Impact of Sugar-Sweetened Beverages on Blood Pressure

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The impact of sugar-sweetened beverages (SSBs) on blood pressure (BP) has been debated, with some evidence suggesting that their increased intake is related to higher risk of developing hypertension. We conducted a systematic review exploring the relation between consumption of SSB and BP. A comprehensive search in 5 electronic databases along with a bibliography search was performed. The keywords “sugar sweetened beverages,” “sugary drinks,” “added sugars,” “blood pressure,” and “hypertension” were indexed in all combinations. Studies were included that reported the effects of intake of SSBs on BP. We excluded studies with <100 subjects and those involving subjects aged <12 years. Of 605 potentially relevant studies, a total of 12 studies (409,707 participants) met our inclusion criteria; 6 were cross sectional studies, whereas the rest were prospective cohort studies. All 12 studies showed positive relation between increased SSB intake and hypertension; however, statistical significance was reported in 10 of these studies. Of the 12 studies, 5 reported an increase in mean BP whereas 7 reported an increase in the incidence of high BP. In conclusion, our systematic review shows that the consumption of SSBs is associated with higher BP, leading to increased incidence of hypertension. Restriction on SSB consumption should be incorporated in the recommendations of lifestyle modifications for the treatment of hypertension. Interventions to reduce intake of SSBs should be an integral part of public health strategy to reduce the incidence of hypertension. © 2014 Elsevier Inc. All rights reserved. (Am J Cardiol 2014;113:1574—1580)

Sugar-sweetened beverages (SSBs) are the largest source of added sugar in our diet. They include any beverage to which a caloric sweetener has been added. In the United States, high-fructose corn syrup (HFCS) is the major source of added sweeteners in sweetened beverages.¹ ² There has been a 40% increase in HFCS consumption over the last 30 years, which is higher than any other food product.³ In the year 2000, 42% of added sugar in food products was in the form of HFCS. On an average day, 67% of adults and 4 in 5 adolescents consume SSBs in the United States.⁴ ⁵ A recent report presented at an American Heart Association meeting implicated 180,000 deaths/year to consumption of SSBs.⁶ The American Heart Association recommends consumption of no more than 450 calories/week from SSBs.⁷ SSBs and their impact on health have been extensively studied over the last 15 years. Consumption of SSBs has been shown to cause an increased risk of obesity, metabolic syndrome, type 2 diabetes mellitus, heart disease, gout, and kidney stones.⁷-¹¹ Recent meta-analyses have confirmed these findings by showing that SSBs are associated with a 26% increased risk of diabetes mellitus and a 20% increased risk of metabolic syndrome.⁷ ¹² To date, no systematic review has been done to summarize the studies that examined the effects of SSBs on blood pressure (BP). The objective of our review is to summarize the studies evaluating the relation between SSBs and BP.

Methods

We searched MEDLINE, MEDLINE In-Process and Other Non-Indexed Citations, EMBASE, Allied and Complementary Medicine Database, and PsycINFO to identify all the relevant studies up to August 2013. The detailed search strategy is explained in the Appendix. The keywords “sugar sweetened beverages,” “sugary drinks,” “added sugars,” “blood pressure,” and “hypertension” were indexed in all combinations for original reports and clinical studies including cross-sectional studies, observational studies, clinical trial studies, and reviews. These reports were evaluated against an a priori inclusion and exclusion criteria. Additionally, we checked reference lists of other published reviews and relevant reports to identify any additional studies. We limited our search to “human studies” and “English language articles.” Two independent reviewers examined titles, abstracts, and full reports for eligibility. We resolved discrepancies by mutual discussion and consensus.

All the studies that measured and reported the effects of SSBs on BP or on the incidence of hypertension were included. We looked at studies involving subjects aged ≥12 years. We excluded studies that did not specifically mention the effects of SSBs on BP, studies involving children aged <12 years, and studies with <100 participants.⁷ ¹² ²¹ We extracted the details on study design and methods, sample size, beverage category, and final outcome on BP. Quality assessment of the studies was conducted by 2 independent reviewers using the Newcastle-Ottawa Scale for observational studies as a guide.²² The quality of the studies

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was further evaluated for selection, attrition, performance, detection, and reporting biases. A final quality grade from A to C was assigned to each study. We resolved discrepancies in quality rating grades by discussion and mutual consensus.

Results

We identified a total of 918 reports in electronic databases. A manual search performed through the reference lists of relevant reviews and reports yielded 7 additional studies. Detailed schema is explained in preferred reporting items for systematic reviews and meta-analyses diagram (Figure 1). After deduplication and title and abstract screening of 605 reports, we retrieved 21 potential full-text reports for in-depth evaluation. On full-text review 9 of these articles were excluded for various reasons as mentioned in Figure 1.

The final 12 studies consisted of 6 cross-sectional and 6 prospective analyses of observational cohort studies. None of the studies showed a beneficial effect on BP from SSB consumption. In this review, 10 of the 12 studies showed a positive relation between increased SSB intake and high BP. The other 2 studies, although showing a positive trend, failed to show an association at a statistical level. These effects are illustrated in Figures 2 and 3. Figure 2 depicts 7 studies that show that increased consumption of SSBs is associated with higher odds of increased incidence of hypertension. Figure 3 illustrates 5 studies showing an average increase in systolic blood pressure (SBP) with increased SSB consumption.

Table 1 summarizes the cross-sectional studies showing association between SSBs and hypertension. The overall relation between consumption of SSB and BP is positive. All 6 studies employed interviewer-administered recall-based structured food frequency questionnaires for dietary assessment. Three studies reported that the odds of becoming hypertensive range from 26% to 70% with increased consumption of SSBs.23–25 The other 3 studies reported increase in the mean BP. They found 0.16- to 1.6-mm Hg increase in mean SBP with increased SSB intake.26–28 Four of 6 studies involved the US population, as they were based on the National Health and Nutrition Examination Survey (NHANES).23,25–27 Cross-sectional analysis of these surveys showed a positive association of SSB intake with incident hypertension. Nguyen
et al26 in 2009 and Kim et al25 in 2012 used NHANES data from different years (1999 to 2004 and 2003 to 2006) for different age groups, 12 to 18 years and ≥19 years, respectively, and came to similar conclusions. In a multivariate model of a relatively younger cohort, Kim et al25 concluded that adolescents who consumed SSBs ≥3 times/day had an 87% increased risk of becoming hypertensive. Nguyen et al26 reported a mean increase of 0.17 mm Hg of SBP in subjects who consumed >36 fl oz of SSBs per day. Similarly, Jalal et al23 in 2010 and Bremer et al27 in 2009 used the exact same NHANES data as previously was done by Nguyen et al26 and Kim et al,25 respectively. In addition, they added 1 extra year in their inclusion criteria. They used ≥18 years instead of ≥19 years for NHANES 1999 to 2004 and 12 to 19 years instead of 12 to 18 years for NHANES 2003 to 2006. As expected, Jalal et al23 concluded that consumption of 2.5 sugary soft drinks per day is independently associated with a higher risk of having increased SBP, whereas Bremer et al27 showed that each additional SSB serving (8 fl oz) resulted in an increase in SBP of 0.16 mm Hg (p <0.05). Later, the multicenter International Study of Macro and Micronutrients and Blood Pressure (INTERMAP) study confirmed these findings by showing that increased SSB intake of 1 serving (12 fl oz) was associated with 1.6-mm Hg increase in SBP.28

Table 2 summarizes the prospective studies showing association of SSB intake and incidence of hypertension. Five of 6 cohort studies represented the US population, and 1 prospective analysis was performed in Australia. Dietary assessment was performed by way of food frequency questionnaires implemented at various times during the studies. There was an overall positive trend of having higher BP with increased intake of SSBs. Two studies reported mean BP difference and showed 1.8- and 1.9-mm Hg increases in average SBP with increased consumption of SSBs (>1 serving/day).29,30 This is in conformity with the conclusion by the INTERMAP study investigators. Three studies of 6 reported an increase in the incidence of hypertension with increased consumption of SSBs, with an odds ratio range of 1.13 to 1.6.31–33 The only conflicting data come from a study by Ambrosini et al.30 of a much younger cohort, which showed no difference in BP after multivariate adjustment. Moreover, Dhingra et al31 in their Framingham Offspring Study also showed only a marginal increase in the incidence of hypertension with >1 serving/day of a 12-fl oz SSB.
The most noteworthy positive evidence in a prospective study comes from Chen et al. who, in an 18-month long, multi-center, behavioral, randomized controlled trial, showed a reduction of 1.8 mm Hg of SBP and 1.1 mm Hg of diastolic BP by reducing 0.9 servings/day (10.5 fl oz) of SSBs. The results attribute SSBs to be responsible for a 6% increase in the risk of hypertension; Cohen et al. displayed a 6% to 20% increase in the incidence of hypertension per 12 fl oz of SSBs. Similarly, Winkelmayer et al. showed 28% to 44% increased risk of developing hypertension with increased SSB intake. The age range of these cohorts was 14 to 75 years with the length of follow-up spanning 18 months to 38 years. This suggests that positive association between increased SSB intake and hypertension is independent of age and becomes significantly greater after 18 months of increased consumption of SSBs.

**Discussion**

Overall, none of the studies showed a beneficial effect on BP from SSB consumption. In general, even by the most conservative estimate, intake of >12 fl oz of SSB per day can increase the risk of having hypertension by at least 6%, and it can increase mean SBP by a minimum of 1.8 mm Hg in roughly over 18 months. This can be very significant at a population level. In the past, a modest reduction in SBP at a population level has been proven to translate into substantial reductions in deaths from stroke and coronary heart disease. On average, a 2-mm Hg reduction in SBP is expected to reduce deaths from stroke by 10%, whereas a similar reduction in diastolic BP may...
account for a 17% reduction in prevalence of hypertension, 6% reduction in coronary heart disease, and a 15% reduction in stroke.45,11,35–38 The results from the PREMIER study showed that the reduction in BP was found not only in the normotensive but also in the hypertensive population. Consequently, these results are generalizable to the adult population, including diseased, prehypertensive, and normotensive subjects. Three studies by Ambrosini et al,30 Bremer et al,27 and Nguyen et al26 evaluated effects of SSBs on adolescent population aged 12 to 18 years. They showed a much reduced effect on BP compared with the studies done in older population. This may be because effects on vessels could be different during adolescence.

Generally, the NHANES and Nurses’ Health Study (NHS) cohorts used in this analysis are relatively large and the main benefit of using these cohorts is that they are representative of a large community, and, therefore, the results are generalizable to a much larger adult population. Also, most studies adjusted for potential confounders in their analyses, including demographics and lifestyle factors. Additionally, to counter a long follow-up period and potential change of diet in such periods, most studies conducted the dietary assessment every 2 years.

SSBs in the United States often contain HFCS, which in the past has been implicated in high BP. It is primarily thought to cause obesity and metabolic syndrome and secondarily can raise BP.39 The most widely known mechanism for HFCS to cause high BP involves an increase in uric acid production, which in turn results in lowering of nitric oxide in the body. A small study showed that consumption of >500 ml/day of HFCS-containing beverages confers 2 times increased risk of developing hyperuricemia.40 Nitric oxide is a vasodilator and its relative reduction can result in high BP.41–44 Other theories behind high SSB intake being implicated in hypertension involve decreased sodium excretion or activation of the sympathetic nervous system.45,46 Additionally, it can also increase the sodium concentration in the body through increased gut absorption.47 Another theory involves a model based on fluid entrapment in the small bowel, leading to sodium retention.48 It has been shown previously that unhealthy lifestyle behaviors and increased sugar consumption go hand in hand with increased salt consumption, and that this in effect can lead to higher BP.49,50 These findings are validated by a recent study by Grimes et al,51 which showed that 17 grams of increased SSB intake is associated with each additional gram of salt intake in 1 day. A recent study of middle-aged twins by Eufinger et al52 showed reduction in coronary flow reserve with increased consumption of SSBs. This could be an interesting finding for future studies evaluating the effects of SSBs on cardiovascular morbidity and mortality. Another study by Sanchez-Lozada et al42 showed that fructose can cause metabolic syndrome through renal hypertrophy, glomerular hypertension, and cortical vasoconstriction. Furthermore, a randomized controlled trial of a low-fructose diet resulted in reduction in BP and inflammation in patients with chronic kidney disease, whereas another randomized controlled trial showed that fructose can raise BP acutely.19,53 In another independent study of 59,334 Danish pregnant women, artificially sweetened carbonated and noncarbonated soft drinks of >1 serving/day increased the risk of preterm delivery by 38% and 20%, respectively.49 Higher preterm deliveries in this study were driven by medically induced deliveries, which suggests that these deliveries might have been due to hypertensive disorders and endothelial dysfunctions associated with them, hence linking HFCS intake and hypertension. Further evidence comes from a Norwegian study showing increased risk of eclampsia with maternal SSB intake.55 In 2009, Forman et al13 used cohorts of NHS I and II and Health Professionals Follow-up Study and failed to show an association between total fructose intake and hypertension. This could be explained by the fact that they calculated total fructose intake, and most of the fructose intake was in the natural form of fruits. This argument is strengthened by the fact that the same cohort produced significant association with hypertension when fructose content from natural fruits was excluded from analysis.

It remains unclear at what dose increased SSB intake leads to development of hypertension. On the basis of these studies, although, there is a suggestion that intake of >1 serving of SSB per day is associated with higher risk of hypertension. A study by the Harvard School of Public Health showed that SSBs account for 25,000 deaths/year, which is equivalent to 8.1/100,000 deaths, in the United States.1 This is higher than the death rate attributed to homicide, AIDS, alcohol, drug use, and certain cancers (leukemia, cervical cancer, skin cancer, and so forth), individually. Most of these deaths due to SSB are reported in a much younger population (<45 years), which is considered to be the most productive age group.6,56 This leads us to the conclusion that persistent long-term consumption of SSBs might lead to the development of hypertension and eventual cardiovascular events.

The major limitations of this review are a lack of randomization and the observational nature of included studies. We cannot link causality on basis of these observations, although they are highly suggestive of the risk. Despite controlling for confounders, there is a potential for residual confounding. It is plausible that subjects who drink more SSBs are less cognizant of their health status and therefore are involved in lifestyle and other dietary practices that may increase their BP.57 Additionally, most of the prospective cohort studies used validated semiquantitative food frequency questionnaires to assess dietary intake. Although it is a valuable tool for observational studies, these recall-based dietary assessment methods are often unreliable and prone to bias.58 However, the errors created because of these somewhat inaccurate questionnaires are likely to be nondifferential, thus driving the bias toward the null. Moreover, subjects tend to underreport unhealthy behaviors, which in fact might diminish the observed effect of SSBs on BP, rendering these results more valid.59 Finally, we should bear in mind the risk of publication bias, as these large studies showing significant findings are more likely to get published.

Disclosures

The authors have no conflicts of interest to disclose.

Supplementary Data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.amjcard.2014.01.437.


