



Sugar intake from sweetened beverages and diabetes: A narrative review

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Author contributions: Tseng TS reviewed and drafted the first manuscript; Lin WT, and Gonzalez GV contributed to the study conception and literature review; Kao YH checked the review quality and results; Tseng TS, Lin HY and Chen LS contributed to the content analysis and the interpretation of the study; all authors contributed to edit and revise the manuscript critically and approve the final version of the article to be published.

Conflict-of-interest statement: Authors have nothing to disclose.

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Abstract

Type 2 diabetes mellitus (T2DM) is one of the fastest growing public health concerns around the world. Sugar-sweetened beverage (SSB) consumption has been proven to be associated with adverse health consequences in the diabetic population. Reducing SSB consumption, body weight control, healthy diets, and increased physical activity have been suggested as strategies to improve diabetes prevention and management. This literature review provides an overview of: (1) The association between SSB consumption and the risk of T2DM; (2) Types of SSB consumption and T2DM; (3) The effect of obesity and inflammation on the association between SSB consumption and risk of T2DM; and (4) SSB consumption in T2DM patients. There is still work to be done to determine how SSB consumption is related to T2DM, but the current research on identifying the association between SSB consumption and T2DM is promising, with the most promising studies confirming the connection between SSBs, T2DM risk, and diabetes management. Future studies should explore more effective SSB related diabetes prevention and management interventions.

Key Words: Sugar-sweetened beverages; Type 2 diabetes mellitus; Inflammation; Obesity; Diabetes management

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Manuscript source: Invited manuscript

Specialty type: Behavioral sciences

Country/Territory of origin: United States

Peer-review report's scientific quality classification

Grade A (Excellent): 0

Grade B (Very good): B

Grade C (Good): 0

Grade D (Fair): 0

Grade E (Poor): 0

Received: January 27, 2021

Peer-review started: January 27, 2021

First decision: April 20, 2021

Revised: May 5, 2021

Accepted: August 3, 2021

Article in press: August 3, 2021

Published online: September 15, 2021

P-Reviewer: Mao RF

S-Editor: Liu M

L-Editor: A

P-Editor: Guo X



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Core Tip: Sugar-sweetened beverage (SSB) consumption has been proven to be associated with adverse health consequences in the diabetic population. This literature review provides an overview of: (1) The association between SSB consumption and the risk of type 2 diabetes mellitus (T2DM); (2) Types of SSB consumption and T2DM; (3) The effect of obesity and inflammation on the association between SSB consumption and risk of T2DM; and (4) SSB consumption in T2DM patients. The current research on identifying the association between SSB consumption and T2DM is promising, with the most promising studies confirming the connection between SSBs, T2DM risk, and diabetes management.

Citation: Tseng TS, Lin WT, Gonzalez GV, Kao YH, Chen LS, Lin HY. Sugar intake from sweetened beverages and diabetes: A narrative review. *World J Diabetes* 2021; 12(9): 1530-1538

URL: <https://www.wjgnet.com/1948-9358/full/v12/i9/1530.htm>

DOI: <https://dx.doi.org/10.4239/wjd.v12.i9.1530>

INTRODUCTION

Type 2 diabetes mellitus (T2DM) is one of the fastest growing public health concerns around the world, and has a high prevalence in the United States as one in every ten Americans has diabetes[1]. Many diabetes-related research studies, including those in the basic, clinical, translational, and public health sciences have identified the mechanisms of the disease, its risk factors, and intervention strategies to prevent or manage T2DM. Weight or diet management, physical activity, glycated hemoglobin level control, and diabetic retinopathy screening are useful approaches for the prevention and management of diabetes. Among these strategies, reducing sugar-sweetened beverages (SSB; beverages with high sugar content) consumption has been identified as one of the most cost-effective diabetes prevention and management approaches in the last decade[2]. Because SSB consumption plays an important role in both diabetes prevention and control, researchers are urging the public to avoid consuming large amounts of SSB's.

Although SSB consumption can lead to diabetes, there is limited information on both how SSB consumption is associated with diabetes, and on how the underlying mechanisms of obesity and inflammation affect the association between SSB consumption and T2DM. This manuscript reviews recent studies investigating the mechanisms and impact of SSB consumption on T2DM. In addition, the impact of SSB consumption on diabetic patients is a critical factor in successfully managing this chronic disease. Many studies have focused on SSB consumption and the risk of T2DM. However, the effect of SSB consumption upon adults with diabetes or prediabetes is unclear. The objective of this literature review is to provide an update on: (1) The association between SSB consumption and T2DM risk; (2) The effect of different types of SSB consumption and T2DM; (3) The effect of obesity and inflammation on the association between SSB consumption and risk of T2DM; and (4) SSB consumption in T2DM patients.

SSB AND RISK OF T2DM

Previous longitudinal and large cohort studies found a strong association between SSB consumption and subsequent T2DM risk. Previous large cohorts that were monitored for long periods (from 4-20 years) found that SSB consumption increased the risk of developing T2DM[3]. It is known that SSB's are the main source of added sugars in American diets. Previous literature and epidemiological evidence supports the fact that SSBs contribute to T2DM[4]. This study combined three cohorts of United States women and men and suggested that increased consumption of sugary beverages and artificially sweetened SSBs was associated with a higher risk of diabetes[4]. Similarly, the other three cohort studies consistently demonstrated that both SSB, and artificially

sweetened SSB consumption were observed to contribute to an increased risk of diabetes development[5-7].

The association of SSB and T2DM can also be observed in SSB related policy. Increased taxation of SSBs was recently implemented to evaluate associated changes in SSB consumption[8-12]. Some studies have suggested that increased taxation of SSBs is likely to reduce SSB consumption, lower the incidence of diabetes, and decrease diabetes related morbidity and mortality. Findings from a South African nationwide survey found an estimated decrease of approximately 108000 cumulative T2DM cases in South African adults after a 20% SSB tax increase was imposed for 20 years. Over the same period, the increased tax on SSB could also have been responsible for an 860 million dollars reduction in T2DM-related healthcare costs in South Africa[11]. A 1.6% and a 0.37% lowering of the incidence rate of diabetes in the populations of India and Ireland respectively was predicted after the imposition of a 20% SSB tax increase for ten years[9]. Although support of taxation on SSBs varies significantly across populations with differing demographic characteristics and health conditions, an SSB tax may have the potential to reduce both obesity-related disease incidence and health care costs.

TYPES OF SSB AND T2DM

SSBs include soda, energy drinks, sweetened tea, sweetened juices, and vitamin water drinks[13]. Although studies have indicated that SSBs are associated with diabetes, it is important to understand the associations that different types of SSBs have upon T2DM. Different types of sweetened beverages may be associated with different risks of diabetes or diabetic-related markers, such as beta-cell function and insulin sensitivity[14]. However, controversial findings were proposed from cohort results including one 14 year longitudinal cohort targeting women that showed both SSB consumption, and non-soda artificially sweetened drink consumption were associated with a higher risk of diabetes, with the exception of 100% fruit juice consumption[5].

The effect of low-calorie-sweetened beverages (LCSB) consumption has been studied to assess its efficacy in assisting in weight control. The American Diabetes Association, the American Heart Association, and the Academy of Nutrition and Dietetics have released statements that LCSBs can be used in a structured diet to replace SSBs and reduce energy intake[15]. Another large cohort study of men collected beverage intake information every 4 years over 20 years of follow-up using food frequency questionnaires. An increased risk of diabetes was found in men who consumed either carbonated or noncarbonated SSB, but not in those who consumed low-calorie sweetened beverages. Artificial sweeteners such as in diet soda, are an alternative to SSBs but they have no nutritional value and their health consequences are still being evaluated. Particularly, consumption of SSBs or artificially sweetened SSBs was associated with a higher risk of diabetes not only in middle-aged or older adults but also in young adults. One multi-city study observed that the long-term consumption of soda or fruit drinks sweetened with non-caloric sweeteners was associated with diabetes development. After adjusting for body mass index (BMI), these two associations were attenuated. However, total SSB (sugar-sweetened soft drinks and fruit drinks) consumption was still significantly associated with a higher risk of diabetes development in United States young adults[16].

Some studies focused on exploring whether the association between diabetes and regular and diet soda consumption was due to the presence of high fructose levels in these beverages. The association between consumption of regular soda and diabetes development, and decreased beta-cell function has been reported[14,17,18]. However, it is still unclear whether the consumption of regular and diet sodas is associated with different diabetes related outcomes. One study conducted by Gardener *et al*[19] showed that the substitution of diet soda or artificially sweetened diet beverages in place of regular soda was not associated with a reduced incidence of diabetes. Consistent results were reported from studies that compared regular and diet sodas. Consumption of SSB or diet sodas were both observed to result in an increased risk of diabetes in middle-aged Japanese men[6].

Reducing SSB consumption to lower diabetes incidence is suggested in the findings of all of the above-mentioned studies. Of these, findings from one cohort study conducted using 3.99 million person-years of data collected in multiple European countries (*e.g.* France, Italy, Spain, the United Kingdom, the Netherlands, Germany, Sweden, and Denmark) suggested that replacing SSBs with coffee or tea may result in a decrease of approximately 20% in diabetes development. This effect was not

observed by substituting SSB or diet soda consumption with fruit juice or milk. However, the consumption of sweetened or unsweetened coffee and tea were not distinguished in this study[20]. Another 10-year follow-up study reported that the replacement of all types of SSB and sweetened milk consumption with unsweetened tea, coffee, or water had a positive effect on diabetes prevention[21].

SSB, OBESITY, INFLAMMATION, AND T2DM

SSBs are a well known contributor to an unhealthy diet that can contribute to obesity due to high sugar consumption and low satiety. Added sugar intake in a liquid form was also found to be associated with higher levels of inflammatory markers[22,23]. In addition to adiposity, inflammation is another factor associated with diabetes. Accumulation of adiposity is one of the risk factors linked with higher inflammation levels. Controlling body weight, maintaining a healthy diet, reducing SSB consumption, and increased physical activity have been reported to have a positive effect on diabetes prevention. In the past decade, some review studies have reported that SSB consumption is likely to contribute to the accumulation of adiposity and a higher risk of future diabetes[3,24,25]. Most of these studies considered adiposity as a confounder to evaluate the association between SSB consumption and diabetes. However, how adiposity influences the association between SSB consumption and diabetes is unclear. It has been hypothesized that a high intake level of added sugars and SSBs can increase chronic inflammation[23]. SSBs have been found to be a contributor to high dietary glycemic load (GL) that can lead to inflammation independent of obesity[3]. The consumption of large amounts of SSBs can increase blood glucose and insulin concentrations, while leading to a high GL. Diets with a high GL can stimulate hunger and lead to weight gain as well as induce glucose intolerance and insulin resistance. High GL can increase inflammatory biomarkers like the C-reactive protein (CRP), which is associated with T2DM.

Aeberli *et al*[26] reported how low to moderate consumption of fructose, glucose, and sucrose-containing beverages can cause an inflammatory response in young men. Fructose, which can trigger inflammation, is a major component of SSBs and has been observed to activate inflammatory pathways. This evidence supports the hypothesis of a positive association between high SSB consumption and inflammation[26,27]. A short 3-wk period of SSB consumption can cause changes in glucose metabolism that can lead to long-term insulin resistance. This study supports other research that found that consumption of SSBs had an adverse effect on lipid and glucose metabolism and raised inflammation levels[26]. Other studies reported fructose as the main component in chronic inflammation, and that there were no observable differences in the triggering of low-grade chronic inflammation due to either short-term or long-term consumption of SSBs[27]. Some review studies have proposed that higher levels of inflammatory markers are associated with an increased risk of diabetes[28,29]. One recent study identified the role of inflammatory markers in the association between SSB consumption and diabetes. Findings showed no significant linear association between SSB and T2DM risk, or CRP levels because of the U-shaped association between SSB consumption or added sugar intake, and diabetes risk and CRP level. However, six plasma proteins, including HGF, tPA, CHI3L1, IL1ra, PRSS8 and FUR, were identified as being associated with SSB consumption[23]. CRP are most commonly studied in relation to added sugars and SSBs, but there is currently a dearth of research on other plasma proteins[23]. SSB's with the familiar caramel coloring found in cola soft drinks are known to have high levels of advanced glycation end products, which can also increase inflammation[3].

Obesity plays an important role in diabetes prevention and management. One survey study reported that the association between SSB consumption and diabetes was marginally significant after adjusting for adiposity indexes, such as body fatness, BMI, and waist circumference[30]. Another cross-sectional study that analyzed data from 75 countries found that sweetened soft drink consumption was related to diabetes prevalence. Findings from one nationwide eight-year cohort study found that BMI mediated the relationship between SSB consumption and diabetes incidence[31], while one case-control study demonstrated that excess weight might partially mediate the association between SSB intake and diabetes development[32].

SSB CONSUMPTION IN T2DM PATIENTS

Identifying which variables are associated with SSB intake among people with T2DM may provide vital evidence for the effective management of diabetes. Two studies assessed large United States nationwide survey datasets (*i.e.*, Behavioral Risk Factor Surveillance System and National Health and Nutrition Examination Survey) to explore associations between sociodemographic and behavioral characteristics and SSB consumption among T2DM patients. Around 16% of adults with diabetes, and about 30% of adults without diabetes reported consuming SSBs at least once per day. Diabetic adults who were younger, male, non-Hispanic Black, lower education, lower income, not married, and current smokers were significantly more likely to consume more SSBs[2,33]. In addition, diabetes management behaviors were also observed to have a significant association with SSB intake. Adults with T2DM who had a shorter duration of diabetes, checked their blood sugar less frequently, and did not attend a diabetes self-management course reported higher SSB consumption[2].

SSB consumption has been proven to be associated with adverse health consequences in both the overall and the diabetic populations. Previous literature has reported that adults with T2DM who consumed more SSBs had an elevated risk of developing numerous adverse health outcomes such as abdominal obesity[34], cardiovascular diseases[35], gout[36], poor cognitive function[37], and tooth loss[34-38]. Although these studies applied a cross-sectional design using a survey questionnaire, a positive association between SSB intake and risk of adverse health outcomes was identified, which should motivate T2DM patients to reduce SSB intake or stop consuming SSBs altogether to decrease the risk of adverse outcomes.

IMPACT OF SSB CONSUMPTION ON T2DM

Our review of the literature found trends in research results connecting SSB consumption to the risk of developing T2DM. Findings from a computer simulation study demonstrated that a 10% reduction in SSB consumption could decrease diabetes incidence over a 10-year period in adults aged 35 and older[39]. The majority of beverages containing high levels of sugar included soft drinks, juices, energy drinks, and vitamin water drinks. Studies showed that current SSB consumption levels resulted in possible increased incidence of T2DM. The added sugar content in these beverages is a major factor contributing to T2DM related adverse health outcomes, though fruit juices can also contribute to increased T2DM risk due to high levels of added sugar in these beverages that were once thought to be healthier alternatives.

Different types of sweetened beverages may be associated with different risks of diabetes or the appearance of diabetic-related markers; however, inconsistent findings were reported. Some studies showed that fruit juice and low-calorie sweetened beverage consumption were not associated with a higher risk of diabetes. The effect of the replacement of SSB's with diet or no-caloric sweetened beverages on diabetes incidence is still uncertain. None of the studies we reviewed suggested diet or zero calorie sweetened beverage consumption as an strategy to prevent diabetes development. The more effective strategy to lower diabetes risk is to substitute water, unsweetened tea, or coffee for SSBs. These are simple and low-cost options to improve glycemic and weight control.

In concluding this review, most studies found that SSB consumption increased the risk of developing T2DM (Figure 1). SSB consumption is thought to add to the risk of individuals developing T2DM as it can lead to obesity. SSBs are likely to contribute to the accumulation of adiposity and a higher risk of developing diabetes in the future. There was a consensus that the obesity rate in the United States could be partly due to the number of individuals consuming more than the recommended daily intake of sugar. Excess adiposity in the body is known to promote inflammation flare-ups, but SSB's can increase the effects of inflammation due to the higher levels of added sugars being absorbed in the body. There was a call for more research into exactly what types of inflammation related proteins are increasing due to excess sugar consumption. CRP are the main area of study related to how inflammation is caused in the body, but broader ranging research has the potential to contribute insight into all sources of inflammation, and how inflammation can be combated it in the future. Scientists agree that high levels of sugar consumed on a daily basis increases inflammation, so the reduction of added sugar in the diet has to potential to significantly improve the health outcomes of individuals living with T2DM and chronic inflammation.

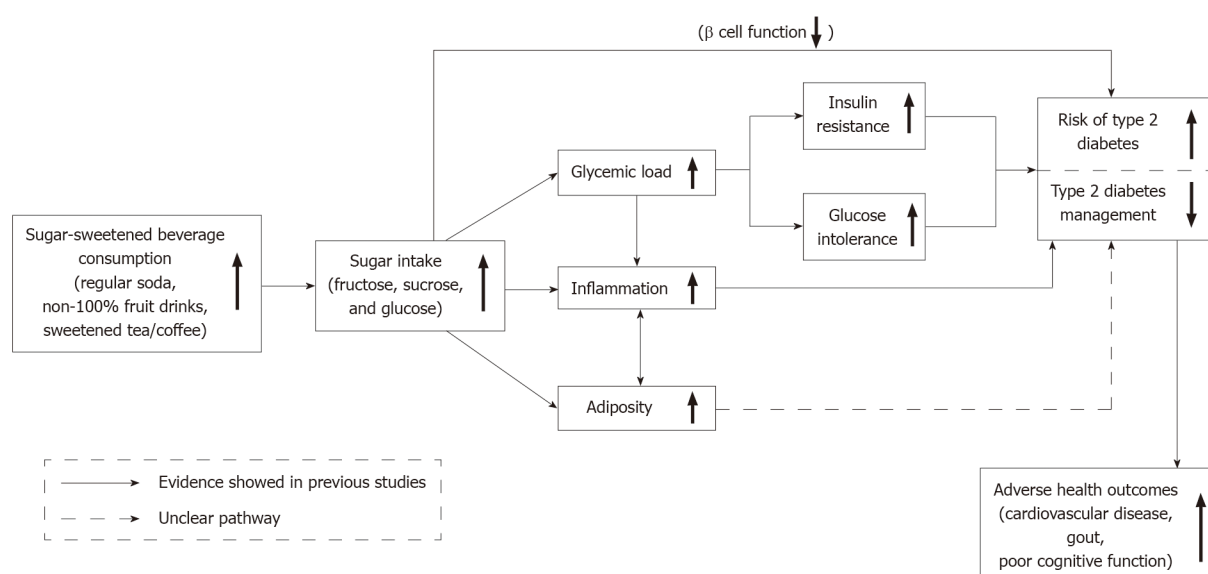


Figure 1 The association between sugar-sweetened beverages and diabetes.

SSBs have been found to be a contributor to high dietary GL that can lead to inflammation independent of obesity. Fructose, which is a major component of SSBs and can trigger inflammation, was observed to activate inflammatory pathways, evidence that supports the hypothesis of a positive association between high SSB consumption and inflammation. SSBs can also cause changes in glucose metabolism that can have the potential to lead to long-term insulin resistance. Large amounts of rapidly absorbable carbohydrates that are found in sugars, a significant component of SSBs, can lead to diabetes independent of obesity. SSB consumption has been found to be an factor in the incidence of T2DM, meaning that sugar content in the diet is more detrimental to health than was previously understood. Different sugars had different effects, but all had an adverse effect on inflammation levels. Thus, the consumption of SSBs has been associated with an increased risk of chronic disease, which may be mediated by low-grade chronic inflammation[27]. SSB consumption can lead to T2DM, weight gain, increased inflammation, impaired beta-cell function, and insulin sensitivity[36]. When SSBs are consumed in large amounts, the possibility of developing glucose intolerance increases along with inflammation levels[40]. This means that SSBs can lead to diabetes independently of obesity.

The literature agreed that persons living with diabetes need to take action to reduce their intake of SSBs. A consensus was seen that a reduction in SSB consumption would improve overall health, including reduction of body fat, inflammation, and insulin sensitivity. Alternatives to SSBs are an option for those living with T2DM, but their lack of nutritional benefits is leading researchers to instead support the consumption of water, tea, and coffee rather than low-calorie or zero-calorie beverages. Patients were found to understand the health benefits of drinking affordable and no-sugar-added beverages, but there is still a large portion of the population that continues to drink SSBs. Education is needed to reduce the consumption of SSBs and reduce the risk of developing T2DM. It is recommended that T2DM patients limit SSB consumption, and increase exercise levels to become physically fit and lose weight [36]. T2DM patients should avoid SSBs due to the adverse health outcomes associated with their consumption, and the effects that dietary sugar consumption has on obesity, glycemic control, and inflammation. Reduced SSB consumption in the daily diet can benefit individuals with T2DM by improving lipid profiles and insulin sensitivity, and by reducing blood pressure, inflammation, and excess visceral adiposity[3]. Recent studies have reported that replacing SSBs with artificially sweetened beverages (ASBs) can positively affect body weight and possibly reduce the risk of diabetes long-term [4]. However, researchers suggest caution in replacing SSBs with ASBs due to findings of weight gain, insulin resistance, and appetite stimulation. In terms of diabetes diagnosis, approximately 7.3 million Americans are undiagnosed[41], which means those adults had a fasting plasma glucose level of ≥ 126 mg/dL but did not be told by the physician. A One study revealed that undiagnosed adults were significantly more likely to consume more SSBs than those who were diagnosed with T2DM[33]. Therefore, undiagnosed adults should be targeted and diagnosed as early as possible,

which may improve their ability to manage their diabetes successfully.

LIMITATIONS

Several limitations of this literature review should be noted. Although this review employed bibliographic search strategies to minimize bias, not all relevant published papers have been included. Second, cross-sectional studies cannot provide evidence of causal linkage. Future studies are needed to clarify the causal relationship between SSB consumption, adiposity, and diabetes. However, the scope of this review provided an update on what is currently known regarding the association between SSBs and T2DM. The literature surveyed mostly relied on large cohorts to generate valid data, the analysis of which resulted in the conclusion that those who consume large amounts of SSBs have a higher chance of developing T2DM, but more research needs to be done to see if that association is a significant factor in disease incidence. An individual's lifestyle and eating habits may also contribute to a T2DM diagnosis just as much or more than consuming SSBs.

CONCLUSION

Overall, consumption of beverages with added sweeteners, including soda, sweetened tea, coffee, juices, and milk is related to a higher risk of diabetes development. However, the interactions between the incidence of diabetes, the type of SSBs consumed, and adiposity is, as yet, unclear. SSB consumption can lead to weight gain, inflammation, and T2DM. The consumption of SSBs was associated with a higher risk of adverse health outcomes in adults with T2DM.

Future perspectives

It is important to continue to educate diabetic patients and those at risk of developing diabetes that high levels of SSB consumption has the potential to lead to T2DM and obesity. There is still more work to be done to definitively determine the effect of SSB consumption on the health of those who have T2DM, and those who are at risk for T2DM. The majority of the studies we reviewed confirmed that large-scale cohorts with long study periods show the most promise in demonstrating the connection between SSB consumption and T2DM. Future work is needed to conduct innovative and effective SSB-related behavioral and community-based research focused on discovering data-driven intervention strategies aimed at both reducing the risk of contracting diabetes, and the successful management of diabetes in those who have been diagnosed.

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