconsistent across age and sex groups (23–29). For example, weekly consumption of vegetables was inversely associated with prevalence of obesity [odds ratio (OR): 0.78; 95% CI: 0.62, 0.98] among Mexican boys aged 6–7 y, but it was not significant among girls the same age or among older boys and girls aged 13–14 y (24). A small case-control study also showed no significant association between fruit and vegetable intakes and risk of overweight (30). Although these studies have methodologic limitations, mostly related to insufficient control of potential confounders, the descriptive data are consistent with the null results observed in well-designed prospective studies. Separating fruit and vegetables by nutrient composition and glycemic index value in several studies did not affect results. These findings are consistent with an earlier review (31), which focused on studies among adults but also included 2 studies among children.

In summary, available data do not support a protective effect of fruit and vegetable consumption on the risk of childhood obesity. These findings are consistent with an earlier review (31), which focused on studies among adults but also included 2 studies among children. Perhaps preparation of fruit and vegetables, which contributes to variation in energy intake, energy density, and macronutrient composition, modifies their effect on body weight (23, 31). Although some studies separated French fried potatoes from other potatoes, this strategy could also be ex-

tended to other vegetable and fruit preparations (eg, broccoli served steamed compared with in a creamy cheese sauce). Likely, differences in cooking and preparation methods reflect different overall dietary patterns, which perhaps are the more meaningful unit of analysis and better poised to elucidate the role of diet in the development of overweight (discussed in Plant-based Dietary Patterns).

GRAINS AND READY-TO-EAT BREAKFAST CEREAL

Grain foods, including whole grains as well as foods made from grains such as bread, tortillas, pasta, polenta, and ready-to-eat (RTE) cereals, are the foundation of most diets. The staple grain consumed by both children and adults varies by geographic region and culture and may be rice, wheat, or corn. Because of the limitation or exclusion of animal products, plant-based diets are often quite high in grain foods. Grains and cereals are high in carbohydrates, thus less energy-dense than high-fat foods because of fewer calories per gram. Children in particular are major consumers of grains, especially yeast bread and RTE cereal (32), but intakes of whole grains are low, ranging from 0.8 servings/d for preschoolers to 1.0 servings/d for adolescents (33).

Most research on grain foods in children has focused on RTE cereal and includes 1 prospective study and 7 cross-sectional studies (Table 2). RTE cereal consumption is associated with higher overall diet quality in children, including higher intakes of micronutrients and lower intakes of total and saturated fat (34–37). Most descriptive studies show that frequency of cereal consumption is associated with lower body fat (21, 29, 36–39), although inconsistencies are again observed across age and sex groups (21, 29, 39). Although Kafatos et al (37) adjusted their models for many important confounders, such as fitness and television viewing, many of the other studies had limited (39) or no (21, 29, 35) control for potential confounding or did not specify (24). Of note, in a model adjusted for age, sex, and physical activity, choosing RTE cereal for breakfast rather than other foods was associated with a 0.67 risk of overweight (95% CI: 0.52, 0.98) in a study of Greek adolescents (39). It is possible, however, that factors such as other dietary intakes or parental body weight could be confounding this observed association. Two cross-sectional studies examined associations with central obesity, reporting inverse associations with waist circumference among adolescents (21, 37). Only one longitudinal study has been performed to my knowledge, showing that cereal consumption was related to a smaller BMI z score and decreased risk of overweight among black and white girls aged 9–19 y participating in the National Heart, Lung, and Blood Institute Growth and Health Study in a multivariate-adjusted model (34).

The study of grain foods other than RTE cereal has received less scientific attention. Only one study examined prospectively the association between breads and grains and obesity among preschool children, showing a 0.16-kg smaller weight gain per year (95% CI: -0.20 , -0.12 ; $P < 0.01$) with each additional daily serving (17). Weekly consumption of pasta was also inversely associated with prevalence of obesity in a cross-sectional study, although relations were inconsistent across age and sex groups (24). Breads were not significantly associated with odds

TABLE 1
Studies examining the association between fruit and vegetable intakes and childhood obesity¹

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Prospective			
Faith et al, 2006 (18)		Fruit and vegetable servings/d were NS associated with monthly change in BMI z score ($\beta = 0.001$, SE = 0.002, $P = 0.76$, and $\beta = -0.002$, SE = 0.002, $P = 0.52$, respectively).	Models were multivariate adjusted for dietary variables, parent feeding variables, and baseline anthropometrics but not for other potential confounders.
Subjects (<i>n</i>)	2801		
Age (y)	1–4		
Dietary assessment	BRFSS-style survey		
Country (state)	United States (NY)		
Field et al, 2003 (19)		Change in fruit intake (in servings/d) was NS associated with annual change in BMI z score in girls ($\beta = -0.001$; 95% CI: -0.013 , 0.010) or boys ($\beta = 0.007$; 95% CI: -0.0008 , 0.022). Change in vegetable intake (in servings/d) was NS associated with annual BMI change in girls ($\beta = 0.012$; 95% CI: -0.002 , 0.026) and boys ($\beta = 0.000$; 95% CI: -0.020 , 0.019). Vegetable servings at baseline were inversely associated with change in BMI z score in boys but not girls but not when energy was included in the model.	Models were multivariate adjusted for many potential confounders, such as physical activity and television viewing. Many regression models were tested.
Subjects (<i>n</i>)	14,918		
Age (y)	9–14		
Dietary assessment	FFQ		
Country (state)	United States (multistate)		
Newby et al, 2003 (17)		Fruit and vegetable servings/d were NS associated with annual weight change ($\beta = 0.02$, SE = 0.03, $P = 0.53$, and $\beta = 0.02$, SE = 0.03, $P = 0.53$, respectively).	Models were multivariate adjusted for many potential confounders but did not include physical activity.
Subjects (<i>n</i>)	1379		
Age (y)	2–5		
Dietary assessment	FFQ		
Country (state)	United States (ND)		
Cross-sectional studies			
Colapinto et al, 2007 (25)		Larger portions of vegetables were NS associated with overweight (OR: 1.11; 95% CI: 0.99, 1.24).	Regression model only adjusted for sex.
Subjects (<i>n</i>)	4966		
Age (grade)	5		
Dietary assessment	FFQ		
Country	Canada		
Humenikova and Gates, 2007 (26)		Fruit and vegetable servings/d were NS associated with BMI (data not shown).	Important confounders (eg, parental BMI, physical activity) were included in the model. Statistical power is probably low because of small sample size.
Subjects (<i>n</i>)	97		
Age (grade)	4–6		
Dietary assessment	Two 24-h recalls		
Country	Czech Republic		
Roseman et al, 2007 (22)		Healthy weight students consumed significantly more servings of vegetables and fruit than did overweight children or those at risk for overweight ($P < 0.01$ for all).	This descriptive study showed mean intakes that were not adjusted for potential confounders.
Subjects (<i>n</i>)	4049		

(Continued)

TABLE 1 (Continued)

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Vågstrand et al, 2007 (29)	Age (grade) Dietary assessment Country (state) Subjects (n) Age (y) Dietary assessment Country	Middle school YRBS questionnaire United States (KY) 494 6–17 FFQ Sweden	Fruit (% of energy) was NS correlated to percentage of body fat in girls ($r = 0.08$) or boys ($r = 0.04$) in $n = 296$ plausible reporters ($P > 0.05$ for both). Stepwise logistic regression was used. No data were provided.
Wang et al, 2007 (28)	Subjects (n) Age (grade) Dietary assessment Country (state)	458 5–7 FFQ United States (IL)	Fruit, vegetable, and green salad intakes were NS associated with overweight (data not shown).
Violante et al, 2005 (24)	Subjects (n) Age (y) Dietary assessment Country	8624 6–7 and 13–14 FFQ-style survey Mexico	Vegetables consumed weekly were inversely associated with obesity prevalence (OR: 0.78; 95% CI: 0.62, 0.98) in boys 6–7 y but not age 13–14 y. Weekly consumption of fruit was inversely associated with obesity prevalence (OR: 0.78; 95% CI: 0.59, 1.01) in girls age 6–7 y but not age 13–14 y.
Kelishadi et al, 2003 (20)	Subjects (n) Age (y) Dietary assessment Country	2000 11–18 FFQ Iran	Fruit and vegetable servings/d were inversely associated with BMI (respectively, $\beta = -0.04$, $P = 0.02$, and $\beta = -0.05$, $P = 0.04$).
Lin and Morrison, 2002 (23)	Subjects (n) Age (y) Dietary assessment Country	3064 5–18 Two 24-h recalls United States	Compared with those not overweight, overweight boys consumed significantly fewer vegetables and fruit (2.5 compared with 2.9 servings/d) and overweight girls consumed significantly less fruit (1.2 compared with 1.5 servings/d)
Baric et al, 2001 (21)	Subjects (n) Age (y) Dietary assessment Country	575 Not specified FFQ Croatia	Fruit servings/d were inversely correlated with body fat in children ($r = -0.20$, $P < 0.05$; mean age: 8.9 y) but not adolescents (mean age: 16.0 y). (Associations were NS for BMI). Associations for vegetables and BMI were NS for both children and adolescents.

(Continued)

TABLE 1 (Continued)

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Hanley et al, 2000 (27)		The highest quartile of vegetable intake defined with the use of a vegetable scale was NS associated with at risk for overweight (BMI \geq 85th percentile) (OR: 0.52; 95% CI: 0.23, 1.21).	The point estimate suggests a risk reduction, although the finding was NS. The model was only adjusted for age and sex.
Subjects (n)	242		
Age (y)	10–19		
Dietary assessment	FFQ		
Country	Canada		
Case-control			
Tanasescu et al, 2000 (30)		Fruit and vegetable intakes were NS associated with risk of overweight (BMI \geq 85th percentile) (data not shown).	Models were multivariate adjusted for variables such as parental BMI and television viewing. Statistical power is probably low because of very small sample size.
Subjects (n)	57		
Age (y)	7–10		
Dietary assessment	FFQ		
Country (state)	United States (CT)		

¹ BRFSS, Behavioral Risk Factor Surveillance System; FFQ, food-frequency questionnaire; YRBS, Youth Risk Behavior Survey; OR, odds ratio; NS, nonsignificant(ly).

TABLE 2
Studies examining the association between grain foods and ready-to-eat (RTE) cereal intakes and childhood obesity¹

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Prospective			
Barton et al, 2005 (34)	Subjects (n) Age (y) Dietary assessment Country (state)	Days eating RTE cereal were inversely associated with BMI z score ($\beta = -0.015$, SE = 0.005, $P < 0.001$). Compared with girls who ate cereal on 0 d, girls who ate cereal on 1, 2, or 3 d were 0.93, 0.90, and 0.87 as likely at risk for overweight ($P < 0.01$).	Longitudinal study with repeated measures of diet and other variables; models were adjusted for many important confounders.
Newby et al, 2003 (17)	Subjects (n) Age (y) Dietary assessment Country (state)	Bread and grain servings were inversely associated with annual weight change ($\beta = -0.16$, SE = 0.04, $P < 0.001$).	Models were multivariate adjusted for many potential confounders but did not include physical activity.
Cross-sectional studies			
Kosti et al, 2008 (39)	Subjects (n) Age (y) Dietary assessment Country (state)	Increasing consumption of RTE cereal (servings/d) was significantly associated with lower BMI in girls ($P = 0.019$) but not boys ($P = 0.08$). Choosing RTE cereal for breakfast was inversely associated with overweight or obesity (OR: 0.67; 95% CI: 0.52, 0.86).	Models were adjusted for age, sex, and physical activity but not other potential confounders.
Vågstrand et al, 2007 (29)	Subjects (n) Age (y) Dietary assessment Country	RTE cereal (% energy) was significantly correlated with percentage body fat measured with densitometry in boys ($r = -0.20$, $P < 0.05$) in plausible reporters ($n = 296$). NS associations with girls ($r = -0.12$, $P > 0.05$).	This study accounted for dietary underreporting. No adjustment was made for potential confounders.
Kafatos et al, 2005 (37)	Subjects (n) Age (y) Dietary assessment Country	Compared with non- and occasional consumers of RTE cereal (servings/d), daily consumers had a lower BMI (P for trend: 0.025), smaller waist circumference (P for trend = 0.04), and lower waist-to-hip ratio (P for trend = 0.01).	Models were multivariate adjusted for important confounders, including fitness and television viewing.
Violante et al, 2005 (24)	Subjects (n) Age (y) Dietary assessment Country	Weekly consumption of pasta was inversely associated with obesity prevalence (OR: 0.79; 95% CI: 0.64, 0.98) in boys 6–7 y, girls 6–7 y (OR: 0.70; 95% CI: 0.56, 0.88), girls 13–14 y (OR: 0.76; 95% CI: 0.60, 0.96). Rice was NS associated for all age or sex groups.	Inconsistent associations across age and sex strata. Unclear whether models were adjusted for potential confounders.
	Subjects (n) Age (y) Dietary assessment Country	8624 6–7 and 13–14 FFQ-style survey Mexico	

(Continued)

TABLE 2 (Continued)

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Albertson et al, 2003 (36)		A higher percentage of children consuming ≤ 3 servings/d RTE cereals were at risk for overweight (47.4%) than were those consuming 4–7 servings/d (36.7%) or ≥ 8 servings/d (21.3%) ($P < 0.001$).	Models were not adjusted for any potential confounders.
Subjects (<i>n</i>)	603		
Age (y)	4–12		
Dietary assessment	14-d diet record		
Country (state)	United States (multistate)		
Kelishadi et al, 2003 (20)		Bread, rice, and pasta servings/d were directly associated with BMI (respectively, $\beta = 0.05$, $P = 0.04$; $\beta = 0.06$, $P = 0.03$; and $\beta = 0.03$, $P = 0.04$).	Models were not adjusted for any potential confounders.
Subjects (<i>n</i>)	2000		
Age (y)	11–18		
Dietary assessment	FFQ		
Country	Iran		
Steffen et al, 2003 (40)		Whole grains were inversely associated with mean BMI (kg/m^2): 23.6 for children consuming < 0.5 serving/d, 22.6 for 0.5–1.5 servings/d, and 21.9 for > 1.5 servings/d (P for trend = 0.05). Inverse associations were also observed for waist circumference: 81.4 cm for children consuming < 0.5 serving/d, 78.3 cm for 0.5–1.5 servings/d, and 76.8 cm for > 1.5 servings/d (P for trend = 0.02). Refined grains were NS associated with BMI or waist circumference (data not shown).	Models were adjusted for many important confounders, including Tanner stage and physical activity.
Subjects (<i>n</i>)	285		
Age (grade)	5–8		
Dietary assessment	FFQ		
Country (state)	United States (MN)		
Baric et al, 2001 (21)		RTE cereal (servings/d) were inversely correlated with body fat measured with an electronic scale in children ($r = -0.34$, $P < 0.001$; mean age: 8.9 y) but not adolescents (mean age: 16.0 y). (Associations were NS for BMI.)	Body fat was measured with an electronic scale. No adjustment was made for potential confounders.
Subjects (<i>n</i>)	575		
Age (y)	Not specified		
Dietary assessment	FFQ		
Country	Croatia		
Hanley et al, 2000 (27)		“Bread foods” were NS associated with a risk for overweight (BMI ≥ 85 th percentile) (OR: 1.16; 95% CI: 0.52, 2.59, fourth quartile compared with first quartile).	Model was only adjusted for age and sex.
Subjects (<i>n</i>)	242		
Age (y)	10–19		
Dietary assessment	One 24-h recall		
Country	Canada		
Gibson et al, 1995 (35)		Increasing consumption of RTE cereal (0 to > 40 g/d) was associated with lower BMI in girls and boys ($P < 0.05$ for both).	This descriptive study presented only mean BMI with no adjustments for potential confounders.
Subjects (<i>n</i>)	2705		
Age (y)	10–15		
Dietary assessment	7-d diet record		
Country	England		

(Continued)

TABLE 2 (Continued)

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Case-control Tanasescu et al, 2000 (30)		Breads and cereals were NS associated with obesity in a multivariate-adjusted model (data not shown).	Models were multivariate adjusted for variables such as parental BMI and television viewing. Statistical power was probably low because of very small sample size.
Subjects (<i>n</i>)	57		
Age (y)	7–10		
Dietary assessment	FFQ		
Country (state)	United States (CT)		

¹ FFQ, food-frequency questionnaire; OR, odds ratio; NS, nonsignificant(y).

of overweight in one cross-sectional study (OR: 1.16; 95% CI: 0.52, 2.59) (27) or in a small case-control study (30). Conversely, intakes of bread, rice, and pasta were directly (although weakly) associated with BMI among boys and girls, although this study did not adjust for potential confounders (20). Only one study measured whole-grain consumption, showing inverse relations with both BMI (*P* for trend: 0.05) and waist circumference (*P* for trend: 0.02) in 285 adolescents; no association was observed between refined grain intake and BMI (40).

In summary, research is somewhat consistent in showing that RTE cereal is protective against weight gain and obesity in children, but prospective studies with better adjustment for potential confounders (dietary and otherwise) are needed; limited evidence supports a protective association of RTE cereal and whole grains on waist circumference. Few studies on other grain foods have been conducted, and findings are inconsistent. Conflicting results may be due to grouping dissimilar types of foods together (eg, pasta, pizza, crackers, bread), as well as whole and refined grains and their products; these foods can differ considerably in nutrient composition and therefore exert different physiologic effects. A recent review of observational and intervention studies concluded that there is strong evidence to show that whole grains are associated with lower body weight, smaller waist circumference, and less risk of obesity and weak evidence to show a direct association between intakes of refined grains and waist circumference (41). Most studies in that review were in adult populations, however. Taking into consideration the studies in children discussed herein, it is clear that further research on grain intakes and obesity in children is warranted, especially because these foods play such a dominant role in children's diets. Fiber, resistant starch, and whole-grain content of grain foods should be considered, as well as glycemic index values, because these properties will affect physiologic effects, hence effects on appetite and weight regulation.

BEANS, LEGUMES, AND SOY

Protein-rich plant foods such as beans, legumes, and soy products play a special role in vegetarian and plant-based diets to meet human protein needs for growth and health. Although intakes of these foods are higher in other parts of the world (eg, beans in Mexico, soy products in Japan), consumption among Americans is low. For example, American boys aged 4–18 y consumed 0.2 ± 0.0 legume servings/d and girls the same age consumed 0.1 ± 0.0 servings/d—far less than the recommended 0.9 servings/d (for a sedentary person) (15). Proteins from soy and other plant foods are higher in nonessential amino acids compared with proteins from animal foods; thus, they may favorably affect insulin sensitivity (42). In particular, legume protein is more slowly absorbed than animal protein, and isolated soy protein increases the release of glucagon, which both enhances fat oxidation and inhibits lipogenesis by down-regulating lipogenic enzymes (43).

Perhaps because of the limited consumption of these foods among children, dietary studies are few and none focused on these foods. Four cross-sectional studies included protein-rich foods in their analysis. Kelishadi et al (20) found neither soy

nor nuts were associated with BMI among Iranian adolescents aged 11–18 y ($r = 0.02$, $P = 0.48$, and $r = 0.01$, $P = 0.57$, respectively). The point estimate for nuts in a study of girls aged 6–7 y in Mexico City was suggestive of a protective association with obesity, although the result was not statistically significant (OR: 0.75; 95% CI: 0.40, 1.03); pulses also were not significantly associated with obesity (OR: 1.18; 95% CI: 0.98, 1.40) (24). Puerto Rican children who were obese consumed fewer servings of legumes per day (0.57 ± 0.46 servings/d) compared with nonobese controls (0.75 ± 0.70 servings/d), but differences were not significant ($P = 0.26$), and legumes were not associated with obesity in a multivariate-adjusted regression model (30). Although not focused on food intakes, an elegant longitudinal study in 203 German children found that in a multivariate-adjusted model those in the highest tertile of vegetable protein intake at age 5–6 y had a lower percentage of body fat at age 7 y than did children in the lowest tertile (16.98% compared with 17.42%; $P = 0.05$). However, associations were not significant for BMI z score (0.16 compared with 0.03; $P = 0.20$) and were not significant when intakes at 1 y of age were used to predict body fat at 7 y of age with either percentage of body fat or BMI z score (44).

Although findings from the above-mentioned studies are not significant, the paucity of data on the topic and inadequate attention to potential confounders and small sample size (ie, limited statistical power) prevent any meaningful conclusions. Insufficient evidence on the relation between legumes and body weight also exists in the adult literature (41). Given the important role these protein-rich foods play in a plant-based diet, more research is warranted.

FIBER

Plant foods are quite rich in many different types of fibers. Fiber contributes limited energy to the diet (≈ 2 kcal/g), and both soluble and insoluble fibers were shown to increase satiety and decrease subsequent hunger (45). Mechanisms, including a slower rate of gastric emptying, reduced postprandial glycemic and insulinemic effects, and metabolism of short-chain fatty acids in the gut, can reduce energy intake within and between meals (41, 46).

Fiber is often a marker of a healthy diet, as seen in children in the Bogalusa Heart Study aged 10–17 y, among whom those with higher fiber intakes consumed less total and saturated fat (47). However, fiber consumption among children in the third National Health and Nutrition Examination Survey 1988–1994 was quite low—10.7 g/d for children aged 2–5 y, 13.4 g/d for children aged 6–11 y, and 14.6 g/d for children aged 12–18 y (41)—and did not come close to current Dietary Reference Intakes (48). Indeed, only 12% of preschool children aged 2–5 y met the current Dietary Reference Intakes in 1994–1996 (49).

Studies examining the association between fiber intakes and childhood obesity are shown in **Table 3** and include 2 prospective studies and 8 cross-sectional studies. Both prospective studies were well designed and adequately controlled for potential confounders, and neither observed a significant association with either annual weight change in preschool children ($\beta = 0.001$, SE = 0.02, $P = 0.97$) (17) or annual BMI

change in adolescent girls ($\beta = -0.0031$, SE = 0.0043, $P = 0.465$) or boys ($\beta = 0.0025$, SE = 0.0049, $P = 0.610$) (50). Similarly, cross-sectional studies among New Zealand children aged 2–5 y (51), Belgian children aged 6–12 y (52), American children aged 9–10 y (53), Czech children in grades 4–6 (26), and Croatian children aged 8.9 and 16.9 y (on average) (21) showed no significant association between fiber intake and measures of body fat. One cross-sectional study found that fiber consumption was associated with a decreased risk of overweight among Native Canadian children (OR: 0.69; 95% CI: 0.47, 0.99) (27), whereas a descriptive study showed significantly lower intakes in overweight boys but not girls in Greece (54).

Fiber content is likely one of the main mechanisms through which plant foods could be related to childhood obesity, although the current evidence in children is limited, and only one cross-sectional study showed a significant protective effect. Studies in adults have shown that the effect of fiber on food intake and body weight depends on food source as well as fiber type (55, 56). In one study, wheat bran had no effect on energy intake or body weight among adults, but cellulose, guar, and psyllium were inversely associated with body weight (56). Cereal fiber was inversely associated with BMI (57, 58) and weight gain (59) in adults. Koh-Banerjee et al (59) also showed a protective effect of total fiber and fruit fiber, but not vegetable fiber, on weight gain in women. Prospective studies are needed to further examine the role of fiber in maintaining body weight and in preventing obesity among children, and future research might separately consider different types of fibers to better understand the association. As with the study of RTE cereal, careful consideration of potential confounding is needed, because fiber is often a marker of a healthy diet and is also associated with other healthy lifestyle behaviors.

PLANT-BASED DIETARY PATTERNS

The study of dietary patterns, in which many dietary items (eg, foods, food groups, nutrients) are grouped together to provide a picture of “total” diet, has gained popularity in nutritional epidemiology in recent years (60, 61). A handful of studies have used the dietary pattern approach among children in the United States (62), Germany (63), Korea (64), and Australia (65); the latter 2 studies observed plant-based dietary patterns and examined associations with obesity.

McNaughton et al (65) derived 3 patterns in 764 Australian adolescents, of which 2 were plant-based (fruit-salad-cereals-fish pattern and vegetables pattern); neither of these patterns was significantly associated with BMI in models adjusted for age, sex, and physical activity, with subjects in the lowest and highest tertiles having a similar BMI (22.6 ± 0.4 for the fruit pattern in both tertiles 1 and 3, 22.6 ± 0.4 for the vegetables pattern in tertile 1, and 22.3 ± 0.4 for tertile 3) (65). Similar null associations were seen for waist circumference (65). Shin et al (64) also derived 3 patterns in Korean preschool children, one of which was high in vegetables, seaweeds, beans, fruit, and dairy products (Korean Healthy); sweets and animal foods patterns were also observed. Although the Korean healthy pattern was not significantly associated with decreased risk of overweight, children in the highest quintile of

TABLE 3
Studies examining the association between fiber intakes and childhood obesity⁷

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Prospective Newby et al, 2003 (17)	Subjects (<i>n</i>) Age (y) Dietary assessment Country (state)	Fiber (g/d) was NS associated with annual weight change ($\beta = 0.001$, SE = 0.02, $P = 0.97$).	Models were multivariate adjusted for many potential confounders but did not include physical activity.
Berkey et al, 2000 (50)	Subjects (<i>n</i>) Age (y) Dietary assessment Country	Change in fiber intake (g/d) was NS associated with annual BMI change in girls ($\beta = -0.0031$, SE = 0.0043, $P = 0.465$) or boys ($\beta = 0.0025$, SE = 0.0049, $P = 0.610$).	Models were multivariate adjusted for many potential confounders, such as physical activity and television viewing. Many regression models were tested.
Cross-sectional studies Humenikova and Gates, 2007 (26)	Subjects (<i>n</i>) Age (grade) Dietary assessment Country	Fiber was NS associated with BMI (data not provided).	Important confounders (eg, parental BMI, physical activity) were included in the model. Statistical power is probably low because of small sample size.
Vågstrand et al, 2007 (29)	Subjects (<i>n</i>) Age (y) Dietary assessment Country	Fiber (g/mJ) was directly associated with percentage of body fat measured with densitometry in girls ($r = 0.22$, $P < 0.01$) but not boys ($r = 0.08$, $P > 0.05$) in adequate reporters ($n = 297$).	This study accounted for dietary underreporting. No adjustment was made for potential confounders.
Hassapidou et al, 2006 (54)	Subjects (<i>n</i>) Age (y) Dietary assessment Country	Fiber intakes were significantly lower in overweight boys than in nonoverweight boys (15 ± 9.7 g/d compared with 19 ± 11.4 g/d; $P < 0.05$); intakes were NS different among girls.	This descriptive study presented only mean intakes with no adjustments for confounders. Inconsistent effects were observed across sex strata.
Grant et al, 2004 (51)	Subjects (<i>n</i>) Age (y) Dietary assessment Country	Fiber intakes in the <95th percentile BMI were NS different from those in the ≥ 95 th percentile BMI (respectively, 9.3 ± 4.9 g/d compared with 11.5 ± 4.9 g/d; $P > 0.05$).	Mean intakes were adjusted for age and sex only.
	Subjects (<i>n</i>) Age (y) Dietary assessment Country		

(Continued)

TABLE 3 (Continued)

Studies (reference)	Study sample and dietary assessment	Findings	Comments	
Baric et al, 2001 (21)	Subjects (<i>n</i>) Age (y) Dietary assessment Country	Fiber (% energy) was NS associated with BMI or body fat in either children (mean age: 8.9 y) or adolescents (mean age: 16.0 y) (data not shown).	Body fat was measured with an electronic scale. No adjustment was made for potential confounders.	
Hanley et al, 2000 (27)	575 Not specified FFQ Croatia	Fiber (g/mJ) was inversely associated with at risk for overweight (BMI \geq 85th percentile) (OR: 0.69; 95% CI: 0.47, 0.99, comparing fourth quartile to first quartile).	Model was only adjusted for age and sex.	
Subjects (<i>n</i>) Age (y) Dietary assessment Country	242 10–19 One 24-h recall Canada	Fiber (g/d and g · kcal ⁻¹ · d ⁻¹) was NS correlated with BMI, waist-hip ratio, or skinfold thickness in boys or girls (data not shown).	Correlations were only adjusted for age.	
Guillaume et al, 1998 (52)	Subjects (<i>n</i>) Age (y) Dietary assessment Country	1028 6–12 3-d diet record Belgium	Mean fiber intakes (g/d) were NS different across tertiles of body fat measured with skinfold thicknesses (<i>P</i> = 0.47).	Models were multivariate adjusted for sex, total energy, fitness, and parental BMI.
Tucker et al, 1997 (53)	Subjects (<i>n</i>) Age (y) Dietary assessment Country	262 9–10 FFQ United States		

/ FFQ, food-frequency questionnaire; OR, odds ratio; NS, nonsignificant(ly).

the animal foods pattern had a 77% increased risk of overweight (95% CI: 1.06, 2.94; $P = 0.0039$) than did children in the lowest quintile.

In summary, only 2 published studies have examined associations between empirically derived plant-based dietary patterns and obesity in children, and neither showed a protective effect. Both studies were cross-sectional and adjusted for some potential confounders. Among adults, plant-based dietary patterns have been inversely associated with body weight and BMI in well-designed prospective studies (66–69). Because foods are not consumed in isolation but, rather, as part of a total dietary pattern, more research with the use of these methods in children is required, and studies should be prospective.

COMMENTS

Although the overall health-promoting benefits of consuming a plant-based diet are well established, the role of plant foods in the prevention of childhood obesity is uncertain. Available data suggest a protective effect of RTE cereal, although prospective studies are still needed. Studies on fruit, vegetables, grains other than RTE cereal, high-protein foods, and fiber are inconsistent or generally null. The diet pattern approach is a relatively new method in pediatric research, and, although some interesting plant-based diet patterns have been observed, significant associations with obesity have not yet been seen.

Overall, the evidence base is limited, and most studies are fraught with methodologic limitations, discussed in depth elsewhere (70) and summarized here. Perhaps most important, many studies did not adjust for any potential confounders or for only a limited set. The issue of confounding in studies of diet and obesity is critical, because many variables may potentially confound the association (eg, physical activity or inactivity, other dietary factors, variables representing heritability, and so forth). This is especially true in studies of plant-based diets: consumption of “healthy” foods—many of which are plant based—is often associated with other healthful behaviors, which in turn are related to weight and body fat; thus, not accounting for these variables in the model can lead to spurious results.

In addition, most studies are cross-sectional, which introduces the possibility of reverse causation. Several studies showed inconsistent effects across subgroups such as age and sex, possibly suggesting effect modification; such findings are intriguing but need to be replicated. Spurious effects may also be attributed to methodologic factors such as reporting bias or measurement errors: overweight persons are more likely to underreport food intakes (71–73), and underreporting among children varies by weight as well as age (71) and sex (74). Vågstrand et al (29) found that associations between diet and body fat were attenuated when underreporters were included in the analysis, as seen in one study (75) but not another (76). It is possible that the spotlight on childhood obesity in society and the media has led to greater underreporting among overweight children and their caretakers.

Also missing from the dietary studies reviewed here is the inclusion of genetic factors. Evidence from genetic epidemiology, molecular epidemiology, and animal studies is limited but clearly

shows gene-diet interactions influencing susceptibility to gaining or losing fat in response to diet; studies among children are specifically needed to determine whether the genes involved are the same as those in adults (77). Genetic variables may confound or modify diet-obesity associations; only 2 studies adjusted their regression models for parental overweight (26, 30), a proxy for genetics. Further, missing from many of the studies is accounting for stage of growth, important because critical periods for the development of obesity have been noted (78), although controversial (79).

It is therefore clear that prospective studies that account for potential confounders are needed; investigations with repeated measures of diet and body composition over time would be most beneficial. Studies that specifically examine abdominal fat are critical because central adiposity poses a special risk to health (80–84). Although studies of individual foods and food groups are useful and more are certainly warranted, studies that use dietary pattern methods may be especially informative. The study of dietary patterns is especially helpful because many dietary variables are considered together in one exposure variable; this reduces the effect of potential confounding by other dietary factors seen in studies of single foods or nutrients. It would be helpful if studies were designed with adequate statistical power to explore potential interactions, especially diet-gene interactions, and considering stage of growth and development and dietary reporting errors are also important. Studies in nonwhite populations are sorely needed, because understanding dietary habits in diverse ethnic groups is required to address health disparities. Finally, multidisciplinary studies that include both genetic and environmental components will be valuable in shedding further light on the increasingly complicated picture of childhood obesity.

Because of the methodologic limitations discussed earlier, many of the findings shown here must be interpreted with caution, and a protective association of plant foods on obesity risk cannot be excluded. Furthermore, the lack of evidence showing an association between plant-based diets and childhood obesity does not mean that such diets should not be encouraged. Plant foods are highlighted in the Dietary Guidelines for Americans (14), yet children do not meet the current recommendations for most plant foods, as aforementioned. Because of the low-energy-dense and high-nutrient-dense nature of plant foods, a physiologic association with lower body weight and decreased body fat is both plausible and likely through myriad biological pathways—especially when supplanting less healthful, high-energy-dense foods (eg, fruit compared with baked goods, vegetables compared with salty snacks). Indeed, vegetarian, semivegetarian, and vegan diets have been associated with lower risk of obesity in many studies in adult populations (85–88), and empirically derived plant-based diet patterns are also consistently associated with lower body weight and decreased body fat, as previously noted. Care should be taken in planning strict vegetarian or vegan diets, especially those that are very low in fat (89), to ensure adequate nutrient intakes to promote normal growth and development of infants, children, and adolescents (90–92).

Because plant foods are generally low energy dense (aside from certain high-energy-dense plant foods, such as nuts and vegetable oils), a plant-based diet tends to be lower in energy density than are diets rich in animal foods. Although the

recommendation to consume a plant-based, low-energy-dense diet is sound nutritional advice, ethical questions arise about the relatively high price of these diets in the United States and the way in which such diets are perceived in other parts of the world. Drewnowski et al (93) has shown that low-energy-dense, high-nutrient-dense foods such as vegetables, fruit, seafood, and dairy products provide energy at the highest cost, and a cost constraint can lead to decreased consumption of these foods (94, 95). The argument is therefore compelling that the relatively lower cost of high-energy-dense foods, which are generally of lower nutritional quality, is an important factor in the disproportionately higher rates of obesity among the poor (96) and therefore contributes to health disparities. However, although fresh fruit and vegetables are costly sources of dietary energy, grain foods, beans, and legumes are relatively less costly than are animal protein sources; consumption of a plant-based diet that includes a combination of these plant foods together may help assuage a more costly diet than one that includes, for example, lean animal protein. In addition, frozen fruit and vegetables are suitable lower-cost, healthy alternatives to fresh, albeit arguably less desirable and appealing.

Unfortunately, in many population subgroups in the United States, and even more so in other parts of the world undergoing the nutrition transition, plant-based diets that exclude more costly animal products are associated with lower socioeconomic status, akin to the belief that overweight is still associated with wealth in many parts of the world. Westernized diets that include animal foods (as well as nutrient-poor, high-energy-dense snack and fast foods) are affiliated with higher socioeconomic status; this perception is a powerful motivator shaping dietary intakes in historically impoverished nations where such foods were not previously available or affordable. Dietary behavior is complex, and attention to social and cultural norms influencing dietary choices and preferences will better equip nutrition educators to help shine a more positive light on plant-based diets in places where pejorative perception rather than price is a barrier to consumption. An additional challenge to increasing intakes of plant foods is that many food environments are obesigenic and encourage consumption of high-fat, high-energy-dense foods that are available in large portions—plant foods often are not prominently placed on the proverbial menu, if at all.

In conclusion, more studies are needed to understand whether plant foods and plant-based diets are protective against childhood obesity. Such diets should nevertheless be encouraged for their other valuable health benefits—human, animal, and environmental. When encouraging consumption of plant-based diets, nutrition scientists, educators, and program planners must be cognizant that dietary behavior occurs within an ecological context: social, cultural, and environmental factors influence food choices as well as personal preferences such as taste, cost, and convenience (97, 98). Reducing the burden of childhood obesity, eliminating health disparities, and preventing the further spread of the disease around the globe will require not only food policy interventions at local, national, and international levels to ensure that plant foods are affordable and accessible to children of all income levels but also awareness of sociocultural norms that affect their consumption. (Other articles in this supplement to the Journal include references 99–125.)

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