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Special Article

Systematic review of the evidence for an association between sugar-sweetened beverage consumption and risk of obesity

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A systematic review of the evidence for an association between sugar-sweetened beverages and risk of obesity was conducted. This review focused specifically on the role of sugar-sweetened beverages in obesity risk, taking into account energy balance. For the purpose of this review, scientific conclusions could not be drawn from the intervention studies that evaluated the relationship between sugar-sweetened beverage intake and obesity risk. Results of observational studies that examined the relationship between sugar-sweetened beverage intake and obesity risk that were adjusted for energy intake and physical activity were inconsistent for each of the three age groups evaluated (children, adolescents, and adults). From this review, evidence for an association between sugar-sweetened beverage intake and obesity risk is inconsistent when adjustment for energy balance is made.

INTRODUCTION

Sugar-sweetened beverages contain sugars that may (e.g., sodas) or may not (e.g., sports drinks) be the sole source of energy. Based on the National Health and Nutrition Examination Survey (NHANES) 2007–2008, mean energy intake from sugar-sweetened beverages (e.g., regular sodas, fruit drinks, and sports energy drinks) ranged from approximately 180 calories/day for children to 340 calories/day for young adults.[1]

There have been a number of meta-analyses and reviews of published studies that evaluated the association between sugar-sweetened beverage consumption and energy intake, weight gain, adiposity, body mass index (BMI), and incidence of being overweight or obese.[2–16] Results of these meta-analyses and reviews have been mixed, due in part to the different outcomes measured and the varying inclusion criteria of the studies. For example, the *Dietary Guidelines for Americans, 2010* recommends reducing the intake of sugar-sweetened beverages because, in part, strong evidence shows that children and adolescents who consume more sugar-sweetened beverages have higher body weights compared with those who drink fewer sugar-sweetened beverages, and moderate evidence supported this relationship in adults.[15,17] However, it was noted that the inclusion criteria for studies differed, as cross-sectional studies were included in situations where only limited prospective studies were available but were excluded from review for other subpopulations.[18] Many of the studies included in the above reviews were not designed to evaluate whether sugar-sweetened beverages contribute to weight gain and obesity, other than their role in contributing calories. It is unclear whether sugar-sweetened beverage intake, as part of current dietary patterns, is associated with obesity risk, and if so, whether such an association is primarily because sugar-sweetened beverages are a major contributor of calories or because of other important factors (e.g., physical activity,[19] socioeconomic status,[20] and the healthfulness of the overall diet[19,20]) that could be associated with sugar-sweetened beverage consumption. The purpose of this systematic evidence-based review is to evaluate the strength of the evidence for the relationship between the consumption of sugar-sweetened beverages and the risk of obesity, when adjustment for energy intake is made. The same systematic evidence-based

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review used for evaluating health claims was used for this systemic review.[21]

Systematic evidence-based review

The systematic evidence-based review used for substantiating health claims is summarized here and involves evaluating the relationship between a specified substance (food or food component) and a disease (or health-related condition).[21] Publically available published studies that evaluate the relationship between the substance and the disease are identified. In addition to individual reports of human studies, other types of data and information are also considered, such as meta-analyses, review articles, and animal and in vitro studies. These other types of data and information may be useful in understanding the scientific issues about the substance, the disease, or both, but cannot by themselves support a health claim relationship. Reports that discuss a number of different studies, such as meta-analyses and review articles, do not provide sufficient information about the individual studies contained in these articles to determine critical elements such as the study population characteristics and the composition of the products used. Similarly, the lack of detailed information on studies summarized in review articles and meta-analyses prevents a determination of whether the studies are flawed in critical elements such as design, conduct of studies, and data analysis.

Individual reports of human studies are evaluated to determine whether any scientific conclusions can be drawn from each study. The absence of critical factors, such as a control group, appropriate statistical analysis, or appropriate adjustment of confounders of disease risk, means that scientific conclusions cannot be drawn from the study. Studies from which scientific conclusions cannot be drawn about the relationship between the substance and the disease are eliminated for further review.

The relevant human intervention and observational studies are rated for methodological quality. This quality rating (high, moderate, or low) is based on several criteria related to study design, data collection, the quality of the statistical analysis, the type of outcome measured, and study population characteristics.

Finally, the strength of the total body of publicly available evidence from which scientific conclusions can be drawn about the substance/disease relationship is evaluated. This evaluation considers the study type (e.g., intervention, prospective cohort, case-control, cross-sectional), the methodological quality rating previously assigned, the quantity of evidence (number of the various types of studies and sample sizes), whether the body of scientific evidence supports a relationship for the US population or target subgroup, whether study results have been replicated, and the overall consistency of the findings from the total body of evidence. Based on the totality of scientific evidence, it is determined whether there is credible evidence to support the substance/disease relationship, and, if so, the strength of the evidence is characterized.

EVALUATION OF SUGAR-SWEETENED BEVERAGE CONSUMPTION AND RISK OF OBESITY

Sugar-sweetened beverages have been identified as the substance, and therefore studies that evaluated sugar-sweetened beverages individually (e.g., sodas) or collectively were included in this review. Obesity is considered a disease, but overweight (i.e., being more than one's ideal body weight, but less than obese) is not.[22] For adults, obesity is defined as a BMI of 30 kg/m^2 or higher.[23] For children, obesity is defined as a BMI at or above the 95th percentile for children of the same age and sex.[23] Therefore, BMI and the incidence of obesity (BMI≥30 kg/m^2 or BMI at or above 95th percentile for children) were the endpoints included for this review.

EVALUATION OF INTERVENTION STUDIES

Energy balance depends on energy intake, and energy expenditure and imbalances can result in gains or losses in body weight.[24] Therefore, besides considering energy intake, it was important to examine the measurement of physical activity in the intervention studies. Based on a literature search, 17 intervention studies that evaluated the effect of sugar-sweetened beverage intake on BMI or obesity were identified.[25–41] Scientific conclusions could not be drawn from these 17 studies for one or more of the following reasons: 1) incidence of obesity was not measured exclusively as an endpoint (i.e., overweight was included); 2) dietary and energy intake and/or physical activity was not measured or controlled for between study groups, and therefore it was impossible to consider energy balance and other dietary factors when evaluating the relationship between sugar-sweetened beverages and obesity risk; 3) sugar-sweetened foods were provided along with sugar-sweetened beverages, and therefore it was not possible to evaluate the role of sugar-sweetened beverages independently; and 4) an appropriate control group was not provided, and therefore it was not possible to ascertain whether changes in the endpoint of interest were due to the sugar-sweetened beverages or to unrelated and uncontrolled extraneous factors (e.g., other sources of calories).[21]

EVALUATION OF OBSERVATIONAL STUDIES

Using literature search key words related to obesity, many prospective cohorts and cross-sectional studies were identified. In general, two types of observational evidence were considered to be relevant: those that measured the association between sugar-sweetened beverage intake and incidence of obesity, and those that measured the association between sugar-sweetened beverage intake and BMI. Based on this literature search, a total of 59 observational studies[42–100] that evaluated the relationship between sugar-sweetened beverage intake and BMI or the risk of obesity were identified. While total energy intake includes energy from sugar-sweetened beverages, observational studies that did not adjust for total energy intake were initially not considered in this systematic review. A separate review, however, was conducted on the limited studies that adjusted for energy intake from non-sugar-sweetened beverage sources.[42,78] In addition to the consideration of energy intake, measurement of physical activity, an important component of energy balance, was also a confounder that needed to be considered in the observational studies.

Conclusions could not be drawn from 45 of the studies identified[42–86] for one or more of the following reasons: 1) associations were not adjusted for total energy intake and/or physical activity; 2) there was no indication that the food frequency questionnaire used to estimate sugar-sweetened beverage intake had been validated; 3) incidence of obesity was combined with incidence of overweight; and 4) statistical analysis for the relationship between sugar-sweetened beverage intake and BMI or incidence of obesity was not provided. Therefore, 14 studies were identified for which the relationship between sugar-sweetened beverage intake and BMI or incidence of obesity could be evaluated (see Table 1).[87–100] These 14 studies were conducted in children,[88,92,93,95] adolescents,[87,90,94,99] or adults.[89,91,96–98,100]

Children

Berkey et al.[88] followed 11,755 children (ages 9–14 y) in a moderate-quality prospective cohort in the US Growing Up Today Study to examine the association between the intake of sugar-sweetened beverages and change in BMI. In a longitudinal analysis of sugar-sweetened beverage intake and 1-year change in BMI, there was a significant association for boys (n = 6,688) ($P = 0.038$), but not for girls (n = 5,067) ($P = 0.096$), for models that adjusted for a number of confounders, including age and physical activity. After adjustment for total energy intake, there was no significant association for boy or girls between sugar-sweetened beverage intake and change in BMI after 1 year.

Ludwig et al.[95] conducted a high-quality prospective cohort that followed US children (average age, 11.7 y) for 19 months. After adjustment for a number of confounders, including physical activity and energy intake, the association between the change in sugar-sweetened beverage intake and BMI was significant ($P < 0.03$). Furthermore, the risk of obesity was significantly increased in children (n = 398) with increased sugar-sweetened beverage intake [odds ratio (OR), 1.60; 95% confidence interval (CI), 1.14–2.2].

Jensen et al.[92] undertook an intervention of moderate quality in Denmark that included, in part, implementation of school canteens selling healthy meals and snacks in one suburb or no implementation in another suburb. There was no information, however, on the intervention and control groups, but rather an analysis of cross-sectional data that combined both suburbs (n = 635). There was no significant association ($P > 0.05$) between sugar-sweetened beverage intake and BMI when adjustment for various confounders that did not include physical activity or energy intake was performed. It was noted, however, that the findings did not change when the association was adjusted for physical activity and energy intake.

Kosova et al.[93] conducted a moderate-quality cross-sectional analysis of NHANES data collected from 1999 to 2004 on children 3–11 years of age (n = 4,743). When adjusted for confounders that included physical activity, age, gender, race, energy intake, and poverty status, the association between sugar-sweetened beverage intake and BMI percentile was not significant ($P = 0.07$).

Adolescents

Ambrosini et al.[87] followed 1,306 adolescent offspring (ages 14–17 y) who were participants in the Western Australian Pregnancy Cohort Study for 3 years. This moderate-quality prospective cohort examined an association between sugar-sweetened beverage intakes and incidence of obesity and change in BMI. Girls who were in the highest tertile of sugar-sweetened beverage consumption (n = 600) (>1.3 servings/d) had significantly greater changes in BMI (3.6%; 95%CI, 1.5–5.8; $P = 0.001$), when adjusted for age and physical fitness. Physical fitness was assessed using a physical working capacity 170 test, which was highly correlated with self-reported physical activity in this cohort. No significant association between sugar-sweetened beverage intake and change in BMI was observed in boys (n = 706). After adjustment for total energy intake, the results were unchanged for both boys and girls.

Stoof et al.[99] undertook a moderate-quality prospective cohort that followed 238 adolescents (mean age, 13 y) to adulthood (24–30 y later) who were part of the Amsterdam Growth and Health Longitudinal Study. This study examined the association between intake of sugar-sweetened beverages during adolescence and weight status as an adult. Linear regression analysis showed that,

Table 1 **Observational studies evaluating the relationship between sugar-sweetened beverage consumption and change in BMI or risk of obesity after adjustment for confounders, including energy intake and physical activity.**

Reference	No. and age of participants	Study design and covariates	Results	
			Change in BMI	Risk of obesity
Children				
Berkey et al. (2004)[88]	11,755 US boys and girls 9–14 y	Prospective cohort Age, Tanner stage, race, menarche, prior BMI *z* score, height, growth, physical activity, milk type, and energy intake	–	
Ludwig et al. (2001)[95]	398 US boys and girls 11.7 y (mean)	Prospective cohort Anthropometrics, demographics, physical activity, television viewing, dietary variables, and energy intake	+	+
Jensen et al. (2013)[92]	635 Danish boys and girls 6–9 y	Cross-sectional analysis of an intervention study Baseline BMI, cluster effect by school, gender, intervention/comparison group, pubertal status, socioeconomic status, physical activity, and energy intake	–	
Kosova et al. (2013)[93]	4,743 US boys and girls 3–11 y	Cross-sectional Age, gender, race, poverty status, physical activity, and energy intake	–	
Adolescents				
Ambrosini et al. (2013)[87]	1,306 Australian boys and girls 14–17 y	Prospective cohort Age, pubertal stage, BMI, maternal education, family income, physical fitness, dietary misreporting, healthy and Western dietary patterns scores, and energy intake	+ Girls – Boys	
Stoof et al. (2011)[99]	238 Dutch boys and girls 13 y (mean)	Prospective cohort Age, BMI, physical activity, and energy intake	–	
Laska et al. (2012)[94]	693 US boys and girls 14.6 y (mean)	Cross-sectional and longitudinal Age, puberty, race, parental education, eligibility for free/reduced-price lunch, physical activity, and energy intake	– Boys – Girls	
Bremer et al. (2010)[90]	1,596 non-Hispanic whites, 2,209 Mexican Americans, and 1,959 non-Hispanic blacks 12–19 y	Cross-sectional Age, gender, physical activity, and energy intake	+ Non-Hispanic whites + Mexican American – Non-Hispanic blacks	
Adults				
Dhingra et al. (2007)[91]	4,277 US men and women 52.9 y (mean)	Prospective cohort Age, gender, physical activity, smoking, glycemic index, and intakes of fat, dietary fiber, *trans* fat, magnesium, and energy		+
Bermudez & Gao (2010)[89]	947 US men and women 20–39 y	Cross-sectional Age, gender, race, education, physical activity, smoking, and intakes of caffeine, dietary fiber, saturated fat, polyunsaturated fat, and energy		+
Sun & Empie (2007)[100]	38,409 US men and women 20–74 y	Cross-sectional Age, gender, smoker, education, television watching hours, physical activity, and intakes of fat, saturated fat, and energy		–
Odegaard et al. (2012)[97]	791 US men and women 18–70 y	Cross-sectional Age, gender, height, education, physical activity, smoking, and intakes of dietary fiber, dairy, vegetable, red meat, alcohol, and energy	–	
Nikpartow et al. (2012)[96]	893 Canadian men and women 19–65 y	Cross-sectional Age, physical activity, and energy intake		+ Women with a predominate pattern of fruit drink intake – All men
Rhee et al. (2012)[98]	2,692 Costa Rican men and women 18–86 y	Cross-sectional Age, gender, education, income, smoking, area of residence, physical activity, and energy intake	– Fresco + Fruit drinks + Sodas	

Abbreviations and symbols: BMI, body mass index; –, no association at $P < 0.05$; +, significant association at $P < 0.05$.

after adjustment for age, physical activity, and total energy intake, there was no significant ($P > 0.05$) association between sugar-sweetened beverages intake at age 13 years and adult BMI in men or women at follow-up.

Laska et al.[94] conducted a moderate-quality study that examined the cross-sectional and longitudinal associations between sugar-sweetened beverage intake and BMI in 693 Minnesota adolescents over 2 years. In the cross-sectional analysis, after adjustment for a number of confounders that included physical activity and total energy intake, there was not a significant association between sugar-sweetened beverage intake and BMI in males ($P = 0.517$) or females ($P = 0.456$). In the longitudinal analysis, there was also not a significant association at the $\alpha = 0.003$ level (used to correct for the number of tests) between sugar-sweetened beverage intake and BMI for males ($P = 0.008$) or females ($P = 0.746$).

Bremer et al.[90] undertook a moderate-quality cross-sectional study that examined the association between sugar-sweetened beverage intake and BMI in 1,596 non-Hispanic white, 2,209 Mexican American, and 1,959 non-Hispanic black adolescents (ages 12–19 y) from NHANES (1999–2004). After adjustment for age, physical activity, and total energy intake, there was a significant association between sugar-sweetened beverage intake and BMI among non-Hispanic whites and Mexican Americans ($P < 0.05$), but not for non-Hispanic blacks.

Adults

Dhingra et al.[91] conducted a moderate-quality prospective cohort that included 4,277 US adults who were participants in the Framingham Heart Study. Higher intake of sweetened soft drinks was significantly associated with a higher incidence of obesity. After adjustment for age, physical activity, and total energy intake, the OR was 1.31 (95%CI, 1.02–1.68) when one or more servings of soft drinks were consumed and 1.50 (95%CI, 1.06–2.11) when more than two servings of soft drinks were consumed.

In a moderate-quality cross-sectional study of 947 US adults (ages 20–39 y), Bermudez and Gao[89] found a significant association between sugar-sweetened beverage intake and incidence of obesity. When comparing the highest quartile with the lowest quartile of sugar-sweetened beverage intake, the OR for obesity was 2.1 (95%CI, 1.2–3.7), after adjustment for age, physical activity, and total energy intake.

Sun and Empie[100] undertook a high-quality set of cross-sectional studies that examined the relationship between sugar-sweetened beverage intake and incidence of obesity in adults ($n = 38{,}409$), using data from the Continuing Survey of Food Intakes by Individuals CSFII 1989–1991, CSFII 1994–1998, and NHANES 1988–1994, and NHANES 1999–2002. There was no significant association between sugar-sweetened beverage intake and incidence of obesity after adjustment for age, physical activity, and total energy intake for CSFII 1989–1991 (OR, 1.003; 95%CI, 0.89–1.131; $P = 0.955$), CSFII 1994–1996 (OR, 1.109; 95%CI, 0.987–1.247; $P = 0.0831$), NHANES III 1988–1994 (OR, 1.06; 95%CI, 0.975–1.152; $P = 0.1742$), or NHANES 1999–2002 (OR, 1.084; 95%CI, 0.973–1.209; $P = 0.1448$).

Odegaard et al.[97] conducted a moderate-quality cross-sectional study of 791 US adults (ages 18–70 y) that evaluated the relationship between sugar-sweetened beverage intake and BMI. After adjustment for age, physical activity, and total energy intake, there was no significant association observed ($P = 0.08$).

In a high-quality cross-sectional study conducted by Nikpartow et al.,[96] the association between sugar-sweetened beverage consumption and incidence of obesity in 893 participants of the Canadian Community Health Survey Cycle was examined. Using cluster analysis, participants were categorized on the basis of patterns of sugar-sweetened beverage intake (e.g., fruit drinks, soft drinks). Women who had a dominant pattern of fruit drink consumption had a significantly higher risk of obesity, after adjustment for total energy intake, age, and physical activity (OR, 2.55; 95%CI, 1.46–4.47; $P = 0.001$), compared with women with no dominate pattern of beverage intake. No association was found for men with any pattern of beverage intake.

In a moderate-quality cross-sectional study conducted by Rhee et al.[98] that evaluated the relationship between the intake of different types of sugar-sweetened beverages and BMI in 2,692 Costa Rican adults, the results were mixed. After adjustment for a number of confounders that included age and physical activity, there was a significant association between intake of fruit drinks ($P = 0.007$) and soda ($P = 0.005$) and BMI. There was no significant association between intake of fresco (a homemade beverage made from sugar, water, and fresh fruit) and BMI ($P = 0.82$). After adjustment for total energy intake, the results for fruit drinks and soda intake and BMI were still significant, but again, not for fresco intake and BMI.

Adjustment for energy from non-sugar-sweetened beverages

A separate review was conducted on observational studies that met the above criteria with the exception of adjustment for total energy intake; however, studies were adjusted for energy intake from all sources except sugar-sweetened beverages. Two observational studies were identified (Table 2).[42,78]

Schulze et al.[78] conducted a prospective cohort analysis of moderate quality that included 51,603 young and

Table 2 **Observational studies evaluating the relationship between sugar-sweetened beverage consumption and change in BMI after adjustment for confounders, including physical activity and energy intake from non-sugar-sweetened beverages.**

Reference	No. and age of participants	Study design and covariates	BMI
Schulze et al. (2004)[78]	51,603 US women 24–44 y	Prospective cohort Age, BMI, smoking, postmenopausal hormone use, oral contraceptive use, physical activity, and intakes of cereal fiber, total fat, red meat, French fries, processed meat, sweets, snacks, vegetables, fruits, alcohol, and energy from non-soda sources	+
Balcells et al. (2010)[42]	7,101 Spanish men and women 35–74 y	Cross-sectional Age, gender, educational level, smoking, leisure-time physical activity, diet quality, energy under-reporting, and intakes of alcohol and energy from non-soft-drink sources	+

Abbreviations and symbols: BMI, body mass index; +, significant association at $P < 0.05$.

middle-aged women from the Nurses' Health Study II. After adjustment for a number of confounders that included age, BMI, physical activity, and energy from non-sugar-sweetened beverage sources, women who consistently consumed ≥1 sugar-sweetened soft drink per day had a significantly greater increase in BMI than women who consumed ≤1 sugar-sweetened soft drink per week ($P < 0.001$).

Balcells et al.[42] carried out a cross-sectional study that included 7,101 Spanish men and women. This moderate-quality study found a significant positive association between soft drink consumption and BMI after adjustment for age, gender, physical activity, and energy intake excluding soft drinks (95%CI, 0.112–0.313; $P < 0.001$).

DISCUSSION

No intervention studies were identified from which scientific conclusions could be drawn about the relationship between sugar-sweetened beverage intake and BMI or risk of obesity. The evidence for an association between sugar-sweetened beverage intake and obesity risk, when adjustment for energy and physical activity was performed, was inconsistent for children, adolescents, and adults. Of the two prospective cohorts conducted in children, one showed a significant association between sugar-sweetened beverage intake and BMI and incidence of obesity,[95] while the other showed no association between sugar-sweetened beverage intake and BMI.[88] The two cross-sectional studies in children did not show a significant association between sugar-sweetened beverage intake and BMI.[92,93] Similarly, in adolescents, the results of the four observational studies were inconsistent.[87,90,94,99] In adults, of the two cross-sectional studies that evaluated beverage type,[96,98] one showed a significant association between a dominant pattern of fruit drink consumption and obesity risk in adult women, but not in men.[96] The other study showed a significant association between fruit drink and sweetened soda consumption and BMI, but not between homemade fresco consumption and BMI.[98] The other observational studies on sugar-sweetened beverage intake in adults were also inconsistent, with one prospective cohort showing an association with the incidence of obesity,[91] while two of the three cross-sectional studies did not show an association between sugar-sweetened beverage intake and incidence of obesity or BMI.[89,97,100] In general, when evaluating a substance and disease relationship, the greater the consistency among the studies in showing a relationship, the greater the level of confidence that a substance/disease relationship exists.[21] While conflicting results do not disprove an association (because the elements of the study design may account for the lack of an effect in negative studies), they tend to weaken confidence in the strength of the association.[21]

Given the lack of feeding trial data and the inconsistencies in the results of the observational studies reviewed, it is unclear whether sugar-sweetened beverage intake is associated with obesity risk, other than contributing calories. Although the evidence is very limited, both of the observational studies that adjusted for energy from non-sugar-sweetened beverage sources showed a significant association between soft drink/soda consumption and increased BMI (Table 2).[42,78]

In a meta-analysis of sugar-sweetened beverage consumption and weight gain, meta-regressions for adjustment for total energy ($P = 0.37$) suggested that total energy intake may not be a substantial source of heterogeneity.[16] However, when the analysis was stratified on the basis of whether the study was adjusted for total energy intake, the estimate for change in body weight was significant and was greater in studies that did not adjust for total energy intake (0.08; 95%CI, 0.02–0.14; $I^2 = 91.1\%$; n = 17) than in studies that did adjust for total energy intake, in which the estimate for change was not significant (0.04; 95%CI, 0.00–0.07; $I^2 = 0\%$; n = 3).

It has been suggested that sugars in sweetened beverages and foods may contribute to obesity, not because of their inherent metabolic effects, but because the beverages and foods in which they are found are inexpensive, palatable, and readily available, which may make them preferentially selected by lower-income consumers.[20] Reviews have indicated there is no unique relationship between weight management and obesity for the different saccharides found in foods and beverages.[101–103] Such information suggests that sugar-sweetened beverages may not be different from other foods whose sole or primary calorie source is sugar (e.g., orange juice), except that sugar-sweetened beverages generally do not contain nutrients.

CONCLUSION

The findings of this systematic review are similar to the collective findings of various meta-analyses and reviews, which have been mixed. Sugar-sweetened beverages are the fourth-highest contributor of calories in the diets of the general US population, with grain-based desserts, yeast breads, and chicken and chicken mixed dishes being the top three contributors.[104] It is not clear how sugar-sweetened beverages contribute to caloric intake and, possibly, obesity in a manner that would be different from these top three contributors. If concern about sugar-sweetened beverage intake is related to consuming foods as part of a daily diet that meets nutrient needs and is within calorie limits, then evaluating the association between sugar-sweetened beverage intake and adequacy of nutrient intake may provide more meaningful findings.

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