Published in final edited form as:

Br J Nutr. 2015 August 14; 114(3): 430–438. doi:10.1017/S0007114515002160.

Sugar-sweetened beverage intake and cardiovascular risk factor profile in youth with type 1 diabetes: Application of measurement error methodology in the SEARCH Nutrition Ancillary Study

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Abstract

Objective—The SEARCH Nutrition Ancillary Study aims to investigate the role of dietary intake on the development of long-term complications of type 1diabetes in youth and capitalize on measurement error (ME) adjustment methodology.

Research Design and Methods—Using the National Cancer Institute (NCI) method for episodically-consumed foods, we evaluated the relationship of sugar-sweetened beverage (SSB) intake and cardiovascular risk factor profile, applying ME adjustment. The calibration sample included 166 youth with two FFQs and three 24-hour dietary recalls within one month. The full sample included 2,286 youth with type 1 diabetes.

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Author contributions: A.D.L. wrote the manuscript, J.L.C. and J.A.T. analyzed the data, drafted the statistical analysis section and reviewed and edited the manuscript, V.K. reviewed and edited the manuscript and contributed to the discussion, R.B., S.C.C., D.D., T.L.C. and E.J.M. reviewed and edited the manuscript. All authors read and approved the final manuscript.

Conflict of Interest: None.

Results—SSB intake was significantly associated with higher triglycerides, total and LDL-cholesterol, adjusted for energy, age, diabetes duration, race/ethnicity, gender, education. The estimated effect size was larger (model coefficients increased approximately threefold) after application of the NCI method than without ME adjustment. Compared to individuals consuming one serving of SSB every two weeks, those who consumed one serving every two days had 3.7 mg/dL higher triglycerides, 4.0 mg/dL higher total cholesterol and LDL cholesterol, adjusted for ME and covariates. SSB intake was not associated with measures of adiposity and blood pressure.

Conclusions—Our findings suggest that SSB intake is significantly related to increased lipid levels in youth with type 1diabetes and that estimates of the effect size of SSB on lipid levels are severely attenuated in the presence of measurement error. Future studies in youth with diabetes should consider a design that will allow for the adjustment for measurement error when studying the influence of diet on health status.

Keywords

Food frequency questionnaire validation; reliability; youth; diabetes mellitus

INTRODUCTION

Not much is known about the role of nutrition in the development of CVD risk in youth with diabetes [1, 2]. Understanding the role of nutrition in the development of diabetes complications is, however, fraught with challenges. The complexities of assessing diet can lead to biased estimates of the relationship between self-reported usual intake and health outcomes. In parallel with ongoing efforts to improve dietary assessment, statistical analysis methods have advanced to adjust for the effects of dietary measurement error in studying usual dietary intake and health outcomes [3, 4]. The method of choice in nutritional epidemiology, regression calibration, requires a subsample with an unbiased measure of dietary intake in addition to a dietary assessment instrument used in the main study, such as a food frequency questionnaire (FFQ). The subsample is used to estimate predicted values of true intake (i.e., its conditional expectation) given FFQ measurements and other covariates in the risk model. Using those predicted values instead of unknown true intake leads to approximately consistent estimates of the regression parameters in the risk model reflecting the relationship between dietary intake and health outcomes.

Intake of sugar-sweetened beverages (SSB) is a high-profile topic in public health policy and research and particularly relevant for persons with diabetes [5, 6]. We have previously shown that high SSB intake as assessed by FFQ is associated with higher levels of total cholesterol, LDL-cholesterol, and plasma triglycerides in youth with type 1 diabetes in the SEARCH for Diabetes in Youth study [7]. However, FFQs are known to be prone to substantial measurement error, which results in the usually attenuated estimate of dietary effect and loss of statistical power to detect the effect [8]. The recent completion of a diet assessment and calibration sub-study in the same study allowed us to re-evaluate the previous findings. Thus, the purpose of this analysis was to obtain estimates of the association of SSB with lipids levels in the SEARCH Study, adjusted for FFQ measurement error using regression calibration, and we further extended this analysis to include measures of adiposity and blood pressure as additional outcomes.

RESEARCH DESIGN AND METHODS

SEARCH Study Design

SEARCH is a multi-center study that began conducting population-based ascertainment of non-gestational cases of physician-diagnosed diabetes in youth less than 20 years of age in 2001. The study ascertained prevalent cases in 2001 and 2009 and incident cases starting from 2002 through the present [(9)]. The protocol was compliant with the Health Insurance Portability and Accountability Act and approved by the local institutional review boards. Case ascertainment was conducted using a network of health care providers including pediatric endocrinologists, hospitals, and other providers. Persons with diabetes or their parent/guardian if they were less than 18 years of age were invited to complete a brief survey. Those whose diabetes was not secondary to other health conditions were invited to the baseline study visit which included questionnaires, physical examinations and laboratory measurements. Diabetes type, as assigned by the health care provider, was categorized as type 1, type 2, and other type (including hybrid type, maturity onset of diabetes in youth, type designated as “other”, type unknown by the reporting source, and missing).

Data Collection in SEARCH

Dietary intake was assessed with a FFQ (available upon request) which was modified from the Block Kids Questionnaire with an expanded list of foods selected to consider ethnic, cultural, and regional diversity [(10)]. The FFQ was only completed by participants age 10 years and older and generally by the youth without assistance after receiving staff instruction. It consisted of 85 food lines for which the participant indicated if the item(s) was/were consumed in the past week (“yes/no”) and if yes, how many days, and the average portion size. SSB intake was aggregated from four questions querying intake of a) soda (Coke, Sprite® etc., not counting diet soda), b) Kool-Aid and Gatorade, c) Sunny Delight®, Hi-C-C®, Hawaiian Punch®, and Ocean Spray®, and d) coffee or tea sweetened with sugar. Participants were asked to report the number of glasses, juice boxes or cups usually consumed in a day for each beverage category. An open-ended question at the end of the FFQ queried other foods that a participant might wish to report. The nutrient and portion size databases for this instrument were modified from the respective Diabetes Prevention Program databases, using Nutrition Data System for Research (NDSR, Nutrition Coordinating Center, University of Minnesota, Minneapolis MN, Database version 2.6/8A/23) and industry sources. Daily energy intake was estimated by aggregating across all foods reported on the FFQ.

Lipid levels were determined in plasma samples taken during the in-person visits and specimens were processed at the site and shipped within 24 hours to the Northwest Lipid Metabolism and Diabetes Research Laboratories in Seattle, Washington. Measurements of plasma cholesterol, triglyceride, and HDL cholesterol were performed on a Hitachi 917 autoanalyzer (Boehringer Mannheim Diagnostics, Indianapolis, IN). LDL cholesterol was calculated by the Friedewald equation for individuals with triglyceride concentration < 400 mg/dL (4.52 mM/L) and by the Beta Quantification procedure for those with triglyceride ≥ 400 mg/dL [(11)].

Height was measured twice (in centimeters) using a stadiometer. Waist circumference was assessed according to the National Health and Nutrition Examination Survey (NHANES) protocol as the circumference just above the right iliac crest at the mid-axillary line [(12)]. A measuring tape was used and two measurements taken If the first two measures differed by >1.0cm for waist circumference or >0.5 cm for height, a third measurement was taken. The average of the two or three measurements was used for analyses. Waist-to-height-ratio (WHtR) was calculated by dividing the average waist circumference by the average height. Weight was measured (in kilograms to the nearest 0.1kg) using an electronic scale. Body mass index (BMI) was calculated for each participant and converted to an age and gender-specific BMI z-score according to CDC guidelines.

Three systolic and diastolic blood pressure measurements were taken using a portable mercury sphygmomanometer, with a cuff chosen to fit the size of the participant's arm. The average of the three measures was used for analyses.

Other data collected from the parent included the following information used as covariates in the present analyses. Date of birth, gender, parental education and date of diabetes diagnosis were obtained through self-report and age and diabetes duration calculated. Race and ethnicity were obtained using the standard census questions [(13)].

This analysis was restricted to youth with type 1 diabetes whose diabetes was prevalent in 2001 or incident in 2002- 2005 who were ≥ 10 years of age at the time of their baseline study visit. Of the 2,792 participants who met these criteria, 2,304 had diabetes for at least 3 months at the time of their study visit and additionally had complete data on fasting lipids, FFQ, and covariates. An additional 18 participants were excluded due to evidence of hypertriglyceridemia (fasting triglycerides >400 mg/dL), yielding a final analytic sample size of N=2,286. Most participants had available data for the non-lipid outcomes, as well: WHtR (N=2,208), BMI z-score (N=2,267), and SBP and DBP (N=2,257).

Calibration Sample

The SEARCH Nutrition Ancillary Study (SNAS) was designed to examine the associations of nutritional factors with the progression of insulin secretion defects and the presence of CVD risk factors in youth with type 1 diabetes. The SNAS protocol was reviewed and approved by the institutional review boards of all participating institutions. SNAS included a dedicated diet assessment sub-study which served as the calibration sample in analyses of dietary intake – disease outcome relationships adjusting for measurement error. The calibration sample consisted of 166 participants with FFQ data and 1-3 24-hour recalls (152 had 3 recalls, 8 had 2 recalls, and 6 had 1 recall, for a total of 494 recalls).

The previous day 24-hour recalls were conducted by trained and certified staff of the University of North Carolina at Chapel Hill (Nutrition Obesity Research Center – Diet, Physical Activity and Body Composition Core) by telephone on randomly-selected, nonconsecutive days including two weekdays and one weekend day during a four-week sampling window. NDSR Version 2008 and 2009 software licensed from the Nutrition Coordinating Center (NCC) at the University of Minnesota was employed, using the multi-pass approach in which a participant was first asked to provide a general listing of foods

consumed on the previous day, starting with the first food consumed after awakening and ending with the last food consumed before sleep, and grouped by eating episode. Subsequently, the interviewing dietitian reviewed the list with the participant and prompted for foods or eating episodes forgotten or omitted, queried for more detail on the time, name and location of the eating episodes, collected details on the foods reported including quantity, portion size, food description, and verified the information and prompted for any omissions.

The 166 individual foods that were ascertained from the 24-hour recalls with the NDSR system were grouped into 27 specific food groups, including SSB, which consisted of sweetened soda, sweetened fruit drinks, sweetened water, sweetened coffee, and sweetened tea. If the portion size units differed between the 24-hour recall and the FFQ, appropriate conversions were made to the FFQ data. We have previously shown reasonable relative validity of the SSB food group with a correlation of ρ_{QT}=0.54 between true and FFQ-reported intakes in a model adjusted for measurement error {Liese AD, 2015 LIESE2014 /id}.

Statistical Analysis

Characteristics of the sample of SEARCH participants included in these analyses and the calibration subsample were computed using means and standard deviations or medians for continuous variables and frequencies for categorical variables. To estimate the relationship between SSB intake on lipids, we regressed log-transformed lipids on SSB intake, energy, and covariates (diabetes duration, age, gender, race/ethnicity, and parental education) in the risk model. Usual statistical methods for assessing exposure-outcome relationships assume that exposure is measured without error. We used the NCI method to apply regression calibration to FFQ-reported SSB and energy intakes to adjust for measurement error in the risk models relating SSB intake to the lipid outcomes [3, 8, 15].

An overview of this process is given here, followed by details of the approach. For both energy and SSB, the 24-hour recall was assumed to be unbiased for true intake. The calibration subsample was used to build measurement error models for 24-hour recall reported intake of SSB and total energy which included FFQ-reported intake of SSB, energy, and the other adjusting covariates in the risk model. The resulting model was then used to predict true usual intake of SSB and energy from SSB and energy intake measured by the FFQ and covariates. Subsequently, the predicted true usual SSB intake and the covariates were used in a regression model for blood lipids in the SEARCH sample.

We used a two-part model (the NCI method) to account for the fact that SSB intake was episodically consumed, that is, not consumed by all participants every day [16]. This requires a special methodology in specifying the measurement error model for SSB intake reported on the 24-hour recalls. Part I of the model predicts the probability of SSB intake on any given day using mixed effects logistic regression, and part II predicts the daily amount of SSB consumed using a mixed effects linear model on a transformed scale. The transformation is chosen so that the person-specific random effect and within-person random error are approximately normally distributed. Both parts of the model are fitted simultaneously allowing person-specific random effects to be correlated [16]. Energy intake

is not episodic, so a simpler model (without the probability of intake component) was appropriate [4].

In the calibration sample, the 24-hour recall data were modeled as a function of the FFQ data for SSB (episodic) and energy (nonepisodic) separately. FFQ energy intake (kcal/day) was log-transformed to improve normality) and FFQ SSB intake (servings/day) was log-transformed after imputing zero intake as 0.01servings/day. The log-transformation of SSB effectively transformed the non-zero amounts to approximate normality, but 61% of the calibration sample reported no FFQ SSB consumption, making it very difficult to transform the FFQ consumption amount to approximate normality. Consequently, the measurement error model was expanded by adding a binary (0/1) indicator of consumption of SSB on the FFQ to the model. The use of two variables to capture FFQ SSB consumption adds flexibility to the model, estimating a separate intercept for non-consumers and a separate regression slope relating consumption amount to usual intake for consumers. In addition to the three FFQ variables, each model included diabetes duration, age, race/ethnicity, gender, and parental education. Then the calibration predictor models of true SSB and energy intakes were estimated from the corresponding measurement error models. For each participant in the full sample (N=2,286), the developed models were used to obtain the regression calibration predictor of each participant's usual SSB and energy intakes, conditional on the observed FFQ and the other model covariates [3].

The predicted SSB (servings/day) and energy values from the calibration models were used in a linear regression risk model, controlling for the same covariates that were in the calibration model. The blood lipid outcomes were log-transformed to improve model fit; other outcomes were left untransformed. To account for the fact that the regression calibration predictors were estimated in a subsample, the standard errors in the disease model were calculated using bootstrap. All analyses were conducted using SAS 9.2 (SAS Institute, Cary, NC).

RESULTS

The primary study sample was composed of 2,286 youth with type 1 diabetes, with a mean age just under 15 years at the time of their baseline study visit (range 10-22) (Table 1). The majority (77%) were non-Hispanic white, 50% were female, and 47% had at least one parent with a college degree. Table 1 also shows comparisons between the study sample and calibration sample. The two groups were similar with respect to gender and race/ethnicity. However, the calibration sample, which consisted of prevalent type 1 cases, had a much longer duration of diabetes than the overall sample, which included incident as well as prevalent cases. The calibration sample was also slightly older at the study visit, and their parents were slightly more educated.

Descriptive statistics for the cardiovascular risk factor outcomes and the FFQ predictors for the SEARCH sample and the calibration sample are given in Table 2. The samples were similar with respect to all outcomes of interest. Note that the distribution of SSB FFQ contained a large number of zeroes, as FFQ non-consumption was reported in 45% and 39% of the SEARCH and the calibration samples, respectively. Table 2 also includes the

predicted intakes for the SEARCH sample. Many predicted SSB intakes were quite low, with the 25th percentile occurring at about 0.07 servings per day (about 1 serving every 2 weeks), and the median occurring at 0.16 servings per day (about 1 serving every 6 days). It is worth noting that the median intakes of SSB and energy predicted by the measurement error model in the SEARCH sample were both higher than the FFQ-estimated intakes, suggesting that the FFQ was under-reporting total intake.

Table 3 presents the associations of SSB intake with cardiovascular risk factors from a naive model without measurement error adjustment and a measurement error adjusted model. Adjusted for age, diabetes duration, race/ethnicity, gender, and energy intake, SSB intake was associated with higher levels of plasma triglycerides (p=0.03), total cholesterol (p=0.04) and LDL cholesterol (p=0.01) in the naive model and with total cholesterol (p=0.03) and LDL cholesterol (p=0.007) in the measurement error adjusted model while the association with triglycerides lost statistical significance (p=0.07). SSB intake was not significantly associated with any of the other outcomes (BMI z-score, WHtR, SBP, DBP) in either the naïve or measurement error adjusted models.

To further understand the nature of the significant findings, we compared two levels of SSB intake, specifically 1 serving every 2 days (0.5 servings per day) and 1 serving every 2 weeks (0.07 servings/day) of SSB. This difference corresponded roughly to the 80th and 20th percentiles of predicted conditional mean intake in the SEARCH sample, or about the 70th and 30th percentiles of FFQ-reported intake in the SEARCH sample. According to the naive model (without adjustment for measurement error), a person with the higher intake had, on average, triglycerides levels that were 2.1% higher (i.e., log-triglycerides 0.020 log-mg/dL higher, calculated as 0.0103*(ln(0.5)-ln(0.07))), cholesterol levels that were 0.8% higher (log-total cholesterol 0.008 log-mg/dL higher); and LDL levels that were 1.4% higher (log-LDL cholesterol 0.014 log-mg/dL higher). After adjustment for measurement error, these estimated mean differences increased so that a person with higher intake had, on average, triglycerides that were 5.2% higher, total cholesterol that was 2.3% higher; and LDL cholesterol that was 4.2% higher.

Because of the log-transformations the outcome, estimated values of the outcomes in original units are dependent on other model covariates. To better understand the clinical implications of SSB intake, Table 4 presents estimated lipid levels for two intake levels of SSB (0.5 servings/day and 0.07 servings/day) for a person with average values on all other model covariates. Without measurement error adjustment, the difference in SSB intake accounted for a difference in each of the lipids of about 1.3-1.4 mg/dL. After adjusting for measurement error, this difference increased almost three fold to 3.7-4.0 mg/dL.

DISCUSSION

This study expands upon our previous report on the association of SSB intake with lipid levels in the SEARCH population [7] in two distinct and important ways. First and foremost, this analysis uses a state-of-the-art statistical approach to adjust for the influence of measurement error [3, 15, 16]. Like the previous study, we found that SSB intake was significantly associated with lipid levels and not with blood pressure or measures of

adiposity. Compared to individuals who consumed 1 serving of SSB every two weeks, those who consumed 1 serving every 2 days had 3.7 mg/dl higher triglycerides and 4.0 mg/dl higher total and LDL cholesterol, adjusting for measurement error. Secondly, built into the measurement error adjustment approach was a more appropriate modeling of the episodic nature of SSB intake. In contrast, the previous study had utilized a categorical approach to exposure classification without consideration of measurement error. The present results underscore the importance of adjusting for measurement error related to dietary exposure assessment. Without adjustment for measurement error, the magnitude of the difference in lipid levels between those consuming 0.07 vs. 0.5 servings of SSB per day would have been underestimated, by about 2.3-2.7 mg/dL.

After adjustment for measurement error, the regression slopes for SSB intake were all higher compared to the naïve model, which was to be expected. These slopes reflect adjustment for bias in the FFQ, giving a more accurate estimate of the impact of SSB on the outcomes. However, regression calibration generally does not restore statistical power lost due to measurement error and the null associations of SSB intake and adiposity and blood pressure (both before and after ME-adjustment) are good examples. In fact, in many cases, loss of power due to measurement error may be somewhat exacerbated since the regression calibration predictors are estimated in a finite subsample. For log-triglycerides, although the magnitude of the slope was increased, the standard error was large, leading to a slight increase in the standard error of the estimate compared to the naïve model and loss of statistical significance of the association. This same power loss is not seen for total and LDL cholesterol, which may be due to the fact that: 1) the regression calibration for SSB intake is highly nonlinear, which may actually improve the power loss, and/or 2) the measurement error model used to calibrate SSB intake also included an indicator of FFQ-reported SSB consumption, which is not included in these risk models, thereby leading to extended regression calibration, which may increase power compared to the naïve risk model [(3)].

There are a number of limitations to the present study. Due to the sampling procedure used, participants in the calibration sample differed from those in the SEARCH sample on a number of attributes. This sampling difference requires the assumption that, although the samples were not from the same underlying population, they have the same measurement error models for SSB and energy intake. The largest demographic differences were in age and disease duration, both of which were included as covariates in the measurement error model, providing some degree of control for this difference. The two samples were similar with respect to the disease outcomes, but the calibration sample reported higher SSB intake and lower overall energy intake on the FFQ. While there is some overlap in terms of individuals between the SEARCH sample and the calibration sample (n=78), there is temporal differentiation in the sense that baseline data were used from the SEARCH sample while the calibration data were obtained at a follow-up visit. Last, similar to other studies, we relied on 24 hour dietary recalls as the reference instrument in the measurement error adjustment. This was done under the assumption that 24 dietary recalls provide an unbiased estimate of true intake, which is a necessary assumption for these models, even though we recognize that the 24 hour recall is somewhat biased for protein, energy, and protein density in adults [(17, 18)].

The SEARCH FFQ queried dietary intake in the preceding week, because most children and youth would not have been able to cognitively integrate dietary intake over a whole year. Thus, the estimate of usual intake of SSB may have been underestimated. According to national data, about 36% of youth do not consume SSBs, 33% consume one SSB per day and 31% two or more per day [5]. Our sample of youth with type 1 diabetes had a lower intake with 45% of youth not reporting any SSB intake, 41% one SSB per day and only 14% consuming two or more SSB per day. While consumption of SSBs is generally not recommended for any population because of the lack of nutritional value and high sugar content, youth with diabetes are particularly discouraged from consuming SSBs in the context of the carbohydrate-counting approaches. Occasionally, however, youth with diabetes will specifically use SSBs to manage low blood sugar levels. Our study was not able to distinguish between these SSB uses but there is no reason to believe SSBs would have a differential impact on lipid levels depending on ambient blood sugar levels.

Though many of the SSB intakes predicted by the measurement error model were quite low, our model did not explicitly allow for never-consumers. There is a model available for this purpose, extending the two-part NCI method to allow for a probability of never-consumption. However, our calibration sample participants completed three or fewer 24-hour recalls, and convergence of the three-part model would be questionable without more 24-hour recalls available [3]. We considered labeling those who reported no SSB intake on the FFQ as never-consumers, rather than including them in the measurement error model, but additional analyses revealed that 27% of FFQ non-consumers reported SSB intake on at least one of the three 24 hour dietary recalls, suggesting that this assumption would be quite poor.

In youth age ≥10 enrolled in the SEARCH study, average lipid levels for youth with type 1 diabetes were elevated with a mean of 174 mg/dL total cholesterol, 102 mg/dL LDL cholesterol, and HDL of 55 mg/dL and triglycerides at 91 mg/dL [19]. Among youth with type 1 diabetes in poor glycemic control, 35%, had high concentrations of total cholesterol (≥200 mg/dL [5.17 mmol/L]), 27% elevated LDL-C (≥130 mg/dL [3.36 mmol/L]), and 12% high triglycerides (≥200 mg/dL [2.26 mmol/L]) suggesting possible early influences on macro- and microvascular disease risk [19]. This profile is all the more concerning because CVD risk factors track from childhood to adulthood and predict adult target organ damage [20-24]. Thus, an adverse risk profile in youth with diabetes may magnify the already three-fold excess risk for CVD mortality associated with diabetes in adulthood [25].

In this context of generally elevated lipid levels in youth with type 1 diabetes, the association of SSB with increased levels of total and LDL cholesterol is particularly important. It is also consistent with results from experimental studies showing impact of high sucrose diets [26, 27] on cholesterol. SSBs also contain a significant amount of fructose (either bound to glucose within the sucrose molecule or in free form) and we have previously shown positive associations of fructose with triglycerides [28] and SSB intake with triglycerides [7]. In the present analyses, SSB intake was significantly positively associated with triglycerides (p=.03) in the naïve models (no ME adjustment) but after adjustment for ME, while the magnitude of the association became larger, the new p-value (.07) was short of statistical significance, likely for the reasons we outlined above.

Even though the last decades have witnessed enormous improvements in the medical treatment of diabetes, the adverse lipid profile suggests that the identification of novel behavioral CVD risk factor reduction strategies in youth with type 1 is particularly important. Our research group and others suggests that, similar to non-diabetic peers, the dietary intake in youth with diabetes falls dramatically short of current recommendations {Mayer-Davis, 2006 MAYERDAVIS2006A /id;Rovner, 2009 ROVNER2009 /id}. Our findings that SSB intake was positively associated with lipid levels suggests this particular dietary behavior may be one of several promising behavioral approaches, alongside intensified glucose control, that should be further evaluated in clinical trials [(30)]. In non-diabetic populations, there is now growing evidence that SSB intake is associated with elevated lipid levels [(31)].

Under the rubric of nutrition for children and adolescents with type 1 diabetes, the 2005 American Diabetes Association position statement on care concluded that “nutrition recommendations are based on requirements for all (...) because there is no research on the nutrient requirements for children and adolescent with diabetes.” [(2)] Our results aim to contribute to this gap in knowledge and underscore the importance of adjusting for measurement error related to dietary exposure assessment in analyses of associations between diet and health outcomes. Future studies in youth with diabetes - be they observational studies evaluating nutritional risk factors or clinical trials of dietary interventions measuring adherence to dietary regimens - should be designed in a manner that will allow for the consideration of measurement error, because without this adjustment, associations between diet and outcomes may be severely underestimated.

ACKNOWLEDGEMENTS

The contents of this paper are solely the responsibility of the authors and do not necessarily represent the official views of the National Institute of Diabetes And Digestive And Kidney Diseases or the National Institutes of Health or the Centers for Disease Control and Prevention.

The SEARCH Nutrition Ancillary Study was funded by 5R01DK077949 (Mayer-Davis, PI). We would also like to acknowledge the staff at the UNC Nutrition Obesity Research Center – Diet, Physical Activity and Body Composition Core (DK-56350) who conducted the 24-hour dietary recalls interviews. The SEARCH for Diabetes in Youth Study is indebted to the many youth and their families, and their health care providers, whose participation made this study possible.

Grant Support: SEARCH for Diabetes in Youth is funded by the Centers for Disease Control and Prevention (PA numbers 00097, DP-05-069, and DP-10-001) and supported by the National Institute of Diabetes and Digestive and Kidney Diseases.

Site Contract Numbers: Kaiser Permanente Southern California (U48/CCU919219, U01 DP000246, and U18DP002714), University of Colorado Denver (U48/CCU819241-3, U01 DP000247, and U18DP000247-06A1), Kuakini Medical Center (U58CCU919256 and U01 DP000245), Children's Hospital Medical Center (Cincinnati) (U48/CCU519239, U01 DP000248, and 1U18DP002709), University of North Carolina at Chapel Hill (U48/CCU419249, U01 DP000254, and U18DP002708), University of Washington School of Medicine (U58/CCU019235-4, U01 DP000244, and U18DP002710-01), Wake Forest University School of Medicine (U48/CCU919219, U01 DP000250, and 200-2010-35171).

The authors wish to acknowledge the involvement of General Clinical Research Centers (GCRC) at the South Carolina Clinical & Translational Research (SCTR) Institute, at the Medical University of South Carolina (NIH/NCRR Grant number UL1RR029882); Seattle Children's Hospital (NIH CTSA Grant UL1 TR00423 of the University of Washington); University of Colorado Pediatric Clinical and Translational Research Center (CTRC) (Grant Number UL1 TR000154) and the Barbara Davis Center at the University of Colorado at Denver (DERC NIH P30 DK57516); and the National Center for Research Resources and the National Center for Advancing

Translational Sciences, National Institutes of Health, through Grant 8 UL1 TR000077; and the Children with Medical Handicaps program managed by the Ohio Department of Health.

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TABLE 1

Descriptive Characteristic of the Study Sample and the Calibration Sample: The SEARCH Nutrition Ancillary Study

Variable	Total sample (N=2,286)		Calibration sample (N=166)	
Age (years), mean, SD	14.8	3.0	16.2	3.5
Duration of diabetes in months, mean SD (range)	55.6	50.5 (3-245)	71.2	11.0 (38-96)
Female gender, N, %	1138	50.2%	83	49.7%
Race/ethnicity, N, %				
Black/African American	189	8.3%	26	15.7%
Non-Hispanic White/Caucasian	1753	76.7%	122	73.5%
Other	344	15.0%	18	10.8%
Highest level of parental education, N, %				
High school or less	461	20.2%	22	13.3%
Some college/Associate's degree	743	32.5%	62	37.4%
Bachelors degree or more	1082	47.3%	82	49.4%

TABLE 2

Distribution of Cardiovascular Risk Factors and SSB Intake in the SEARCH Sample and the Calibration Sample: The SEARCH Nutrition Ancillary Study

Variable	SEARCH sample (N=2,286)		Calibration sample (N=166 participants, 494 24-hour recalls)	
	Median/N	IQR/%	Median/N	IQR/%
Triglycerides (mg/dL)	67	50-96	68	53-102
Total cholesterol (mg/dL)	165	145-186	166	147-185
LDL cholesterol (mg/dL)	95	80-113	94	75-114
BMI z-score	0.66	0.06-1.25	0.67	0.13-1.20
Waist-to-height ratio	0.47	0.44-0.52	0.48	0.45-0.52
Systolic blood pressure	107	99-113	107	100-115
Diastolic blood pressure	68	61-73	70	63-76
FFQ SSB (servings/day)	0.14	0.0-0.57	0.29	0-1
FFQ energy (kcal/day)	1764	1358-2341	1473	1127-2115
FFQ No SSB consumption (%)	1020	44.6%	65	39.2%
24 hour recalls				
No SSB consumption (%)	-	-	383	77.5%
Predicted SSB intake based on ME model (servings/day)	0.16	0.07-0.40	-	-
Predicted energy intake based on ME model (kcal/day)	1967	1764-2217	-	-

TABLE 3

Association of SSB Intake and Cardiovascular Risk Factors in Youth with Type 1 Diabetes ≥ 10 years of Age, With and Without Adjustment for Measurement Error: The SEARCH Nutrition Ancillary Study

	Naïve model- no ME adjustment		Model after ME adjustment	
Outcome	**Beta (SE) for log-SSB intake from FFQ**	***P***	**Beta (SE) for log-predicted mean SSB intake**	***P***
Log-triglycerides	.0103 (.0049)	.03	.0258 (.0141)	.07
Log-total cholesterol	.0040 (.0019)	.04	.0117 (.0054)	.03
Log-LDL cholesterol	.0070 (.0027)	.01	.0210 (.0077)	.007
BMI z-score	.0023 (.0090)	.80	.0297 (.0286)	.30
Waist to height ratio	−.0003 (.0003)	.61	.0014 (.0020)	.47
Systolic blood pressure	−.1290 (.1020)	.21	−.4227 (.2990)	.16
Diastolic blood pressure	−.0019 (.0948)	.98	.0418 (.2792)	.88

SSB intake and predicted SSB intake were in servings per day, before log transformation. All lipid models were adjusted for log- energy intake (FFQ-based for the naive model, calibrated usual intake, i.e., its conditional mean true intake given FFQ intakes and other disease model covariates, for the model adjusted for measurement error), age, diabetes duration, race, gender, and parental education.

TABLE 4

Estimated Mean Difference in Lipid Levels for 0.07 vs. 0.50 Servings of SSB intake Per Day, With and Without Adjustment for Measurement Error: The SEARCH Nutrition Ancillary Study

	Naïve model- no ME adjustment			Model after ME adjustment		
Outcomes (back-transformed)	**Estimated Outcome at 0.07* servings/day**	**Estimated Outcome at 0.5 servings/day**	**Difference in Estimated Outcome**	**Estimated Outcome at 0.07* servings/day**	**Estimated Outcome at 0.5 servings/day**	**Difference in Estimated Outcome**
Triglycerides (mg/dL)	70.7	72.1	1.4	69.2	72.9	3.7
Total cholesterol (mg/dL)	165.1	166.4	1.3	163.4	167.4	4.0
LDL cholesterol (mg/dL)	94.6	95.9	1.3	93.0	97.0	4.0

*0.07 servings/day equals a serving every two weeks