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Sugar-sweetened and diet beverages in relation to visceral adipose tissue

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Abstract

Frequent sugar-sweetened beverage (SSB) intake has been consistently associated with increased adiposity and cardio-metabolic risk, whereas the association with diet beverages is more mixed. We examined how these beverages associate with regional abdominal adiposity measures, specifically visceral adipose tissue (VAT). In a cross-sectional analysis of 791 non-Hispanic white men and women aged 18-70 we examined how beverage consumption habits obtained from a food frequency questionnaire associate with overall and abdominal adiposity measures from MRI. With increasing frequency of SSB intake we observed increases in waist circumference (WC) and the proportion of visceral to subcutaneous abdominal adipose tissue (VAT%), with no change in total body fat (TBF %) or BMI. Greater frequency of diet beverage intake was associated with greater WC, BMI and TBF %, but was not associated with variation in visceral adiposity We conclude that increased frequency of SSB consumption is associated with a more adverse abdominal adipose tissue deposition pattern.

Frequent sugar-sweetened beverage (SSB) intake has been consistently associated with increased adiposity measures and cardio-metabolic risk in observational studies, whereas the association with diet beverages is more mixed.[1] However, there is minimal research on how intakes of these beverages associate with regional abdominal adiposity measures, specifically visceral adipose tissue (VAT). Therefore we examined the cross-sectional association between SSB and diet beverages with abdominal adiposity, specifically to VAT, subcutaneous adipose tissue (SAT) and other adiposity measures in healthy adults.

Research Design and Methods

The sample included 791 healthy (free of chronic disease), non-Hispanic white participants aged 18–70 years who were enrolled in ongoing studies of body composition and cardiometabolic risk at the Lifespan Health Research Center (Dayton, OH) and seen between 2003 and 2006.[2] Anthropometric, dual energy x-ray absorptiometry and multiple image MRI data were collected using methods previously described to characterize overall

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adiposity and regional abdominal adiposity measures.[2] From this we created a variable to further characterize abdominal adiposity: percent visceral adipose tissue (%VAT = (VAT/(VAT + SAT))*100).

Usual dietary intake was assessed with the Willett semi-quantitative food frequency questionnaire assessing frequency of intake of ~130 food items over the previous year.[3] Exclusions were made for extreme sex specific energy intakes (< 960 or > 3362 kcal women) (<1085 or > 3900 kcal men) equal to the top 2.5% and bottom 2.5% of the population. Sugar-sweetened beverages were defined as summed intake of carbonated soft drinks, carbonated sweetened drinks, non-carbonated sweetened fruit/punch drinks. Diet beverages were defined as the summed intake of no/low caloric carbonated colas or other soft drinks, and other no/low caloric beverages. Main non dietary confounders include habitual physical activity (self-reported using the sports activity index of the Baecke questionnaire of physical activity),[4] current smoking (self-reported (yes/no)) and education (some education beyond high school or high school or less).

All analyses were conducted using SAS version 9.1 (SAS institute, Cary, NC). Multivariate least squares adjusted means for adiposity measures by beverage intake frequency were obtained from the general linear models procedure (SAS PROC GLM). All models were adjusted for age, sex, height, physical activity, smoking status, educational level, and nutritional intake (fiber, high and low fat dairy, green leafy vegetable intake, red meat intake, alcohol and total energy). The nutritional covariates in the models presented were included because they are markers of an overall dietary pattern and significantly contributed to the model. Inclusion of other dietary covariates did not materially affect any of the results. Further specific adjustments for measures of adiposity are noted in the footnote of the results table. Tests for a linear trend across the components were performed by assigning the median value of intake to the respective categories and entering this as a continuous variable into the models. We also examined the measures stratified by age and sex.

Results

Participant characteristics are reported in Supplemental Table 1. Participants with greater SSB intake were younger, more likely to be male, and less educated with greater estimated dietary energy intake, greater carbohydrate intake, less fiber and less diet beverage intake. Participants with greater diet beverage intake were more likely to be female, smoke less, with lower estimated energy and overall carbohydrate intake and less SSB intake. In multivariate adjusted models (Table 1) we observed a significant increase in waist circumference (WC) and VAT% with increasing SSB frequency. There was no association with total body fat (TBF %) or BMI. We carried out sex stratified analyses for all measures and the sex stratified trends were similar to the main results. For example, in men VAT% increased monotonically from a mean of 40.9% without SSB intake to 44.4% for ≥ 1 SSB a day, p trend =0.17. In women the mean ranged from 22.1% for no SSB intake with a monotonic increase to 24.5% % for ≥ 1 SSB a day, p trend=0.03. Trends for age stratified measures were also similar, for example VAT% for ages 18-43 increased monotonically from 25.9-28.3%, p trend=0.16 and ages 44-69 increased from 34.2-38.0%, p trend=0.039. Increased frequency of diet beverage intake was associated with greater WC, BMI and TBF %, but was not associated with variation in VAT or SAT mass or VAT %. Diet beverages also displayed similar age and sex stratified trends to the main results upon stratification (data not reported).

Discussion

In this cross-sectional analysis, individuals with frequent SSB consumption had a more adverse abdominal adipose tissue deposition pattern (i.e., higher VAT %) than those with less frequent consumption, despite SSB intake showing no association with overall adiposity. We also observed that greater frequency of diet beverage intake was associated with greater markers of adiposity with significant increases in WC, BMI and TBF % but not with any variation of VAT or SAT mass.

A growing body of observational evidence has shown that frequent SSB intake is a risk factor for weight gain and cardio-metabolic outcomes.[5] SSB are typically sweetened with high-fructose corn syrup (HFCS), which is usually 45-58% glucose and 42-55% fructose in composition; or sucrose which is 50% glucose and 50% fructose. This study examines SSB intake in this common form in relation to abdominal adipose tissue deposition, and specifically VAT. Importantly, other related research has presented data demonstrating the plausibility of these findings. In a study of overweight and obese subjects consuming 100% glucose or fructose sweetened beverages as 25% of total energy requirements for 10 weeks, independent effects of both these beverages on total body fat were observed.[6] Moreover, abdominal visceral adipose tissue volume was significantly increased with fructose consumption, and subcutaneous adipose tissue was significantly increased with glucose consumption suggesting differential effects of these monosaccharides on regional adipose measures. As discussed, the different pathways of metabolism of these sugars are the salient mechanisms.[6] Trials have not addressed how HFCS or sucrose relate to regional adipose tissue deposition.

From a public health perspective understanding dietary attributes that may influence VAT accumulation is important. Greater abdominal VAT is strongly associated with greater levels of insulin resistance.[7] Indeed, insulin resistance is the hallmark condition involved with type 2 diabetes and a cluster of metabolic and cardiovascular disorders.[8] Relative to this topic Yoshida et al.[9] found significantly increasing levels of fasting insulin and insulin resistance measures with increasing sugar sweetened beverage consumption. These results align with the greater levels of insulin resistance observed with greater VAT levels from the same study.[7] Thus, our results add another piece to this puzzle. However, because of the non-temporal study design our results are only hypothesis forming in relation to another upstream pathway in which SSB may affect cardio-metabolic risk.

Examination of diet beverages in relation to adiposity and cardio-metabolic risk is a lesser studied topic with mixed evidence on the association with adiposity and cardio-metabolic risk. Some studies have found greater frequencies associated with increased adiposity measures and other have not.[5] This topic merits more careful consideration of the evidence and future research due to potential confounding, biases and mechanisms involved. Indeed, a study examining diet beverage consumption with type 2 diabetes incidence found a positive association until BMI, health-status, dieting behaviors and weight change prior to enrollment were considered making the association non-significant.[10] We found no association of diet beverage consumption with regional abdominal adipose tissue deposition, but increased WC, BMI and total body fat with increased consumption. On a metabolic level, no data indicate that the intrinsic properties of diet beverages modify energy balance independently of any potential influence on macronutrient and energy intakes.[11] Diet beverages have few to no calories and very little is known about any physiological effects of artificial sweeteners, while their relation to appetite and energy intake is also unresolved[11]. Thus, it is impossible to conclude whether more frequent diet beverage consumption is a dietary behavior marker related to persons looking to lose weight, or a dietary behavior that leads to accumulation of general adiposity through multiple potential pathways.

In conclusion, we observed a significant cross-sectional association between increased frequency of SSB consumption and a more adverse abdominal adipose tissue deposition pattern (i.e. greater VAT%), and no association between diet beverage intake and abdominal adipose tissue pattern. Overall, the examination of dietary intake and abdominal adipose tissue partitioning has received sparse investigation in humans with few other studies besides the current.[12,9, 13] Our data are hypothesis forming and suggest the need for prospective studies and randomized clinical trials examining the association between dietary intake and adipose tissue deposition, especially in the abdominal cavity as it associates more strongly with cardio-metabolic disorders and diseases.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Adjusted means for measures of adiposity by frequency of beverages

Sugar-Sweetened Beverages	None	1 – 2 / wk	3-6 / wk	≥ 1 / day	*P Trend*
N	259	272	98	162	
[a]VAT%	30.00 (29.03-30.96)	32.14 (31.24-33.03)	32.78 (31.28-34.29)	32.81 (31.55-34.08)	0.03
[b]VAT (kg)	2.01 (1.89-2.14)	2.17 (2.05-2.29)	2.21 (2.01-2.41)	2.26 (2.10-2.43)	0.10
[c]SAT (kg)	4.20 (4.06-4.34)	4.16 (4.02-4.29)	4.03 (3.82-4.25)	4.19 (4.01-4.38)	0.87
[d]WC (cm)	93.28 (92.24-94.33)	94.68 (93.71-95.65)	95.70 (94.13-96.27)	96.11 (94.81-97.42)	0.01
BMI (kg/m^2)	27.2 (26.5-27.9)	27.6 (26.9-28.2)	27.4 (26.3-28.5)	26.4 (25.5-27.4)	0.08
[e]Total body fat (%)	29.3 (28.4-30.1)	29.9 (29.1-30.6)	30.6 (29.3-31.8)	29.8 (28.8-30.9)	0.71
Diet Beverages	**None**	**1 – 2 / wk**	**3-6 / wk**	**≥ 1 / day**	***P Trend***
N	351	190	77	173	
[a]VAT%	31.46 (30.67-32.25)	31.68 (30.63-32.73)	31.60 (29.94-33.26)	32.01 (30.86-33.17)	0.48
[b]VAT (kg)	2.09 (1.98-2.19)	2.13 (1.99-2.27)	2.22 (2.00-2.43)	2.24 (2.09-2.39)	0.13
[c]SAT (kg)	4.21 (4.10-4.33)	3.99 (3.84-4.14)	4.30 (4.07-4.54)	4.20 (4.03-4.36)	0.56
[d]WC (cm)	94.28 (93.45-95.11)	93.59 (92.47-94.72)	95.88 (94.14-97.62)	96.02 (94.76-97.29)	0.009
BMI (kg/m^2)	26.5 (25.9-27.0)	27.5 (26.7-28.2)	27.6 (26.4-28.8)	28.3 (27.5-29.1)	0.003
[e]Total body fat (%)	28.9 (28.2-29.5)	29.9 (29.0-30.7)	30.4 (29.0-31.8)	31.1 (30.1-32.1)	0.001

VAT –Visceral Adipose Tissue (abdominal)

SAT – Subcutaneous Adipose Tissue (abdominal)

-VAT%= VAT%, the percentage of total abdominal adiposity [(VAT kg/(VAT kg +SAT kg))*100]

-All models adjusted for age, sex, height, physical activity, smoking status, educational level, and nutritional intake (fiber, high and low fat dairy, green leafy vegetable intake, red meat intake, alcohol and total energy).

[a]-VAT% further adjusted for lean mass and non-abdominal body fat

[b]-VAT further adjusted for lean mass, non-abdominal body fat, and SAT

[c]-SAT further adjusted for lean mass, non-abdominal body fat and VAT

[d]-WC further adjusted for lean mass

[e]-Total body fat % further adjusted for lean mass