Are Dietary Intakes and Eating Behaviors Related to Childhood Obesity? A Comprehensive Review of the Evidence

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Introduction

Childhood obesity is a serious problem for increasing numbers of children around the world. According to the International Obesity Task Force, 1 of 10 school-aged children worldwide is overweight or obese, a number totaling 155 million; of these, 2-3% (30-45 million) are obese.[1] Prevalence is highest in the Americas and Europe, followed by the Near/Middle East, with smaller but growing numbers in the Asia-Pacific and Sub-Saharan regions of the world.[2]

In the United States, which provides the data for much of this report, prevalence continues to rise. The most recent nationally representative data indicate that 33.6% of individuals aged 2-19 years were overweight and 17.1% were at risk for overweight in 2003-2004, compared to 28.2% and 13.9% in 1999-2000, respectively.[3] In this age group, the prevalence of overweight or at risk for overweight was highest among Mexican Americans (56.2%), followed by Non-Hispanic blacks (55.1%) and Non-Hispanic whites (49.8%), and a higher percentage of males were overweight (18.2%) compared to females (16.0%).[4]

Obesity poses a significant public health threat to children for reasons that affect both their current and future health. Obese children suffer from a broad range of physical and psychosocial health consequences[5] and are more likely to become obese adolescents[6] and adults.[7] Cardiovascular risk factors which arise as sequelae to childhood obesity also appear to persist into adulthood.[8] Obese adults, in turn, are at increased risk of insulin resistance, hypertension, hypertriglyceridemia, dyslipidemia, cardiovascular diseases, non-insulin dependent diabetes, gallstones, cholecystitis, respiratory dysfunction, certain cancers, and overall mortality.[9]

Dramatic increases in obesity over the past several decades suggest the predominance of influential environmental factors over genetic factors.[10] While a host of factors work in tandem at the population level to favor increased food intake and decreased physical ac-

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tivity, obesity at the individual level ultimately results from an imbalance between energy intake and energy expenditure. Several review articles have examined the connection between diet and obesity among children to a limited degree.[11] The purpose of this article is to comprehensively review studies that have examined the relation between diet and childhood obesity. In the paper, "children" are broadly defined as individuals aged 2-19 years and "diet" includes multiple aspects of dietary intake and eating behavior. This paper focuses on observational data that have examined the dietary etiology of obesity, rather than dietary treatment of obesity, and clinical studies are also included where possible. The main goal of this paper is to review the evidence and highlight methodological considerations, as well as to identify research gaps and future directions.

The review begins with a discussion of secular trends in dietary behavior and is then organized into several specific sections, as follows: total energy intake and energy density; dietary composition; individual foods, food groups, and dietary patterns; beverage consumption; and eating behavior. Within each section appear sub-sections that highlight the key areas of inquiry (e.g., dietary fat, fruit juice, skipping breakfast). Not included in this review are the important dietary variables of prenatal and infant feeding behaviors, including breastfeeding and supplemental feeding behavior, which are discussed in another paper in this symposium.[12] The final section discusses methodological considerations and future research directions. The paper concludes by summarizing the evidence presented and highlighting the ethical issues that surround providing dietary advice.

An Overview of Children's Diets: Secular Trends in Dietary Intake

A logical place to begin a discussion of the dietary correlates of childhood obesity is to first examine secular trends in dietary intake, as it is from these data that hypotheses are generated regarding how diet may be related to the childhood obesity at the individual level. What are children eating today, and how do these diets differ from the past?

Given that obesity results from a positive energy balance, of interest is whether total energy intake has in fact increased over time. It is essential to note from the outset that it is extremely difficult to accurately measure total energy intake in epidemiologic studies. The most recent, nationally representative data showing changes in total energy intake and eating location, as well as changes in specific food groups, are reported by Samara Nielsen et al.[13] In this report, data from the Nationwide Food Consumption Surveys (NFCS) show that while total energy intake decreased from 1840 kcal/d in 1977-78 to 1778 kcal/d in 1989-91 among children aged 2-18 years, as noted in an earlier report,[14] energy intake increased to 1958 kcal/d in 1994-96. Thus, increases in calorie consumption among children have only been noted in recent years, possibly reflecting secular increases in portion sizes,[15] which result in increased energy intake.[16] Indeed, energy intake and portion sizes of food consumed both at home and away from home increased considerably between 1977 and 1998.[17] Of note, portions of salty snacks increased by 93 kcal (from 1.0 to 1.6 oz), soft drinks by 49 kcal (13.1 to 19.9 fl oz), hamburgers by 97 kcal (5.7 to 7.0 oz), and french fries by 68 kcal (3.1 to 3.6 oz),[18] all of which are commonly consumed by children.

Dietary composition (the relative proportions of fat, carbohydrate, and protein) has also changed somewhat over the years. Consumption data from the United States indicate that percent of calories from fat has decreased[19] and percent from carbohydrate has increased[20] alongside the growing prevalence of obesity. Among preschool children, food consumption data comparing the 1989-91 Continuing Survey of Food Intakes by Individuals (CSFII) to the 1994-95 CSFII found that the percent of calories from fat decreased – although *total* fat grams increased – while the percent of calories from carbohydrate increased. In this study, the top 5 food sources of dietary carbohydrate among preschoolers were yeast bread (12.1%), soft drinks/soda (4.9%), milk (10.2%), ready-to-eat cereal (8.6%), and cakes/cookies/quick breads/donuts (6.6%).[21] Notable increases were also observed in the consumption of salty snacks, candy, soft drinks, fruit drinks, french fries, and pizza over the past several decades.[22]

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Although percent energy from carbohydrates has increased, largely due to increased consumption of refined grain products, intakes of total fiber have decreased—although fiber from cereals increased and fiber from fruits and vegetables declined.[23] In 1987-88, the percentages of children not meeting current fiber recommendations increased with age: 45% of children aged 2-5 years, 65% of children aged 6-11 years, and 83% of children aged 12-18 years did not meet the American Health Foundation recommended fiber intake of age + 5 g/d.[24] Mean daily intakes of fiber were

10.7 g/d for children aged 2-5 years, 13.4 g/d for children aged 6-11 years, and 14.6 g/d for children aged 12-18 years as reported in NHANES III 1988-1994.[25] During the same time period, yeast bread and cereal contributed 23% of fiber intake.[26]

There have been many changes in children's beverage consumption patterns over the past several decades, including an increase in soft drinks[27] and fruit juice consumption and a decrease in milk consumption.[28] Nationally representative data show a steady increase in energy intake from soft drinks and fruit drinks from 1977-78 through 1999-2001, from 3.0% to 6.9% and 1.8% to 3.4%, respectively; in the same time period, milk consumption decreased from 13.2% to 8.3% of total energy intake.[29] Interestingly, recent data suggest that mean calcium intake has not decreased as a result of this shift in beverage consumption, possibly due to the fortification of non-dairy products with calcium.[30] The portion sizes of sweetened beverages (e.g., soft drinks and fruit drinks) also significantly increased, from 13.1 fl oz to 18.9 fl oz.[31] Changes in beverage intake also occur as children age. Data from CSFII 1998 indicate that mean daily intakes of 100% fruit juice were 4.6 oz/d among children aged 6 months-6 years and 3.4 oz/d among children aged 7-18 years; consumption of sweetened fruit drinks exceeded that of fruit juice by age 5, and consumption of soft drinks exceeded that of fruit juice, milk, or sweetened fruit drinks by age 13.[32] These changes in trends at the population level, in addition to changes in intakes as children age, therefore suggest a possible role for beverages in the development of childhood obesity.

Perhaps as relevant to the issue of what foods are consumed (in relation to obesity) is the behavior surrounding food consumption itself, including such factors as how often meals are consumed, whether one snacks, and whether one eats at home or away from home. For example, nationally representative data show a decline in breakfast consumption among children in all age groups during the past several decades,[33] and frequency of breakfast consumption decreased with age among girls participating in the National Heart, Lung, and Blood Institute Growth and Health Study.[34] Additional changes in food behaviors have also occurred in the past several decades. The percentage of energy consumed at restaurants or fast food establishments increased significantly among children, from 4.8% in 1977-78 to 14.8% in 1994-96, while percentage of energy from meals at home decreased from 75.2% to 64.2% in the same time period.[35] In addition, significantly greater amounts of energy came from snacking, increasing throughout the study period from 240 kcal/d in 1977-78 to 267 kcal/d in 1989-91 and 409 kcal/d in 1994-96.[36]

In summary, there have been many changes in children's eating patterns over the past several decades, including changes in total energy intake and macronutrient composition, as well as the types of foods and beverages that are consumed. Further, there have been alterations in eating behavior, including increased away-from-home dining and snacking. As these changes in diet have occurred alongside the increase in the prevalence of overweight and obesity, it is reasonable to test the hypotheses that these factors may be related to childhood obesity.

Total Energy Intake and Energy Density

As obesity ultimately results from an imbalance in energy intake and energy expenditure, considering whether total energy intake (i.e., total calories) has been associated with childhood obesity is a natural place to begin the discussion. On the other hand, perhaps the volume of food consumed rather than the energy content per se is more important. Both factors are discussed below.

Total Energy

Because obesity reflects an imbalance between energy intake and expenditure, of major interest has been the role of total calories in obesity. Although energy intake and its counterpart, energy expenditure, clearly impact energy balance, both are imperfectly measured in epidemiological studies among free-living populations.[37] In fact, total energy is tightly regulated physiologically and largely reflects body weight, basal metabolic rate, and physical activity. It is therefore extremely difficult to assess the independent effects of either energy intake or energy expenditure, as well as to adequately control for confounding by other factors. Likely due to these reasons and others, data assessing the relationship between total energy and obesity among children are therefore quite conflicting.

An earlier review of childhood obesity indicates that obese children do not tend to massively overeat,[38] which supports findings from descriptive studies that mean energy intakes are not significantly different among overweight and normal weight children[39] and cross-sectional studies that show no association between total energy intake and Body Mass Index (BMI).[40] Evidence for a lack of association also comes from several well-designed prospective studies,[41] two of which examined associations with change in weight or BMI over the time period.[42] A null association was therefore observed in many studies, which included studies among children and adolescents of different ages.

There is limited evidence to suggest a positive association between total energy intake and obesity. Higher intakes among overweight children were observed in a few descriptive studies,[43] and two cross-sectional studies observed a significant positive association between energy intake and obesity in models that adjusted for other risk factors for obesity,[44] although the effect was only significant among boys in one study.[45] In addition, one prospective study showed that a larger increase in energy intake was associated with larger gains in BMI over 1 year in a large sample of adolescents.[46] None of these studies adjusted for parental overweight, however, and energy intake was no longer significant in a model which further adjusted for parental overweight in a carefully controlled metabolic study.[47]

Conversely, an inverse association between total energy and obesity has also been observed. Three studies observed lower energy intakes among overweight children compared to normal weight children,[48] and energy intake was also significantly lower among obese children compared to non-obese children in two carefully controlled studies.[49] In an early study, higher energy intakes were observed among children with a normal weight parent compared to those with an overweight parent, although resting energy expenditure was lower among children of overweight parents.[50] In a similar design, mean caloric intake was 16% lower among high risk individuals, suggesting lower energy expenditure, likely voluntary energy expenditure through physical activity.[51] A cross-sectional study[52] and a small case control study that adjusted for resting energy expenditure and physical activity[53] also reported inverse associations.

A review found that studies which show an inverse association between energy intake and obesity may be explained by under-reporting, as obese children and adolescents under-report more than normal weight counterparts.[54] Reported intakes were significantly less than predicted energy needs based on the calculated ratio of EI:BMR (energy intake to basal metabolic rate) in one study.[55] Linda G. Bandini et al. thus concluded that differences in energy intake are due to reporting errors.[56] Lower energy intakes, if a true finding, may also reflect lower physical activity levels of obese children.[57] Because of the bias due to under-reporting, this should be taken into account during the analysis. In an elegant study, energy intake was not significantly associated with BMI in a sample which included under-reporters but was positively and significantly associated with BMI percentile in a sample which only included plausible reporters, although associations were not consistent across all age and sex groups studied.[58]

In summary, evidence of an association between total energy intake and obesity among children is conflicting and may be explained in part by inadequate control of potential confounders such as parental overweight and lack of consideration for the role of under-reporting. Recall that energy intake is determined by energy expenditure, with relatively small offsets in one direction or the other if gaining or losing weight. It is therefore not surprising that the majority of studies show no association, likely due to the difficulty in measuring either total energy or small changes in total energy, as previously noted. Reported inverse associations between total energy and obesity are therefore likely explained by under-reporting, lower physical activity, or lower total energy expenditure. Inverse associations observed in cross-sectional studies might also be due to reverse causation, in which overweight children are decreasing energy intake in an attempt to lose weight.

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Energy Density

An aspect of total energy, energy density is defined as the amount of available dietary energy per unit weight (kcal/g or kJ/g). Water accounts for most of the variability in energy density, since it provides weight but not energy, and fiber also contributes to energy density since it provides little energy; foods high in water and/or fiber are therefore energy dilute, or low-energy-dense. Conversely, fat provides the greatest amount of energy per gram, hence foods high in fat tend to be high-energy-dense. The concept of energy density as a property of food weight, or volume, has received increasing attention in relation to obesity and metabolic studies suggest that energy density is responsible for energy intake rather than dietary composition per se.[59] A study of the demographic factors associated with energy density among a nationally representative sample of children participating in the 1994-96 CSFII found that a high-energy-dense diet was associated with lower household incomes and with enrollment in the food stamp program among children aged 4 years; a low-energy-dense diet was associated with being Asian or Hispanic, and with consumption of milk among children aged 11 years or older.[60] To date, no studies of which I am aware have been published concerning the relation between energy density and obesity among children, although studies among adults have shown a positive association,[61] warranting further examination of this hypothesis.

Dietary Composition: Fat, Protein, Carbohydrate, and Fiber

Dietary composition generally refers to the relative percentages of energy provided to the diet by fat, carbohydrate, and protein. Unlike total energy, which is tightly regulated as previously noted, the relative mix of macronutrients in the diet can be modified and may be related to energy imbalance given their differential effects on hunger, satiety, satiation, and food intake, as well as on substrate utilization.[62] Studies conducted in the 1950s and 1960s indicated that dietary composition did not differ among obese and non-obese children and adolescents.[63] Today, the relative roles of fat, protein, carbohydrate, and fiber continue to be studied as possible risk factors for obesity.

Fat

Of all the macronutrients, fat has received the greatest attention by far in its relationship to obesity, and there are a number of different mechanisms by which dietary fat may lead to excess body fat. First, fat is considered more palatable and flavorful than carbohydrate, increasing the probability of greater energy intake due to passive over consumption. Because fat is the most energy dense nutrient, fat consumption may lead to increase in energy intake if volume is not regulated (see above discussion of energy density). In addition, fat intake does not induce as potent satiety signals or a compensation effect on subsequent energy intake as do diets rich in carbohydrate or protein.[64] In fact, fat may be more metabolically 'efficient' and likely to be stored than carbohydrate, as carbohydrates have a greater thermogenic effect than fat. A few carefully controlled metabolic studies among children have shown that meal-induced thermogenesis is higher after a low-fat meal (i.e., high-carbohydrate) compared to a high-fat meal and, despite higher fat oxidation on a high-fat meal, postprandial fat storage is also higher; these observations have been reported in both normal weight and overweight individuals.[65] Conversely, some data suggest that obese children may have lower thermogenesis in response to a high-carbohydrate meal, especially recently obese children, although there were no differences in response to a high-fat meal.[66] Further, changes in liver glycogen level and liver substrate oxidation rates provide feedback signals to the central nervous system (CNS) to regulate carbohydrate utilization, availability, and food intake; fat oxidation is not so regulated and is available for long term storage in almost unlimited quantities.[67]

There is continued controversy regarding the role of dietary fat in the obesity epidemic.[68] Among young girls, a high-fat diet was associated with poorer diet quality, including less fiber and vitamins, as well as fewer fruits and more sweets.[69] Comparing dietary intakes among obese and non-obese children, percentage of energy from fat was not significantly different in three descriptive studies[70] but was significantly higher among older obese children[71] and adolescents[72] in two other studies.

Data from cross-sectional studies are equivocal. Among girls aged 5-11 years, percent of energy from fat was significantly and directly associated with sum of skinfolds and hip girth, but not BMI or waist circumference; no associations were significant among boys.[73] Conversely, associations with BMI and skinfolds were only significant among girls in another study.[74] Children in the lowest quartile of fat intake (expressed both as a percentage of total energy intake and in absolute g) had significantly less body fat compared to those in the highest quartile (19.5% fat vs. 24.9% fat, respectively, p for trend < 0.05),[75] while fat intake was not significantly correlated with BMI among preschool children[76] or older children.[77] However, none of the above studies adequately adjusted their models for potential confounders. In a multivariate analysis, Larry A. Tucker et al. reported a positive association between percent energy from fat and percent body fat measured by skinfolds in a model which adjusted for sex, total energy intake, physical fitness, and parental body mass,[78] and similar positive associations were seen in two other small studies.[79] Fat intake was also positively associated with BMI percentile in a nationally representative sample which also adjusted for potential confounding,[80] although associations were not consistent among all age and sex groups. On the other hand, a study among preschool children found no significant association between fat intake and percent body fat in a model adjusted for physical activity,[81] nor was consumption of high-fat foods related to obesity in a case-control study.[82] Adjustment for potential confounders is critically important to isolate the effect of a dietary variable such as fat. As seen in previously noted studies of total energy, percent energy from fat was no longer significant in a model which further adjusted for parental overweight.[83]

Findings remain inconsistent when considering prospective and longitudinal studies. Among preschool children, one prospective study observed no significant association with fat intake and change in BMI or weight,[84] although both fat at baseline and 2 year change in fat intake were associated with greater gains in BMI in another study.[85] In another study of children the same age, fat was significantly related to body fat measured using dual energy x-ray absorptiometry (DEXA), but findings were not robust across several models.[86] Studies among older children also conflict. In a prospective study, children aged 3-7 years who had increased their sum of seven skinfolds by 1.5 standard deviations had a higher intake of total fat grams,[87] as seen elsewhere.[88] However, percent energy from fat was not significantly associated with BMI among children of the same age.[89] Two well-designed longitudinal studies with repeated measures of diet show opposite findings: While one study which modeled fat intake (g/d) among children from age 2 to 8 showed a positive association with BMI at 8 years,[90] a similarly designed study showed no significant association.[91] Among children aged 2-15 years with a 15 year follow-up and repeated measures of fat intake, very few significant associations with either BMI or skinfolds standard deviation score (i.e., *z*-score) were observed among the various time intervals studied,[92] and change in fat intake was not associated with BMI over 1 year among a large study of adolescents.[93]

Type of fat has received very little attention regarding associations with obesity. Obese children consumed a higher amount of saturated fat compared to non-obese children (35 g/d vs. 27 g/d, respectively),[94] and saturated fat was also significantly associated with BMI and skinfold thickness among Belgian children.[95] In the latter study, the effect of saturated fat was more pronounced among boys with an overweight parent.[96] A significant inverse association was observed between monounsaturated fat and percent body fat in one longitudinal study, although findings were not robust across several models.[97] Quite recently, a pilot clinical study among 11 obese Japanese children aged 7-11 years found that total body and subcutaneous fat were significantly lower after consuming diacylglycerol oil compared to that made from triacylglycerols,[98] although it should be noted that diacylglycerols do not readily appear in the food supply. Although the energy density of different classes of fats does not differ (i.e., saturated, monounsaturated, polyunsaturated, and trans-fat all contain ≈9 kcal/g), the consideration of different types of fat in obesity requires further investigation given their variable physiological effects, including the potential role of individual fatty acids.

Protein

Very few studies have specifically investigated the role of protein intake in childhood obesity. Mean intake of protein (as a percentage of energy) was not significantly different comparing obese and non-obese children in New Zealand[99] and France,[100] although percent energy from protein was significantly greater among overweight adolescents in Spain[101] and Iran.[102] In two well-designed longitudinal studies, protein intake at age 2 predicted adiposity at age 8,[103] possibly due to its effect on earlier adiposity rebound, which is independently and significantly related to obesity.[104] Protein (percent energy) was significantly related to percent body fat measured using DEXA among preschool children, although findings were not robust in several models,[105] and no association was seen in another study among preschool children.[106] Likewise, protein intake was not related to BMI or skinfold *z*-scores in another longitudinal study[107] or to percent body fat in a cross-sectional study adjusted for physical activity.[108] There are therefore insufficient data to support an association between dietary protein and childhood overweight, although the impacts of early protein intake on increased growth, resulting in earlier rebound, require further study.

Carbohydrate

Like fat, the role of dietary carbohydrate in the obesity epidemic is also a source of considerable controversy. Carbohydrates are significantly lower in energy density than fat (≈4 kcal/g vs. ≈9 kcal/g, respectively), thus provide substantially less energy for a given volume of intake. Therefore, it seems a reasonable hypothesis that carbohydrate intake may be inversely related to obesity, as has been suggested by the past several decades of nutrition policy and popular diets which have purported high-carbohydrate, low-fat diets. However, the increase in percent energy over the past several decades, which matches the increase in obesity prevalence, has led to the hypothesis that carbohydrate intake may be directly related to obesity, and this theory has enjoyed significant attention over the past 5 years due to media attention towards low-carbohydrate diets.

Some of the studies that have examined the role of dietary fat, discussed in the previous section, have also examined the role of dietary carbohydrate. As was seen for dietary fat, findings for dietary carbohydrate are just as ambiguous. In descriptive studies, percent of energy from carbohydrate was not significantly different among overweight and normal weight children.[109] Among adolescents, obese teenagers consumed significantly more energy from carbohydrates than normal weight subjects in one study,[110] significantly less energy from carbohydrates in another study,[111] and no significant differences in intakes in yet another study.[112]

The majority of studies examining the association between carbohydrate intake and obesity have been cross-sectional. While two studies among preschool children saw no significant association,[113] many cross-sectional studies have shown an inverse effect. Low carbohydrate density (less than 45% energy) was directly related to an increased risk of overweight in a cross-sectional study among adolescents in Canada (Odds Ratio [OR] = 1.27, Confidence Interval [CI]: 1.02-1.57).[114] In another study, percent of energy from carbohydrate was inversely associated with several measures of adiposity, including smaller sum of skinfolds, lower BMI, lower relative weight, and smaller waist and hip girth among girls aged 5-11 years, although the association was not significant among boys.[115] A similar study showed inverse associations with carbohydrate and adiposity, but the association was not significant among girls.[116] Although none of these studies adequately adjusted their models for potential confounders, a study which further adjusted for resting energy expenditure and physical activity also observed an inverse association with carbohydrate intake (percent energy) and percent body fat.[117] Two other cross-sectional studies also observed an inverse association using multivariate techniques,[118] although associations were not consistent among all age and sex groups in one of these studies,[119] possibly supporting the null findings seen in another study.[120] As seen in studies of dietary fat and obesity which adjusted for parental obesity, percent energy from carbohydrate was no longer significant in models which further adjusted for parental overweight.[121] Very few prospective studies have specifically examined the relation between dietary carbohydrate and obesity among children. Three studies found no association among preschool children,[122] although an inverse association was observed in one longitudinal study.[123]

As with dietary fat, findings between dietary carbohydrate and obesity are not conclusive. While the majority of cross-sectional studies show an inverse association, all but one prospective study show no association. Inconsistent findings are likely due to adequate control for confounding but may also be explained in part by the grouping of all carbohydrates together. More recently, increased attention to *type* of carbohydrate (e.g., refined carbohydrates vs. higher fiber counterparts), rather than *total* carbohydrate, has begun to clarify the role of carbohydrate in the obesity epidemic among adults,[124] but no studies of this nature have been performed in children.

Fiber

As fiber is a non-digestible carbohydrate, with properties different from digestible carbohydrates, it is discussed here in its own section. The interest in dietary fiber as a protective factor against the development of obesity is based upon the ecologic observations of low rates of obesity among populations with a high fiber intake and high rates of obesity among Western populations with low fiber intakes.[125] Fiber contributes limited energy to the diet (≈2 kcal/g), and also contributes to feelings of satiety and satiation, which may reduce energy within and between meals. Fiber is often a reflection of a healthy diet, as seen in children in the Bogalusa Heart Study aged 10-17 years, among whom those with higher fiber intakes consumed less total and saturated fat.[126]

Fiber intakes were higher among non-overweight boys compared to overweight boys (19 g vs. 15 g, respectively), but no significant difference in intake was seen for girls in the same study[127] or among preschool children in another study.[128] Very few studies among children have specifically examined fiber intake. Anthony J. G. Hanley et al. found that fiber consumption was associated with a decreased risk of overweight among Native Canadian children (OR = 0.69, CI: 0.47-0.99).[129] However, no significant relation between fiber intake and weight change was observed in a prospective study of preschool children,[130] nor in a prospective study among preadolescents aged 9-14 years.[131] In addition, two additional cross-sectional studies among children aged 6-12 years[132] and children aged 9-10 years saw no association between fiber intake and overweight.[133]

Reviews on the subject[134] have found that the effect of fiber on food intake and body weight depends on the food source and/or type of fiber. Wheat bran had no effect on energy intake or body weight but some types of fiber (e.g., cellulose, guar, psyllium) were inversely associated with body weight among adults.[135] The role of fiber in body weight requires further study among children, and perhaps future studies should separately consider different types of fiber to better understand the association.

Glycemic Index

The glycemic index (GI) estimates the postprandial rise in blood glucose after carbohydrate consumption;[136] the glycemic load (GL) may be measured by multiplying each food's glycemic index by its carbohydrate value and the frequency of consumption and summing over all foods.[137] Studies among adults showing a relation between glycemic index or load and measures of obesity are inconsistent;[138] limited studies have investigated the association among children. Among children aged 8 years, a high GL diet reflected a poorer quality diet, including high intakes of white bread and sweetened baked goods and low intakes of fiber, fruit and vegetables.[139]

In a seminal crossover study, David S. Ludwig et al.[140] observed an 81% greater voluntary energy intake after a high-GI meal compared to low-GI meal among obese boys aged 12 years; the study also showed that the high GI meal resulted in higher serum insulin level, lower plasma glucagon, lower post-absorptive plasma glucose and serum free fatty acids, and elevation in plasma epinephrine, all of which may promote excessive food intake.[141] Likewise, greater energy intakes at lunch were observed among both overweight and normal weight children aged 9-12 years after consuming a high-GI breakfast compared to a low-GI breakfast.[142] A small randomized controlled trial among 16 adolescents saw greater changes in BMI and body fat for those following a low-GI diet versus a low-fat diet,[143] confirming results from an observational study among obese children.[144] Conversely, no significant association was observed between glycemic load and odds of overweight among children aged 6-7 years in Hong Kong,[145] although the study may have lacked adequate statistical power. The effect of GI and GL on adiposity measured using sum of skinfolds was modified by sex and age among Danish children. No associations were observed among girls or among boys aged 10 years, but the effects of both GI and GL were significant among boys aged 16 years.[146] Thus, while several small clinical studies have shown a direct association between GI/GL and obesity, additional studies with larger sample sizes and greater diversity of participants (e.g., age, sex, ethnicity) are necessary.

Individual Foods, Food Groups, and Dietary Patterns

The study of single nutrients such as fat, carbohydrate, and protein discussed above is plagued with methodological limitations since many nutrients occur together in foods and meals. For example, legumes are high in carbohydrate, fiber, and protein, and animal products are often high in both saturated fat and protein. Therefore, it is important to study the role of individual foods and food groups in dietary studies to complement nutrient-based approaches. Furthermore, studies of food are better poised to provide dietary advice, since individuals consume foods and not nutrients.

Fruits and Vegetables

Fruits and vegetables are important sources of fiber and micronutrients, but data from CSFII 1989-91 indicate that only 20% of children consumed 5 or more servings of fruits and vegetables recommended per day, and half of all children aged 2-18 years consumed less than a serving of fruit per day; about half of vegetables consumed were french fries.[147] Fruits and fruit juices (16% of juices consumed were sweetened) comprised about one-third of fruit and vegetable intakes among children.[148] Intake of fruits and vegetables increased slightly with rising yearly income, from a mean serving of 3.4 for an income less than $10,000 to 3.8 servings for an income greater than $50,000.[149]

It is reasonable to think that consumption of fruits and vegetables would be protective against obesity, as these foods are generally low in calories due to their high water and fiber content. Fruits and vegetables are thus low-energy-dense foods which contribute to satiety and may also displace other high-energy-dense foods from the diet. However, a recent review on the relation between fruit and vegetable consumption and body weight concluded that the evidence was inconsistent, although the article only included two studies among children.[150] These studies, and additional studies performed among children, are discussed below.

A descriptive study using nationally representative data observed smaller intakes of total vegetables, potatoes, and fruits among overweight boys compared to normal weight boys, although only the finding for fruits was significant among girls, and relations were inconsistent across age groups.[151] Inverse associations were observed between frequency of consumption of fruits and vegetables and BMI among adolescents in Iran[152] and between fruit intake and percent body fat among children and adolescents in Croatia.[153] In Mexico, weekly consumption of vegetables was inversely associated with prevalence of obesity among boys aged 6-7 years, but was not a significant variable among girls of the same age, nor among boys and girls aged 13-14 years,[154] as seen in another study.[155]

Three prospective studies have examined the association between fruit and vegetable consumption and obesity among children. Among preschool children, consumption of fruits (with or without fruit juice) and vegetables (with or without potatoes) was not significantly related to changes in BMI or weight in models adjusted for dietary and non-dietary confounders.[156] 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).[157] Likewise, fruit intake (with or without juice) was not significantly associated with change in BMI z-score in another prospective study among older children 9-14 years.[158] Alison E. Field et al. did observe a significant inverse association with vegetables and change in BMI z-score in the same study, although the association was no longer significant when energy was included in the model. However, it is not necessarily clear that energy intake should be included in the model, as energy intake is likely the mechanism by which foods such as fruits and vegetables exert an effect on body weight.

It is possible that preparation of vegetables, which contribute to variation in energy intake, energy density, and macronutrient composition, will modify the effect of vegetables on body weight.

The available data on fruit and vegetable consumption are limited but do not seem to suggest a protective effect on the risk of obesity. It is possible that preparation of vegetables, which contribute to variation in energy intake, energy density, and macronutrient composition, will modify the effect of vegetables on body weight (e.g., raw versus fried, consumed with or without sauces).[159] Therefore, future studies are needed which consider preparation methods.

Breads, Grains, and Pasta

Only one study examined prospectively the association between breads and grains and obesity among children. In that study, P. K. Newby et al. found that there was a 0.16 kg smaller weight change per year (CI: -0.20, -0.12 kg; $p < 0.01$) with each additional daily serving of breads and grains.[160] Weekly consumption of pasta was also inversely associated with prevalence of obesity in a cross-sectional study, although relations were inconsistent across all age and sex groups.[161] Breads were not significantly associated with odds of overweight in another study.[162] Conversely, intakes of bread, rice, and pasta were directly (though weakly) associated with BMI among boys and girls, although this study did not adjust for potential confounders.[163] Further research in this area may be warranted, with attention to fiber and whole grain content of grain foods, and possibly glycemic index values of individual foods, since these will impact the metabolism of these foods, hence impact satiety and possibly energy intake.

Cereal

Among children, a number of studies have reported that cereal consumption is associated with a higher quality diet, including lower fat and cholesterol and higher fiber and micronutrients (folate, vitamin C, zinc, and iron).[164] However, few studies have specifically examined the association between cereal consumption and weight.

Descriptive studies have shown that cereal consumers have significantly lower BMI than non-consumers.[165] Normal weight children consumed cereal at breakfast more often than overweight children,[166] and a significant, inverse linear trend was observed between frequency of cereal consumption and BMI in two studies.[167] Consumption of cereal was inversely correlated with percent body fat among children and adolescents ($r = -0.34$, $p < 0.0001$)[168] and inversely related to waist circumference among Greek adolescents.[169] Only one longitudinal study has been performed on this subject, which showed that cereal consumption was related to a smaller BMI z-score among girls in the U.S.[170] As with other carbohydrate sources discussed above, attention to fiber and sugar content as well as glycemic index may further clarify the association between cereal and body weight, and adequate control for confounding is also important.

"Junk Food" and Snack Food

"Junk" and snack foods tend to be high in fat, saturated fat, sucrose, and sodium, and can displace more healthful (snack) foods from the diet, such as fruits, vegetables, and nuts. Compared to meals, snacks are higher in energy density and lower in vitamins and minerals.[171] Sweet baked goods and salty snacks (which included potato chips, corn chips, and popcorn) contributed 12% to total fat intake and 8% to saturated fat intake among children aged 2-18 years in 1989-1991.[172]

An early study observed no significant differences in snack purchasing at a movie theatre by weight status.[173] Although that study looked only at purchasing, not consumption, the available data remain unclear as to whether overweight children consume more snack foods than normal weight children. Overweight adolescents in Greece consumed more snack foods than normal weight adolescents.[174] In a small U.S. sample, 21 non-obese girls reported consuming more high-calorie, low-nutrient-dense foods compared to obese girls, but after adjustment for under-reporting the association was no longer significant.[175] Likewise, consumption of snacks was not significantly associated with risk of overweight among Canadian children,[176] and two well-designed longitudinal studies also saw no significant association between consumption of snack foods and BMI and percent body fat[177] or change in BMI[178] in multivariate adjusted analyses. Further, an analysis of individual snack foods showed no significant effects between percentage of energy from candy, chips, baked goods, or ice cream and BMI z-score.[179]

A few studies suggest a positive association between snack food consumption and obesity. "Fat foods" (e.g., ice cream, potato chips, cookies, chocolate, fried foods) were positively associated with weight change in one prospective study of preschool children,[180] although the "fat foods" food group included foods other than snack foods. Consumption of snacks was also directly related to BMI among adolescents in a cross-sectional study,[181] while another study showed a positive association only among children with an overweight parent.[182] A unique study among girls aged 5 years observed that girls who consumed large amounts of snack foods in the absence of hunger in an experimental setting were 4.6 times as likely to be overweight at baseline and two years later.[183] These studies suggest that shared genetics or family experiences (such as presence of an overweight parent), or an environment which provides ubiquitous access to snack foods, may mediate the relation between snack food consumption and risk of obesity. More studies are needed to test these hypotheses.

Dietary Patterns

The study of dietary patterns, in which many dietary items (e.g., foods, food groups, nutrients) are grouped together to provide a picture of "total" diet, has gained popularity in nutritional epidemiology in recent years. This method may use statistical techniques such as cluster or factor analysis to derive patterns empirically[184] or it may use an index, which ranks multiple nutritional elements to provide a total score of overall diet quality.[185] The dietary pattern approach has rarely been used in children[186] and only one of these studies has examined associations with obesity. In that prospective study, four different dietary patterns using cluster analysis were observed among German children, and although the patterns differed significantly with regards to many food and nutrient intakes, notably fat intake, none of the patterns were significantly related to BMI z-score at either baseline or follow-up.[187] Among adults, the dietary pattern approach has been used successfully to show inverse associations with body weight and BMI,[188] thus more research using these methods in studies of children is warranted.

Beverage Consumption: Fruit Juice, Sugar-Sweetened Beverages, and Milk

Beverage consumption among children generally falls into two categories: (1) those which provide valuable nutrients, such as milk and (2) those which provide limited nutritional value and are high in sugar, such as sweetened fruit drinks, teas, ades, and soft drinks. Fruit juice, if comprised of 100% fruit and/or fortified with vitamins, might also be considered nutritious, although it is generally high in sugar and calories even so. While water, sports drinks, and diet soft drinks also contribute to beverage intake, especially among older children and adolescents, certainly milk, fruit juice, fruit drinks, and soft drinks comprise the large majority of beverages consumed. In this section, I discuss the studies that have examined the roles of fruit juice, sweetened beverages (e.g., soft drinks, sweetened fruit drinks), and milk in the childhood obesity epidemic.

Fruit Juice

Fruit juice intake among infants and children has typically been related to failure to thrive, in which excessive consumption leads to carbohydrate malabsorption,[189] hypocaloric intake, and compromised intakes of protein, fat, and micronutrients.[190] Fruit juices have also been associated with dental caries[191] and gastrointestinal symptoms such as bloating, diarrhea, and cramping. These health risks led to consensus recommendations in the early 1990s discouraging excess consumption of fruit juice, including the use of fruit juices in a bottle.[192] More recently, the American Academy of Pediatrics recommended that fruit juice should be limited to 4-6 oz/d for children aged 1-6 years and 8-12 oz/d for children aged 7-18 years.[193]

The hypothesis that fruit juice might be related to obesity gained increasing attention in the late 1990s, after a small cross-sectional study among 168 children aged 2 and 5 years found that 53% of children drinking 12 oz/d fruit juice or more had a BMI greater than or equal to the 75th percentile compared to 32% among those consuming less than 12 oz/d.[194] (Twelve oz/d was selected as the cutpoint in that study since it was the lower range of intake associated with non-organic failure to thrive among children aged 14-27 months.[195]) A follow-up study of this cohort later reported positive associations for apple juice with BMI and ponderal index (kg/m^3), but no significant associations with intakes of orange juice, grape juice, or other mixed juices.[196] However, data from CSFII 1994 showed no significant differences in BMI at the same level of juice consumption,[197] and another cross-sectional study also showed no association between fruit juice and BMI.[198] While one small case-control study among 53 Puerto Rican children aged 7-10 years saw a four-fold greater odds of obesity with increasing frequency of fruit juice consumption (OR = 4.02, CI: 1.48-10.95),[199] the authors were not able to adequately separate 100% fruit juice from other fruit juices, thus the effect may be due to sweetened fruit drinks rather than fruit juice.

The vast majority of prospective and longitudinal studies do not support a positive association between fruit juice consumption and anthropometric measures or obesity. A prospective study of 105 children aged 2-3 years found no relation between daily fruit juice intake and height, BMI, or ponderal index nor did they find that fruit juice consumption displaced milk from the diet.[200] In a longitudinal study of 205 German children aged 3-5 years, no children consuming greater than 12 ounces/d of fruit juice over four repeated measurements were obese, and BMI and height z-scores were not related to excessive juice consumption.[201] Another longitudinal study with repeated measures of diet found that changes in fruit juice intakes were not related to height, weight, BMI, or ponderal index.[202] Further, one prospective study found no significant relation between either change in weight or change in BMI and fruit juice consumption, where subjects were consuming on average greater than 10 fl oz/d and models were adjusted for intakes of other beverages.[203] Additional prospective reports among preschool children[204] and older children[205] confirm a lack of association between fruit juice and change in BMI. In fact, only one recent prospective cohort study reports a positive association between fruit juice and gains in BMI z-score,[206] but this association was only observed among children who were already overweight at baseline.

Whereas fruit juice can contribute substantially to total energy and carbohydrate intakes of sucrose, fructose, glucose and sorbitol, it is also an important source of vitamins A and C, potassium, and flavonoids. While three small studies showed a positive association between fruit juice intake and obesity, the evidence to date is fairly consistent among well-designed longitudinal and prospective studies that fruit juice is not associated with various measures of weight and obesity among children. It is important that future studies adequately control for both dietary and non-dietary confounders in the analyses, and special attention should be given to ensure that beverage intakes are not misclassified (i.e., that beverages considered "100% fruit juice" do not include sweetened fruit drinks). Future studies might also consider exploring interactions with baseline weight in light of recent findings.[207] The American Academy of Pediatrics reminds pediatricians to routinely discuss the use of fruit juice in children's diets and to differentiate between 100% fruit juice and sweetened fruit drinks.[208]

Sugar-Sweetened Beverages

The possible relation between sugar-sweetened beverages (SSBs) and obesity emerged when a prospective study among 548 children aged 11-12 years reported that consumption of SSBs (non-diet soft drinks, fruit drinks, and sweetened teas) was associated with a 60% increase in the risk of obesity (OR = 1.60, CI: 1.14-2.24).[209] The association between SSBs and obesity may be explained by incomplete compensation of calories from liquids, which leads to higher energy intake;[210] preschool children are better able to compensate for energy consumed from liquids and thus may be less susceptible to the effects of beverages on body weight.[211] Indeed, there is some evidence to suggest that SSBs contribute to greater energy intakes among consumers[212] and may also displace more nutritious beverages from the diet such as milk.[213] Nonetheless, additional evidence supporting an association between SSBs and obesity among children is limited and inconclusive.

Among preschool children, two prospective studies saw no association between intakes of either fruit drinks or soft drinks, although both studies had methodological limitations,[214] while another found that the effect of SSBs on obesity was modified by baseline BMI.[215] In that study, children at risk of overweight who consumed at least 3 "sweet" drinks/d were 1.8 times more likely (CI: 1.1-2.8) to become overweight compared to those consuming less than one drink per day, and children who were overweight were 1.8 times more likely to remain overweight at the same levels of consumption; no significant associations were observed among children who were normal weight or underweight.[216] Findings from this study are also difficult to interpret, since the authors included 100% fruit juice in their measurement of "sweet" drinks.

Among older children, cross-sectional studies are inconsistent, with some studies showing a positive association between body fat and total SSBs[217] or soft drinks,[218] and other studies showing no association.[219] Consumption of "non core beverages," which included SSBs, was significantly higher among overweight and obese children compared to normal weight children in Australia, although results were not consistent across all age groups.[220] One large study reported that the risk of overweight was modified by ethnicity, showing an increased risk among white children, but not African-American children.[221] Effect modification was also observed in a longitudinal study of more than 10,000 adolescents, which reported a significant positive association between intakes of SSBs and BMI among boys, but findings among girls were less robust, and associations were no longer significant for either when total energy was included in the models.[222] (Recall that it is arguable as to whether total energy should be included in the model, however.) Another longitudinal study among girls aged 8-12 years with a 10 year follow-up reported a significant association between percent of energy consumed from soft drinks and BMI z-score, but not percent body fat.[223]

The evidence for an association between SSBs is limited, and age, baseline BMI, and other factors may modify the association. Additional studies will be needed to further examine this hypothesis, but the limited nutrient content and high caloric value of SSBs suggest these beverages should be limited.

Milk, Dairy Foods, and Calcium
The interest in calcium as a dietary strategy to control body weight gained considerable attention early this century after studies in transgenic animal models found that high calcium diets accelerated fat loss through its role in lipid metabolism.[224] Additional research found that dairy foods in particular may have an even greater benefit than calcium alone, possibly due to additional bioactive components in these foods.[225] On the other hand, estrone, a hormone found in milk and other foods, has been found to increase body weight among Zucker rats.[226] As many of the studies in this area test together the effects of milk, dairy foods, and calcium, all three variables are discussed in this section.

Inverse associations were observed between dairy foods and body fat in a small case control study[227] and between milk and BMI in two other cross-sectional studies,[228] although the effect in the latter study was no longer significant when skim milk was included in the milk group.[229] However, null associations between calcium and dairy foods and BMI and percent body fat measured by DEXA were seen in an obesity-prone population of Pima Indian children aged 10 years,[230] as seen in another cross-sectional study.[231]

Four prospective studies reported no significant association between milk consumption and BMI among children.[232] Inconsistent results were seen in several well-designed longitudinal studies, including null associations between both calcium and dairy foods and BMI and percent body fat among girls aged 8-12 years,[233] and inverse associations between body fat and calcium,[234] as well as dairy foods.[235] One longitudinal study showed a positive association between high milk consumption (more than 3 servings/d) and greater gains in BMI among children aged 9-14 years but concluded the effect was due to increases in total energy; a positive association with BMI was also observed for calcium.[236] Although calcium intake was inversely associated with body fat at baseline ($r = -0.242, p = 0.011$) in a recent randomized controlled trial of calcium supplementation,[237] no significant association with body weight was observed during the 1 year follow-up, supporting results from earlier trials on calcium and bone mineral density.[238]

Several studies have suggested that the effect of calcium and dairy products may be modified by age, sex, ethnicity, and/or health status. An elegant prospective study conducted among children aged 4-10 years observed inverse relations between calcium and dairy foods with both BMI and skinfolds among children aged 7-10 years who were normocholesterolemic, but no effect was seen among hypercholesterolemic children, nor among normocholesterolemic children aged 4-6 years.[239] Two cross-sectional studies showed inverse associations among milk consumption and BMI, but only among girls.[240] Another study among girls aged 9-14 years observed inverse relations between total calcium and dairy calcium with iliac skinfold, but not with weight, and the effect was greatest among Asian girls.[241] Findings of effect modification may be spurious and need to be replicated in future studies.

Thus far, research among adults and in animal models showing a clear role for calcium and dairy products in weight maintenance and weight loss appears possible but remains equivocal.[242] Along with the inconsistent findings observed among children as summarized above, the current body of literature suggests that more research is needed to establish a conclusive relation between calcium, milk, and dairy foods and adiposity among children. Greater attention to potential confounding and interaction effects may clarify the association.

In addition to what is eaten during the day, perhaps specific aspects of eating behavior – where, when, how often, and with whom – may also be of importance in the development of obesity. Should food be consumed as "three square meals" or is it better to "graze"?

Eating Behaviors: Where, When, How Often, and With Whom

In addition to what is eaten during the day, perhaps specific aspects of eating behavior – where, when, how often, and with whom – may also be of importance in the development of obesity.[243] Should food be consumed as "three square meals" or is it better to "graze"? How frequently should food be consumed? Does timing of food consumption matter? Questions such as these are addressed in this section.

Where: Fast Food and Away-From-Home Dining
The increase in away-from-home dining may contribute to the obesity problem, as these foods tend to be higher in fat and saturated fat and lower in fiber than foods prepared at home.[244] Frequenting fast food

restaurants is one form of "away from home" dining, although which establishments should be considered "fast food" is not always straight forward. Comparing food and nutrient intakes of children's diets on days they did and did not consume fast food showed that "fast food" days were of poorer nutritional quality,[245] including higher intakes of total energy, saturated fat, and sugar-sweetened beverages and lower intakes of fruits, vegetables, fiber, and milk. Overweight subjects aged 10-17 years consumed significantly more calories at a fast food meal than did normal weight subjects, and total daily energy intakes were also significantly higher on days where fast food was consumed among overweight subjects, but not normal weight subjects.[246]

The evaluation of food away from home and/or fast food dining in relation to obesity among children has received very limited research attention. While one small clinical study observed that obese children consumed food away from home more frequently than non-obese children,[247] no significant associations were observed in a cross-sectional study between foods consumed away from home and risk of overweight.[248] A cross-sectional study among boys and girls in three age groups found that percent energy from foods consumed away from home was positively related to BMI percentile among boys and girls aged 12-19 years, but not among younger children.[249] Fast food consumption was significantly related to BMI among Iranian adolescents[250] and to the prevalence of obesity among Mexican girls, but not boys,[251] while no relation was observed with BMI among children in another study.[252]

A recent longitudinal study specifically considering the consumption of fried food away from home observed a significant increase in BMI (Beta [ß] = 0.21, CI: 0.03-0.39) among children aged 9-14 years who increased consumption from less than once/wk to 4-7 times/wk,[253] confirming results from another prospective study which saw a larger change in BMI *z*-score among girls consuming "quick service food" at least 2 times/wk compared to those consuming such food less than once/wk.[254] The latter study, however, saw no significant associations between BMI and total away from home eating, as well as eating at coffee shops or restaurants, whether measured as frequency or percent of energy.[255] Evidence is therefore inconclusive, and careful consideration is required when comparing results across studies due to the different ways in which "away from home" and "fast food" are defined and measured.

When: Breakfast Consumption and Meal Skipping

Irregular meal consumption or meal skipping may have implications for health. Breakfast consumption, or non-consumption, has been of particular interest. Two reviews indicate that diets among those who skip breakfast are less healthful and that skipping breakfast interferes with cognition and learning,[256] especially among children at nutritional risk.[257] More recently, studies among adolescents suggested that skipping breakfast is related to dieting behavior and attempts to lose weight,[258] perhaps supporting findings that overweight subjects who did consume breakfast consumed significantly less calories at the meal than normal weight subjects.[259]

Gail C. Rampersaud et al. recently reviewed sixteen studies examining the relation between breakfast consumption and weight status and concluded that breakfast consumers generally had higher energy intakes yet were less likely to be overweight, although findings with overweight were inconsistent.[260] Several studies have shown that those who consume breakfast have a lower BMI[261] and lower prevalence of overweight[262] compared to those who do not, and percent of energy consumed at breakfast was inversely associated with BMI in another study.[263] Swedish adolescents who consumed breakfast irregularly consumed significantly more sucrose, sweets, and salty snacks, along with fewer vegetables and less fiber and calcium, but clear associations with both weight and BMI did not emerge when compared with those who consumed breakfast "regularly."[264] Theresa A. Nicklas et al.[265] also saw no relation between skipping breakfast and odds of overweight among children aged 10 years participating in the Bogalusa Heart Study. Skipping breakfast was associated with overweight among children aged 9-14 years at baseline,[266] as seen in a cross-sectional study,[267] but the longitudinal analysis showed an interaction with baseline BMI: overweight children who never ate breakfast had a smaller BMI at follow-up, whereas normal weight children who never ate breakfast had a larger BMI at follow-up, compared to those who consumed breakfast 5 or more days/wk.

While findings between breakfast skipping and overweight are inconsistent, several studies discussed above seem to clearly indicate the presence of reverse causality. That is, overweight subjects are skipping breakfast in *response* to their weight; skipping breakfast is not *causing* overweight. Therefore, prospective and longitudinal studies are clearly needed, and including measures of dieting or weight loss intention may help to clarify the association between breakfast skipping and obesity.

How Often: Meal Frequency and Timing

The question of timing, including both what time(s) and how frequently one consumes a meal or snack, is not a new research question.[268] Quantification of these concepts can be challenging, as it is likely that individuals differently define what constitutes a "snack" versus what constitutes a "meal." In fact, a recent study pointed out the difficulty in measuring meal and snack consumption due to the "atypical" patterns in a population of adolescent girls, thus used the term "dietary events" to measure both the timing and frequency of food consumed throughout the day.[269] That prospective study found that fewer than 2 events per evening and 6 events per day were associated with smaller changes in BMI z-score.[270] Similarly, a cross-sectional study among German children observed that consuming greater than 4 daily meals was associated with a decreased risk of overweight (OR = 0.73, CI: 0.56-0.96), with the greatest risk reduction observed for those consuming 5 or more meals/d (OR = 0.56, CI: 0.42-0.75).[271] Meal frequency was also inversely associated with BMI percentile among boys aged 12-19 years, although associations were not significant in girls of the same age, or in younger girls or boys.[272] Total number of eating episodes and total number of snacks were not related to risk of overweight in two other large cross-sectional studies,[273] although an inverse relation was observed in one of these studies for the number of meals among African-American girls only (OR = 0.56, CI: 0.33-0.95).[274] Snacking "irregularity" was significantly associated with risk of obesity among children aged 3 years in Japan in a model which adjusted for parental obesity, whereas snacking frequency lost significance.[275]

Energy intake at specific meals has received some research attention. Claudio Maffeis et al. observed that the percentage of energy consumed at dinner was directly related to adiposity among children aged 7-11 years in a model that adjusted for parental weight status.[276] While another study among children aged 10-19 years showed no significant associations with percent energy consumed at dinner, positive associations were observed with energy consumed at lunch for both boys and girls ($r = 0.16$ and $r = 0.22$, respectively; $p < 0.05$).[277] Together, these studies raise the possibility that perhaps the number and timing of meals consumed throughout the day are less important than the distribution of energy across those meals, but additional research is needed to confirm these findings. In addition, as with studies of breakfast skipping, timing and frequency of meal and snack intake may be in response to weight, so prospective studies are needed.

With Whom: Family Dinner

Decreased frequency of meals consumed at home, around the family dinner table, has occurred alongside the increasing frequency of fast food consumption and food consumed away from home. Frequency of family dinner has been associated with healthier meals, including higher intakes of vegetables, fruit, and dairy products,[278] as well as higher intakes of vitamins and minerals[279] and a lower risk of skipping breakfast.[280] Only one study has examined the association between consumption of family dinner and obesity, finding that overweight was inversely related to consumption of family dinner at baseline, likely an example of reverse causation since no significant association was observed with incidence of obesity.[281]

Methodological Considerations and Future Research Directions

Several themes emerge after reviewing the literature on the role of diet in childhood obesity and are discussed below, along with suggestions for future research.

Limited Literature: More Research is Needed

It can first be noted that studies on the association between diet and obesity among children are limited. Much of the data come from descriptive studies, in which mean intakes are compared across individuals of varying weight groups but are not adjusted for potential confounding. Among analytical studies, the majority are cross-sectional in design, which introduces the possibility of reverse causation, in which the temporal relation between diet and weight is distorted. This was suggested specifically by cross-sectional studies examining breakfast skipping and meal frequency and overweight, but might also be indicated in studies of dietary fat, such as when one tries to follow a low-fat diet for weight loss, or in studies of fruit juice, in which overweight individuals replace soft drinks or sweetened fruit drinks with fruit juice. Indeed, with many of the dietary factors discussed herein, it could be seen that findings from cross-sectional studies were not always confirmed in prospective or longitudinal designs. In addition, relatively few studies conducted multivariate analyses, in which statistical models were adequately adjusted for both dietary and non-dietary variables to reduce the impact of confounding. Total energy also requires special consideration, since it might confound the association between diet and obesity. On the other hand, total energy might be in the causal pathway between diet and obesity as increased energy intake may be the mechanism through which dietary factors exert their effect. Ideally, studies should model associations with and without total energy to better understand the effect of total energy. For all of these reasons, it is clear that additional well-designed, prospective studies are needed, ideally with repeated measures of both exposure and outcome to minimize reverse causation. Adequate control for potential confounders and consideration of total energy intake in statistical models is critical.

Interaction Effects: Effect Modification of Dietary Intakes

Of interest is that many of the studies observed interaction effects with the associations of diet and obesity, including with baseline BMI, age, sex, ethnicity, and presence of an overweight parent. Results that suggest effect modification are interesting and important, but need to be replicated in additional studies since methodological factors such as reporting bias may be responsible for interaction effects (e.g., girls are more likely to under-report than boys).[282] Interaction effects are also more likely to occur by chance due to repeated analyses and are often not reproducible.[283] Nonetheless, it would be helpful if studies were designed with adequate statistical power to explore potential interactions. The possibility of effect modification also challenges us to consider how these effects might be operating. Likely, some of these effects, if true, would have a genetic basis, so genetic studies, including both basic science and epidemiological studies with genetic biomarkers, are urgently needed to deepen our understanding of the dietary correlates of childhood obesity.

Under-Reporting

Under-reporting of dietary intake is a serious concern in observational studies, and it is of even greater concern in obesity studies, since overweight individuals are more likely to under-report.[284] Linda G. Bandini et al.[285] observed that both obese and normal weight adolescents under-reported dietary intake, but under-reporting was greater among obese subjects and recording errors increased with increasing weight. A later review of 10 validation studies found that under-reporting was also a serious error among children and varied by weight as well as age.[286] Hence, under-reporting can bias results and distort relations, as under-reporting differs by BMI. An elegant study by Terry TK Huang et al. found that associations between total energy and meal portions were stronger and more consistent when under-reporters were excluded from the analysis.[287] On the other hand, dietary composition was no longer significant in a model which adjusted for dietary under-reporting in another study.[288] It is notable that adjustment for under-reporting strengthened dietary associations in the first study but attenuated the associations in the second. It is possible that under-reporting may be contributing to the inconsistency seen in the literature, and the ability to account for under-reporting in dietary studies may clarify associations between diet and obesity. It is also possible that the increased focus on obesity in society has led to even greater under-reporting among overweight individuals, further contributing to the difficulty in accurately measuring dietary intakes, hence in quantifying diet-obesity associations.

Changing Food Supply and Dietary Databases

In epidemiological studies, the analysis of diet and diseases such as obesity is dependent upon the availability of accurate, up-to-date dietary databases. While constructing such databases has always been a challenge, the task is becoming even more difficult due to the ever-changing food supply. As food science, food technology, and nutrition science progress, the food industry is anxious to produce new products with the latest health benefits. There are far too many examples to list in this space, but the recent change from refined grains to whole grains in the case of ready-to-eat breakfast cereals and the addition of nutrients to foods in which they don't naturally occur (e.g., the addition of fiber to yogurt, the fortification of orange juice with calcium) are just a few examples of "improved" foods with altered nutrient content. The ability to detect an association in an epidemiologic study is utterly dependent on the ability of the database to accurately capture the correct food and its nutrient composition, and limitations of nutrient databases lead to measurement errors in dietary intake; this point cannot be understated.

Genetic Influences

Animal studies, twin studies, linkage studies, and genome scanning all support the strong role of genetics in impacting body weight and fat,[289] and genetics also influences energy and macronutrient intakes, food intake behaviors, and energy expenditure.[290] Nutrigenetics (or nutrigenomics) brings together the study of diet and genetics, in which the way specific genes and bioactive food components interact is examined,[291] and this discipline will lead to new insights on how diet is related to obesity. At the heart of this field is the study of inter-individual variation in response to dietary intake, hence modification of diet-disease associations, which may be explained in part by genetic factors. In time, it is possible that findings from nutrigenetic studies will lead to personalized dietary recommendations.[292]

In fact, none of the studies reviewed herein included genetic variables. Several studies were able to adjust for parental overweight, a proxy for genetics,[293] finding that associations between dietary fat, carbohydrate, and total energy and obesity were attenuated or no longer significant when parental weight status was included in the models. Evidence from genetic epidemiology, molecular epidemiology, and animal studies supports the role of genetics in modifying the association between dietary intake and body fat, which has been studied most often in animal models examining fat intake.[294] Among adults, for example, only overweight women with an overweight parent gained body fat over 6 years after consuming a high-fat diet; neither lean women nor overweight women without an overweight parent increased their BMI during the study period.[295] The consideration of parental overweight therefore plays a role not only as a possible confounder of the relation between diet and obesity due to shared environment and genes, but also as a potential effect modifier of certain types of diets (e.g., high-fat).

It is clear that genetic studies should be used to inform future studies, and genetic measures should also be included directly in the design and analysis of epidemiologic studies, where possible. Nutrigenetic studies that specifically examine the differential impact of diet on weight due to genetic factors are sorely needed, in addition to traditional studies on the study of genetic influences on food intake behavior and body composition. Studies among children are specifically needed, as some genes may exert a different effect on children than in adults.[296] In summary, genetic studies are of paramount importance in moving forward our understanding of diet and obesity, and may be especially critical during times of growth and changes in body composition such as in childhood and adolescence, further discussed below.

Genetic studies are of paramount importance in moving forward our understanding of diet and obesity, and may be especially critical during times of growth and changes in body composition such as in childhood and adolescence.

Growth

Critical periods in childhood for the development of obesity include gestation, early infancy, adiposity rebound (the time in early childhood when body fat begins to increase), and puberty, all of which are times of intensive growth.[297] It should be noted, however, that the degree to which said critical periods are physiologically meaningful, rather than just a statistical phenomenon, remains controversial.[298] Nonetheless, earlier adiposity rebound increases the risk of obesity in later childhood[299] as well as adulthood,[300] and one study observed that age at adiposity rebound was more closely related to later obesity than nutritional status during infancy.[301] It may be that dietary intake and composition play a particularly important role in body fat accumulation during these times of dynamic changes in growth and body composition; thus it is possible that some of the inconsistencies in the literature may be explained in part by different growth stages. As such, special attention should be given to stage of growth in studies of childhood obesity, not simply age, and longitudinal studies designed to specifically examine dietary intakes during critical periods are needed. For example, well-designed studies among adolescents often adjust for pubertal stage to adjust for the changes in body composition that occur naturally during this period of growth.

Generalizability

Generalizability, also known as external validity, refers to the ability to extrapolate results from one population to another, which is a necessary task when synthesizing the literature on a given topic. That is, will studies performed in one population give the same results if conducted in a different population? To address this issue we must understand whether differences in participants versus non-participants with regards to disease status and other factors (sex, age, ethnicity, etc.) would impact study findings.

In this review, as in many reviews, the majority of research comes from studies of Caucasian children living in North America or Europe. The populations included herein varied by age, sex, socioeconomic status, and geographic region, and these variables may partially explain inconsistent findings. However, studies among African-American, Hispanic, and Native-American children are sparse and greatly needed, as dietary intakes vary due to culturally defined food habits and prevalence of obesity is generally highest among these ethnic groups. When racial groups were included in individual research studies, interaction effects of these variables were not uncommon, as previously noted, suggesting that caution may be warranted when generalizing results across ethnic groups. Comparing findings across studies is further complicated as methods for measuring diet and overweight also differ, thus it cannot be concluded that differences in findings can be attributed to differences in study populations per se. It therefore remains unclear the extent to which findings should be expected to differ purely by population characteristics, and differences may also be attributed to genetic variation or to environmental differences. Future studies which include racial, genetic, and environmental components may shed further light on the increasingly complicated picture of diet and obesity.

Summary of the Evidence

The main goal of this paper was to comprehensively review the evidence on the association of diet and obesity among children and to highlight methodological issues. Keeping in mind the research considerations discussed above, what can be concluded about the role of diet in the childhood obesity epidemic from the research discussed herein?

In summary, although there are multiple aspects of diet that have changed over the past several decades that may account for the association between diet and obesity, the available literature does not generally support a consistent association between most dietary factors and obesity among children, although strength of evidence varies by dietary factor. Inconsistent findings were especially pronounced for total energy, and for all of the reasons discussed earlier, it is not generally advisable to consider total energy as an independent exposure variable in epidemiologic studies. Although inconclusive, there appears some evidence to suggest a positive association between fat intake and obesity. There are too few studies on protein, carbohydrate, and fiber intakes to make any statement about their associations with overweight; this is also true for glycemic index and load. Energy density has been positively associated with weight among adults and appears a promising area, although studies are needed among children.

While evidence regarding the association between milk and dairy food intakes and obesity is inconsistent and sparse, several well-designed studies have shown significant associations between sugar-sweetened beverages (SSBs) and excess weight, leading to advice to limit consumption of SSBs, especially in light of the limited nutritional value these beverages provide. SSBs are different from 100% fruit juice, which can be an important source of energy and nutrients for some children, especially low-income children. In fact, the majority of data from longitudinal studies do not show an association between consumption of fruit juice and obesity, and fruit juice has been positively associated with calcium intake, possibly suggesting that fruit juice is generally consumed as part of a healthy diet.[302] As with any energy-containing food or beverage, consumption should be monitored to ensure fruit juice intake does not exceed total energy requirements. This is especially important among older children who may be more susceptible to weight gain following consumption of fruit juice, as they are less able to compensate for energy from liquids. Fruit juice can also be diluted with water to preserve flavor with a diminished energy cost. It is also important to remember that fruit juice should not supplant consumption of whole fruits, which are generally lower in calories and higher in many nutrients, including fiber.

Studies on major food groups, including fruits, vegetables, and cereals, are too limited and inconsistent to draw conclusions about associations with obesity although these foods are nutritious and should be consumed as part of a healthful diet. More studies are needed in this area, as food-based studies provide results that are easily translated to dietary advice (since individuals are better able to understand food-based, rather than nutrient-based, guidelines). Dietary pattern studies, which study the joint effect of multiple dietary components, are particularly needed. While increases in snack foods have been observed over time, the evidence does not clearly support an association between snack food consumption and overweight. As with soft drinks, limited consumption of snack foods may be advised due to the displacement of more nutritious foods, and this is true for children of any weight.

Inconsistent associations were also seen when examining patterns of eating behavior in relation to childhood obesity. Results were conflicting for fast food/away-from-home consumption as well as meal frequency and timing, and data on family dinner are too sparse to draw conclusions. The data on breakfast skipping cannot be easily interpreted, as a number of studies have shown breakfast consumption to be a weight loss strategy. Therefore, while breakfast consumption is advisable for children since it has been shown to improve learning and cognitive performance, the evidence to suggest that breakfast skipping is associated with overweight is weak.

Although perhaps unsatisfying, the strongest conclusion that can therefore be made from this review regarding associations between dietary intakes, eating behaviors, and childhood obesity is that more research is clearly needed, and future studies should seek to address the methodological limitations addressed above that plague the current body of evidence. In the meantime, what dietary advice can be given to prevent childhood obesity? Although some comments appear in this section and providing dietary advice is not the goal of this article per se, a few concluding words of dietary advice appear in the final section below.

Concluding Thoughts: Dietary Advice and Ethical Considerations

In the era of evidence-based medicine, or, in this case, evidence-based dietary advice, we are rightly encouraged to consider the research basis for interventions, treatment, and recommendations. Lack of data does not always warrant inaction, which is to say that we need to act based on the best available evidence and, in the case of dietary recommendations, may also consider the broader knowledge base of nutritional quality of foods, as well as what is known about diet and overall health. For example, although evidence supporting an association between soft-drink and fast food consumption and body weight is limited, dietary guidance on preventing childhood obesity might nonetheless encourage reducing intakes of these foods, as they often come in large portion sizes that contribute to increased energy intakes. These foods also generally tend to be of relatively lower nutritional quality. Decreasing the energy density of the diet by increasing consumption of fiber-rich foods such as fruits, vegetables, and whole grains might also be recommended, as low-energy-dense diets have been related to higher dietary quality and lower risk of obesity among adults, and these foods have many other health benefits. Although care must be taken to ensure adequate intake of high-energy-dense foods rich in healthful monounsaturated and polyunsaturated fats (e.g., nuts, olive oil), the concept of energy density brings together many sound nutritional concepts. In addition, low-energy-dense diets are also generally consistent with the Dietary Guidelines for Americans.[303]

The dietary advice to consume a low-energy-dense diet, however, brings forth ethical considerations. At the heart of the matter is the fact that low-energy-dense diets are expensive. High-energy-dense foods such as fats, oils, sugar, and refined grains provide energy at the lowest cost, while low-energy-dense foods such as vegetables, fruits, seafood, and dairy products provide energy at the highest cost;[304] a cost constraint can lead to decreased consumption of nutrient-dense, low-energy-dense foods and increased consumption of high-energy-dense foods.[305] 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[306] and therefore contributes to health disparities among ethnic groups. The advice for low-income families to consume healthier but more costly foods may even be considered elitist.[307]

Dietary advice that focuses on individual behavior change also demonstrates a lack of understanding of the role the broader food environment plays in influencing food choices, which underscores another important consideration: Dietary intake and choices do not occur in a vacuum, but, rather, in an obesigenic environment which encourages consumption of high fat, high-energy-dense foods that are available in large portions. It is thus critical to remember that dietary behavior occurs within an ecological context, which includes social, cultural, and environmental factors as well as personal preferences that together shape dietary behavior.[308] The very act of providing individual dietary advice – which is often incongruous with environmental cues to encourage over-consumption and unhealthful eating behavior – therefore raises additional ethical questions, and we are reminded of the public health model which encourages intervention "upstream" rather than at the individual level to exert the greatest benefit to the public health. Indeed, the Institute of Medicine report on preventing childhood obesity encourages "public health in action at its broadest and most inclusive level," emphasizing that the federal government, industry and media, state and local governments, health care professionals, community and nonprofit organizations, state and local education authorities and schools, and parents and families must all be involved in creating an environment which supports healthy dietary (and physical activity) behavior.[309]

In conclusion, more studies are needed to establish the evidence base of dietary factors related to childhood obesity. Recognizing the dietary causes of obesity is important in understanding the physiology of diet and weight, and such knowledge can be used not only to inform dietary guidelines and treatment, but also to inform food technology. Although dietary counseling is an important and necessary part of patient care, physicians and dietitians are cautioned to remember that healthful diets are expensive and that dietary behavior is influenced by forces beyond individual choice, and these forces are especially strong in low-income populations. Even if we had complete knowledge of the dietary determinants of childhood obesity, preventing and treating the disease at a population level must go far beyond individual advice. Successful – and ethical – interventions should involve comprehensive nutrition programs designed to facilitate healthy behaviors and food policy interventions at local, national, and international levels to ensure that nutritious foods are affordable and accessible to children of all income levels.

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these same cutpoints to be consistent with the adult definitions. T. J. Cole, M. C. Bellizzi, K. M. Flegal, and W. H. Dietz, "Establishing a Standard Definition for Child Overweight and Obesity Worldwide: International Survey," *British Medical Journal* 320, no. 7244 (2000): 1240-1243. The studies that will be discussed in this review are inconsistent in their definition of "overweight" or "obesity," and body fat may also be measured using different methods, including body mass index (BMI), percent body fat, skinfold thicknesses, etc. While some effort is made to define how "overweight" was measured, clearly this is not feasible to do for every study cited. Therefore, while differences in how excess body fat is measured are important methodological considerations, for the purposes of this review article the terms "overweight" and "obese" should be considered relative terms.
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116. See Guillaume, *supra* note 40.
117. See Gazzaniga, *supra* note 48.
118. See Tucker, *supra* note 44; Huang, *supra* note 58.
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Childhood Obesity

Guest Edited by
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