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 extended 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

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TABLE 1
Studies examining the association between fruit and vegetable intakes and childhood obesity[1]

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 (*n*)	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 (*n*)	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 (*n*)	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 (*n*)	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 (*n*)	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 (*n*)	4049		

(*Continued*)

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TABLE 1 (*Continued*)

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Age (grade)	Middle school		
Dietary assessment	YRBS questionnaire		
Country (state)	United States (KY)		
Vågstrand et al, 2007 (29)		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).	This study accounted for dietary underreporting. No adjustment was made for potential confounders.
Subjects (*n*)	494		
Age (y)	6–17		
Dietary assessment	FFQ		
Country	Sweden		
Wang et al, 2007 (28)		Fruit, vegetable, and green salad intakes were NS associated with overweight (data not shown).	Stepwise logistic regression was used. No data were provided.
Subjects (*n*)	458		
Age (grade)	5–7		
Dietary assessment	FFQ		
Country (state)	United States (IL)		
Violante et al, 2005 (24)		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.	It was unclear whether this study adjusted for potential confounders. Inconsistent effects were seen across age and sex strata.
Subjects (*n*)	8624		
Age (y)	6–7 and 13–14		
Dietary assessment	FFQ-style survey		
Country	Mexico		
Kelishadi et al, 2003 (20)		Fruit and vegetable servings/d were inversely associated with BMI (respectively, $\beta = -0.04$, $P = 0.02$, and $\beta = -0.05$, $P = 0.04$).	It was unknown whether this study adjusted for potential confounders.
Subjects (*n*)	2000		
Age (y)	11–18		
Dietary assessment	FFQ		
Country	Iran		
Lin and Morrison, 2002 (23)		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)	This descriptive study presented only mean intakes with no adjustments for potential confounders.
Subjects (*n*)	3064		
Age (y)	5–18		
Dietary assessment	Two 24-h recalls		
Country	United States		
Baric et al, 2001 (21)		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.	Body fat was measured with an electronic scale. No adjustment was made for potential confounders.
Subjects (*n*)	575		
Age (y)	Not specified		
Dietary assessment	FFQ		
Country	Croatia		

(*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 ≥ 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 ≥ 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 obesity[1]

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Prospective			
Barton et al, 2005 (34)		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.
Subjects (n)	2379		
Age (y)	9–19		
Dietary assessment	3-d diet record		
Country (state)	United States (CA, MD, OH)		
Newby et al, 2003 (17)		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.
Subjects (n)	1379		
Age (y)	2–5		
Dietary assessment	FFQ		
Country (state)	United States (ND)		
Cross-sectional studies			
Kosti et al, 2008 (39)		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.
Subjects (n)	2008		
Age (y)	12–17		
Dietary assessment	FFQ		
Country	Greece		
Vågstrand et al, 2007 (29)		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.
Subjects (n)	494		
Age (y)	6–17		
Dietary assessment	FFQ		
Country	Sweden		
Kafatos et al, 2005 (37)		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.
Subjects (n)	392		
Age (y)	Not specified		
Dietary assessment	FFQ		
Country	Greece		
Violante et al, 2005 (24)		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)	8624		
Age (y)	6–7 and 13–14		
Dietary assessment	FFQ-style survey		
Country	Mexico		

(*Continued*)

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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 (*n*)	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, β =0.05, $P = 0.04$; β =0.06, $P = 0.03$; and $\beta = 0.03$, $P = 0.04$).	Models were not adjusted for any potential confounders.
Subjects (*n*)	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 (*n*)	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 (*n*)	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 ≥ 85th 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 (*n*)	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 (*n*)	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 (*n*)	57		
Age (y)	7–10		
Dietary assessment	FFQ		
Country (state)	United States (CT)		

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

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 obesity[1]

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Prospective			
Newby et al, 2003 (17)		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.
Subjects (*n*)	1379		
Age (y)	2–5		
Dietary assessment	FFQ		
Country (state)	United States (ND)		
Berkey et al, 2000 (50)		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.
Subjects (*n*)	10,769		
Age (y)	9–14		
Dietary assessment	FFQ		
Country	United States (multistate)		
Cross-sectional studies			
Humenikova and Gates, 2007 (26)		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.
Subjects (*n*)	97		
Age (grade)	4–6		
Dietary assessment	Two 24-h recalls		
Country	Czech Republic		
Vågstrand et al, 2007 (29)		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.
Subjects (*n*)	494		
Age (y)	6–17		
Dietary assessment	FFQ		
Country	Sweden		
Hassapidou et al, 2006 (54)		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.
Subjects (*n*)	512		
Age (y)	11–14		
Dietary assessment	3-d diet record		
Country	Greece		
Grant et al, 2004 (51)		Fiber intakes in the <95th percentile BMI were NS different from those in the ≥95th 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 (*n*)	60		
Age (y)	2–5		
Dietary assessment	2-d diet records		
Country	New Zealand		

(*Continued*)

TABLE 3 (*Continued*)

Studies (reference)	Study sample and dietary assessment	Findings	Comments
Baric et al, 2001 (21)		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.
Subjects (*n*)	575		
Age (y)	Not specified		
Dietary assessment	FFQ		
Country	Croatia		
Hanley et al, 2000 (27)		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 (*n*)	242		
Age (y)	10–19		
Dietary assessment	One 24-h recall		
Country	Canada		
Guillaume et al, 1998 (52)		Fiber (g/d and $g \cdot kcal^{-1} \cdot d^{-1}$) was NS correlated with BMI, waist-hip ratio, or skinfold thickness in boys or girls (data not shown).	Correlations were only adjusted for age.
Subjects (*n*)	1028		
Age (y)	6–12		
Dietary assessment	3-d diet record		
Country	Belgium		
Tucker et al, 1997 (53)		Mean fiber intakes (g/d) were NS different across tertiles of body fat measured with skinfold thicknesses ($P = 0.47$).	Models were multivariate adjusted for sex, total energy, fitness, and parental BMI.
Subjects (*n*)	262		
Age (y)	9–10		
Dietary assessment	FFQ		
Country	United States		

[1] 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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REFERENCES

1. Dwyer JT, Andrew EM, Valadian I, Reed RB. Size, obesity, and leanness in vegetarian preschool children. J Am Diet Assoc 1980;77: 434–9.
2. Dwyer JT, Palombo R, Valadian I, Reed RB. Preschoolers on alternate life-style diets. Associations between size and dietary indexes with diets limited in types of animal foods. J Am Diet Assoc 1978;72: 264–70.
3. Shull MW, Reed RB, Valadian I, Palombo R, Thorne H, Dwyer JT. Velocities of growth in vegetarian preschool children. Pediatrics 1977; 60:410–7.
4. Dwyer JT, Andrew EM, Berkey C, Valadian I, Reed RB. Growth in "new" vegetarian preschool children using the Jenss-Bayley curve fitting technique. Am J Clin Nutr 1983;37:815–27.
5. O'Connell JM, Dibley MJ, Sierra J, Wallace B, Marks JS, Yip R. Growth of vegetarian children: The Farm Study. Pediatrics 1989;84: 475–81.
6. Stahler C. How many youth are vegetarian? Vegetarian J, 2005. Available from: http://www.vrg.org/journal/vj2005issue4/vj2005issue4youth.htm (cited 26 Feb 2008).
7. International Association for the Study of Obesity. International Obesity Taskforce, 2006. Childhood obesity. Available from: http://www.iotf.org/childhodobesity.asp (cited 2 Oct 2007).
8. Lobstein T, Baur L, Uauy R. Obesity in children and young people: a crisis in public health. Obes Rev 2004;5(suppl 1):4–104.
9. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999-2004. JAMA 2006;295:1549–55.
10. Dietz WH. Childhood weight affects adult morbidity and mortality. J Nutr 1998;128(suppl):411S–4S.
11. Pi-Sunyer FX. Medical hazards of obesity. Ann Intern Med 1993;119: 655–60.
12. Lobstein TJ, James WP, Cole TJ. Increasing levels of excess weight among children in England. Int J Obes Relat Metab Disord 2003;27: 1136–8.
13. Krebs NF, Jacobson MS. American Academy of Pediatrics Committee on Nutrition. Prevention of pediatric overweight and obesity. Pediatrics 2003;112:424–30.
14. United States Department of Agriculture. MyPyramid, 2005. Available from: http://www.mypyramid.gov (cited 10 April 2008).
15. Guenther PM, Dodd KW, Reedy J, Krebs-Smith SM. Most Americans eat much less than recommended amounts of fruits and vegetables. J Am Diet Assoc 2006;106:1371–9.
16. Krebs-Smith SM, Cook A, Subar AF, Cleveland L, Friday J, Kahle LL. Fruit and vegetable intakes of children and adolescents in the United States. Arch Pediatr Adolesc Med 1996;150:81–6.
17. Newby PK, Peterson KE, Berkey CS, Leppert J, Willett WC, Colditz GA. Dietary composition and weight change among low-income preschool children. Arch Pediatr Adolesc Med 2003;157: 759–64.
18. Faith MS, Dennison BA, Edmunds LS, Stratton HH. Fruit juice intake predicts increased adiposity gain in children from low-income families: weight status-by-environment interaction. Pediatrics 2006;118: 2066–75.
19. Field AE, Gillman MW, Rosner B, Rockett HR, Colditz GA. Association between fruit and vegetable intake and change in body mass index among a large sample of children and adolescents in the United States. Int J Obes Relat Metab Disord 2003;27:821–6.
20. Kelishadi R, Pour MH, Sarraf-Zadegan N, et al. Obesity and associated modifiable environmental factors in Iranian adolescents: Isfahan Healthy Heart Program - Heart Health Promotion from Childhood. Pediatr Int 2003;45:435–42.
21. Baric IC, Cvjetic S, Satalic Z. Dietary intakes among Croatian schoolchildren and adolescents. Nutr Health 2001;15:127–38.
22. Roseman MG, Yeung WK, Nickelsen J. Examination of weight status and dietary behaviors of middle school students in Kentucky. J Am Diet Assoc 2007;107:1139–45.

23. Lin B-H, Morrison RM. Higher fruit consumption linked with lower body mass index. FoodReview 2002;25:28–32.
24. Violante R, del Rio Navarro BE, Berber A, Ramirez Chanona N, Baeza Bacab M, Sienra Monge JJ. Obesity risk factors in the ISAAC (International Study of Asthma and Allergies in Childhood) in Mexico City. Rev Alerg Mex 2005;52:141–5.
25. Colapinto CK, Fitzgerald A, Taper LJ, Veugelers PJ. Children's preference for large portions: prevalence, determinants, and consequences. J Am Diet Assoc 2007;107:1183–90.
26. Humenikova L, Gates GE. Dietary intakes, physical activity, and predictors of child obesity among 4-6th graders in the Czech Republic. Cent Eur J Public Health 2007;15:23–8.
27. Hanley AJ, Harris SB, Gittelsohn J, Wolever TM, Saksvig B, Zinman B. Overweight among children and adolescents in a Native Canadian community: prevalence and associated factors. Am J Clin Nutr 2000; 71:693–700.
28. Wang Y, Liang H, Tussing L, Braunschweig C, Caballero B, Flay B. Obesity and related risk factors among low socio-economic status minority students in Chicago. Public Health Nutr 2007;10: 927–38.
29. Vågstrand K, Barkeling B, Forslund HB, et al. Eating habits in relation to body fatness and gender in adolescents–results from the 'SWEDES' study. Eur J Clin Nutr 2007;61:517–25.
30. Tanasescu M, Ferris AM, Himmelgreen DA, Rodriguez N, Perez-Escamilla R. Biobehavioral factors are associated with obesity in Puerto Rican children. J Nutr 2000;130:1734–42.
31. Tohill BC, Seymour J, Serdula M, Kettel-Khan L, Rolls BJ. What epidemiologic studies tell us about the relationship between fruit and vegetable consumption and body weight. Nutr Rev 2004;62: 365–74.
32. Morton JF, Guthrie JF. Changes in children's total fat intakes and their food group sources of fat, 1989–91 versus 1994–95: implications for diet quality. Fam Econ Nutr Rev 1998;11:44–57.
33. Harnack L, Walters SA, Jacobs DR Jr. Dietary intake and food sources of whole grains among US children and adolescents: data from the 1994–1996 Continuing Survey of Food Intakes by Individuals. J Am Diet Assoc 2003;103:1015–9.
34. Barton BA, Eldridge AL, Thompson D, et al. The relationship of breakfast and cereal consumption to nutrient intake and body mass index: the National Heart, Lung, and Blood Institute Growth and Health Study. J Am Diet Assoc 2005;105:1383–9.
35. Gibson SA, O'Sullivan KR. Breakfast cereal consumption patterns and nutrient intakes of British schoolchildren. J R Soc Health 1995;115: 366–70.
36. Albertson AM, Anderson GH, Crockett SJ, Goebel MT. Ready-to-eat cereal consumption: its relationship with BMI and nutrient intake of children aged 4 to 12 years. J Am Diet Assoc 2003;103: 1613–9.
37. Kafatos A, Linardakis M, Bertsias G, Mammas I, Fletcher R, Bervanaki F. Consumption of ready-to-eat cereals in relation to health and diet indicators among school adolescents in Crete, Greece. Ann Nutr Metab 2005;49:165–72.
38. Ortega RM, Requejo AM, Lopez-Sobaler AM, et al. Difference in the breakfast habits of overweight/obese and normal weight schoolchildren. Int J Vitam Nutr Res 1998;68:125–32.
39. Kosti RI, Panagiotakos DB, Zampelas A, et al. The association between consumption of breakfast cereals and BMI in schoolchildren aged 12-17 years: the VYRONAS study. Public Health Nutr 2008;11: 1015–21.
40. Steffen LM, Jacobs DR Jr, Murtaugh MA, et al. Whole grain intake is associated with lower body mass and greater insulin sensitivity among adolescents. Am J Epidemiol 2003;158:243–50.
41. Williams CL. Dietary fiber in childhood. J Pediatr 2006;149(suppl): S121–30.
42. McCarty MF. Vegan proteins may reduce risk of cancer, obesity, and cardiovascular disease by promoting increased glucagon activity. Med Hypotheses 1999;53:459–85.
43. McCarty MF. The origins of western obesity: a role for animal protein? Med Hypotheses 2000;54:488–94.
44. Gunther AL, Remer T, Kroke A, Buyken AE. Early protein intake and later obesity risk: which protein sources at which time points throughout infancy and childhood are important for body mass index and body fat percentage at 7 y of age? Am J Clin Nutr 2007;86: 1765–72.
45. Howarth NC, Saltzman E, Roberts SB. Dietary fiber and weight regulation. Nutr Rev 2001;59:129–39.
46. Slavin JL. Dietary fiber and body weight. Nutrition 2005;21: 411–8.
47. Nicklas TA, Myers L, Berenson GS. Dietary fiber intake of children: the Bogalusa Heart Study. Pediatrics 1995;96:988–94.
48. Institute of Medicine of the National Academy of Sciences. Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients). Washington, DC: National Academy Press, 2002.
49. Kranz S. Meeting the dietary reference intakes for fiber: sociodemographic characteristics of preschoolers with high fiber intakes. Am J Public Health 2006;96:1538–41.
50. Berkey CS, Rockett HR, Field AL, et al. Activity, dietary intake, and weight changes in a longitudinal study of preadolescent and adolescent boys and girls. Pediatrics 2000;105:E56.
51. Grant AM, Ferguson EL, Toafa V, Henry TE, Guthrie BE. Dietary factors are not associated with high levels of obesity in New Zealand Pacific preschool children. J Nutr 2004;134:2561–5.
52. Guillaume M, Lapidus L, Lambert A. Obesity and nutrition in children. The Belgian Luxembourg Child Study IV. Eur J Clin Nutr 1998;52: 323–8.
53. Tucker LA, Seljaas GT, Hager RL. Body fat percentage of children varies according to their diet composition. J Am Diet Assoc 1997;97: 981–6.
54. Hassapidou M, Fotiadou E, Maglara E, Papadopoulou SK. Energy intake, diet composition, energy expenditure, and body fatness of adolescents in northern Greece. Obesity (Silver Spring) 2006;14: 855–62.
55. Blundell JE, Burley VJ. Satiation, satiety and the action of fibre on food intake. Int J Obes 1987;11(suppl 1):9–25.
56. Stevens J. Does dietary fiber affect food intake and body weight? J Am Diet Assoc 1988;88:939–45.
57. Newby PK, Maras J, Bakun P, Muller D, Ferrucci L, Tucker KL. Intake of whole grains, refined grains, and cereal fiber measured with 7-d diet records and associations with risk factors for chronic disease. Am J Clin Nutr 2007;86:1745–53.
58. Lairon D, Arnault N, Bertrais S, et al. Dietary fiber intake and risk factors for cardiovascular disease in French adults. Am J Clin Nutr 2005;82:1185–94.
59. Koh-Banerjee P, Franz M, Sampson L, et al. Changes in whole-grain, bran, and cereal fiber consumption in relation to 8-y weight gain among men. Am J Clin Nutr 2004;80:1237–45.
60. Newby PK, Tucker KL. Empirically derived eating patterns using factor or cluster analysis: a review. Nutr Rev 2004;62:177–203.
61. Kant AK. Indexes of overall diet quality: a review. J Am Diet Assoc 1996;96:785–91.
62. Knol LL, Haughton B, Fitzhugh EC. Dietary patterns of young, low-income US children. J Am Diet Assoc 2005;105:1765–73.
63. Alexy U, Sichert-Hellert W, Kersting M, Schultze-Pawlitschko V. Pattern of long-term fat intake and BMI during childhood and adolescence: results of the DONALD Study. Int J Obes Relat Metab Disord 2004;28:1203–9.
64. Shin KO, Oh SY, Park HS. Empirically derived major dietary patterns and their associations with overweight in Korean preschool children. Br J Nutr 2007;98:416–21.
65. McNaughton SA, Ball K, Mishra GD, Crawford DA. Dietary patterns of adolescents and risk of obesity and hypertension. J Nutr 2008;138: 364–70.
66. Newby PK, Muller D, Hallfrisch J, Qiao N, Andres R, Tucker KL. Dietary patterns and changes in body mass index and waist circumference in adults. Am J Clin Nutr 2003;77:1417–25.
67. Newby PK, Weismayer C, Akesson A, Tucker KL, Wolk A. Longitudinal changes in food patterns predict changes in weight and body mass index and the effects are greatest in obese women. J Nutr 2006;136: 2580–7.
68. Quatromoni PA, Copenhafer DL, D'Agostino RB, Millen BE. Dietary patterns predict the development of overweight in women: the Framingham Nutrition Studies. J Am Diet Assoc 2002;102: 1239–46.
69. Schulze MB, Fung TT, Manson JE, Willett WC, Hu FB. Dietary patterns and changes in body weight in women. Obesity (Silver Spring) 2006;14:1444–53.

70. Newby PK. Are dietary intakes and eating behaviors related to childhood obesity? A comprehensive review of the evidence. J Law Med Ethics 2007;35:35–60.
71. Livingstone MB, Robson PJ. Measurement of dietary intake in children. Proc Nutr Soc 2000;59:279–93.
72. Livingstone MB, Black AE. Markers of the validity of reported energy intake. J Nutr 2003;133(suppl 3):895S–920S.
73. Bandini LG, Schoeller DA, Cyr HN, Dietz WH. Validity of reported energy intake in obese and nonobese adolescents. Am J Clin Nutr 1990;52:421–5.
74. Nielsen BM, Bjornsbo KS, Tetens I, Heitmann BL. Dietary glycaemic index and glycaemic load in Danish children in relation to body fatness. Br J Nutr 2005;94:992–7.
75. Huang TT, Howarth NC, Lin BH, Roberts SB, McCrory MA. Energy intake and meal portions: associations with BMI percentile in U.S. children. Obes Res 2004;12:1875–85.
76. Maffeis C, Provera S, Filippi L, et al. Distribution of food intake as a risk factor for childhood obesity. Int J Obes Relat Metab Disord 2000; 24:75–80.
77. Perusse L, Bouchard C. Gene-diet interactions in obesity. Am J Clin Nutr 2000;72(suppl):1285S–90S.
78. Dietz WH. Critical periods in childhood for the development of obesity. Am J Clin Nutr 1994;59:955–9.
79. Cole TJ. Children grow and horses race: is the adiposity rebound a critical period for later obesity? BMC Pediatr 2004;4:6.
80. Katzmarzyk PT, Srinivasan SR, Chen W, Malina RM, Bouchard C, Berenson GS. Body mass index, waist circumference, and clustering of cardiovascular disease risk factors in a biracial sample of children and adolescents. Pediatrics 2004;114:e198–205.
81. Teixeira PJ, Sardinha LB, Going SB, Lohman TG. Total and regional fat and serum cardiovascular disease risk factors in lean and obese children and adolescents. Obes Res 2001;9:432–42.
82. Garnett SP, Baur LA, Srinivasan S, Lee JW, Cowell CT. Body mass index and waist circumference in midchildhood and adverse cardiovascular disease risk clustering in adolescence. Am J Clin Nutr 2007; 86:549–55.
83. Freedman DS, Kahn HS, Mei Z, et al. Relation of body mass index and waist-to-height ratio to cardiovascular disease risk factors in children and adolescents: the Bogalusa Heart Study. Am J Clin Nutr 2007;86: 33–40.
84. Lee S, Bacha F, Gungor N, Arslanian SA. Waist circumference is an independent predictor of insulin resistance in black and white youths. J Pediatr 2006;148:188–94.
85. Newby PK, Tucker KL, Wolk A. Risk of overweight and obesity among semivegetarian, lactovegetarian, and vegan women. Am J Clin Nutr 2005;81:1267–74.
86. Appleby PN, Thorogood M, Mann JI, Key TJ. Low body mass index in non-meat eaters: the possible roles of animal fat, dietary fibre and alcohol. Int J Obes Relat Metab Disord 1998;22:454–60.
87. Key T, Davey G. Prevalence of obesity is low in people who do not eat meat. BMJ 1996;313:816–7.
88. Berkow SE, Barnard N. Vegetarian diets and weight status. Nutr Rev 2006;64:175–88.
89. Kaplan RM, Toshima MT. Does a reduced fat diet cause retardation in child growth? Prev Med 1992;21:33–52.
90. Mangels AR, Messina V. Considerations in planning vegan diets: infants. J Am Diet Assoc 2001;101:670–7.
91. Messina V, Mangels AR. Considerations in planning vegan diets: children. J Am Diet Assoc 2001;101:661–9.
92. Truesdell DD, Acosta PB. Feeding the vegan infant and child. J Am Diet Assoc 1985;85:837–40.
93. Drewnowski A, Darmon N. The economics of obesity: dietary energy density and energy cost. Am J Clin Nutr 2005;82(suppl): 265S–73S.
94. Darmon N, Ferguson EL, Briend A. A cost constraint alone has adverse effects on food selection and nutrient density: an analysis of human diets by linear programming. J Nutr 2002;132:3764–71.
95. Darmon N, Ferguson E, Briend A. Do economic constraints encourage the selection of energy dense diets? Appetite 2003;41:315–22.
96. Drewnowski A, Specter SE. Poverty and obesity: the role of energy density and energy costs. Am J Clin Nutr 2004;79:6–16.
97. Newby PK. Examining energy density: comments on diet quality, dietary advice, and the cost of healthful eating. J Am Diet Assoc 2006; 106:1166–9.
98. Newby PK. The future of food: how science, technology, and consumerism shape what we eat. In: Ulm JW, ed. Vision: essays on our collective future. Cambridge, MA: The Dipylon Press, 2003: 3–24.
99. Rajaram S, Sabaté J. Preface. Am J Clin Nutr 2009;89(suppl): 1541S–2S.
100. Jacobs DR Jr, Gross MD, Tapsell LC. Food synergy: an operational concept for understanding nutrition. Am J Clin Nutr 2009;89(suppl): 1543S–8S.
101. Jacobs DR Jr, Haddad EH, Lanou AJ, Messina MJ. Food, plant food, and vegetarian diets in the US dietary guidelines: conclusions of an expert panel. Am J Clin Nutr 2009;89(suppl):1549S–52S.
102. Lampe JW. Interindividual differences in response to plant-based diets: implications for cancer risk. Am J Clin Nutr 2009;89(suppl): 1553S–7S.
103. Simon JA, Chen Y-H, Bent S. The relation of α-linolenic acid to the risk of prostate cancer: a systematic review and meta-analysis. Am J Clin Nutr 2009;89(suppl):1558S–64S.
104. Pierce JP, Natarajan L, Caan BJ, et al. Dietary change and reduced breast cancer events among women without hot flashes after treatment of early-stage breast cancer: subgroup analysis of the Women's Healthy Eating and Living Study. Am J Clin Nutr 2009;89(suppl): 1565S–71S.
105. Barnard ND, Cohen J, Jenkins DJA, et al. A low-fat vegan diet and a conventional diabetes diet in the treatment of type 2 diabetes: a randomized, controlled, 74-wk clinical trial. Am J Clin Nutr 2009;89(suppl): 1588S–96S.
106. Mangat I. Do vegetarians have to eat fish for optimal cardiovascular protection? Am J Clin Nutr 2009;89(suppl):1597S–601S.
107. Willis LM, Shukitt-Hale B, Joseph JA. Modulation of cognition and behavior in aged animals: role for antioxidant- and essential fatty acid–rich plant foods. Am J Clin Nutr 2009;89(suppl):1602S–6S.
108. Fraser GE. Vegetarian diets: what do we know of their effects on common chronic diseases? Am J Clin Nutr 2009;89(suppl): 1607S–12S.
109. Key TJ, Appleby PN, Spencer EA, Travis RC, Roddam AW, Allen NE. Mortality in British vegetarians: results from the European Prospective Investigation into Cancer and Nutrition (EPIC-Oxford). Am J Clin Nutr 2009;89(suppl):1613S–9S.
110. Key TJ, Appleby PN, Spencer EA, Travis RC, Roddam AW, Allen NE. Cancer incidence in vegetarians: results from the European Prospective Investigation into Cancer and Nutrition (EPIC-Oxford). Am J Clin Nutr 2009;89(suppl):1620S–6S.
111. Craig WJ. Health effects of vegan diets. Am J Clin Nutr 2009; 89(suppl):1627S–33S.
112. Weaver CM. Should dairy be recommended as part of a healthy vegetarian diet? Point. Am J Clin Nutr 2009;89(suppl):1634S–7S.
113. Lanou AJ. Should dairy be recommended as part of a healthy vegetarian diet? Counterpoint. Am J Clin Nutr 2009;89(suppl): 1638S–42S.
114. Sabaté J, Ang Y. Nuts and health outcomes: new epidemiologic evidence. Am J Clin Nutr 2009;89(suppl):1643S–8S.
115. Ros E. Nuts and novel biomarkers of cardiovascular disease. Am J Clin Nutr 2009;89(suppl):1649S–56S.
116. Rajaram S, Haddad EH, Mejia A, Sabaté J. Walnuts and fatty fish influence different serum lipid fractions in normal to mildly hyperlipidemic individuals: a randomized controlled study. Am J Clin Nutr 2009;89(suppl):1657S–63S.
117. Lampe JW. Is equol the key to the efficacy of soy foods? Am J Clin Nutr 2009;89(suppl):1664S–7S.
118. Badger TM, Gilchrist JM, Pivik RT, et al. The health implications of soy infant formula. Am J Clin Nutr 2009;89(suppl):1668S–72S.
119. Messina M, Wu AH. Perspectives on the soy–breast cancer relation. Am J Clin Nutr 2009;89(suppl):1673S–9S.
120. Lönnerdal B. Soybean ferritin: implications for iron status of vegetarians. Am J Clin Nutr 2009;89(suppl):1680S–5S.
121. Chan J, Jaceldo-Siegl K, Fraser GE. Serum 25-hydroxyvitamin D status of vegetarians, partial vegetarians, and nonvegetarians: the Adventist Health Study-2. Am J Clin Nutr 2009;89(suppl): 1686S–92S.

122. Elmadfa I, Singer I. Vitamin B-12 and homocysteine status among vegetarians: a global perspective. Am J Clin Nutr 2009;89(suppl):1693S–8S.
123. Marlow HJ, Hayes WK, Soret S, Carter RL, Schwab ER, Sabaté J. Diet and the environment: does what you eat matter? Am J Clin Nutr 2009;89(suppl):1699S–703S.
124. Carlsson-Kanyama A, González AD. Potential contributions of food consumption patterns to climate change. Am J Clin Nutr 2009;89(suppl):1704S–9S.
125. Eshel G, Martin PA. Geophysics and nutritional science: toward a novel, unified paradigm. Am J Clin Nutr 2009;89(suppl):1710S–6S.