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Soft drink consumption: Do we know what we drink and its implication on health?

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Abstract.
BACKGROUND: Intake of sugar sweetened beverages has been consistently linked to increased risk of obesity, type 2 diabetes, osteoporosis and cardiovascular disease, among other diseases. Putative underlying mechanisms include incomplete compensation for liquid calories, adverse glycemic effects, and increased hepatic metabolism of fructose leading to *de novo* lipogenesis, production of uric acid, and accumulation of visceral and ectopic fat.
OBJECTIVE: This study aims to elucidate any existing link between energy-containing liquids, as consumed in various forms within the diet, and the effect they may have on body weight or other diseases; and whether soft drink consumption displaces water consumption.
METHODS: A self-administered online survey was conducted in 2496 participants from different countries, in six languages (Spanish, English, Chinese, French, German and Portuguese). Questions referred to their soft drink and water consumption habits, physical exercise performed, presence or absence of certain diseases and medication.
RESULTS: There is statistically significant difference ($p < 0.001$) in BMI and consumption of cola per week: those who consumed 0–3 cans a week have a lower BMI than those who consume >7 cans of cola a week. Statistically significant difference ($p = 0.02$) was found when consuming soft drinks different from cola. There is greater presence of obesity ($p < 0.001$), gastritis ($p < 0.001$), constipation ($p < 0.001$) and mental illness ($p = 0.003$) among people who drink cola soft drinks.
CONCLUSION: Removal of energy-containing beverages from our diet may be an appropriate public health message to support those interested in preventing weight gain as well as other diseases.

Keywords: Sugar-sweetened beverages, hydration, obesity, disease

1. Introduction

Energy-containing beverages have been increasing as a percentage of the westernized diet over the past 20 years, and have contributed significantly to an increase in energy consumed in liquid form [1]. They appear in wide ranging formats including alcoholic beverages, "soft" or "fizzy" beverages or fruit juices with added sugar

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(sugar-sweetened beverages, SSB), diet drinks, energy drinks, sports and isotonic drinks and tea/coffee-based sugary drinks.

One of the two nutritive beverages formats that are of particular interest and relevance to the control of body weight are the SSB [1], which are the focus of this study. The other is the alcoholic beverages, which are not our aim.

The SSB are commonly consumed by both adults and children, many of which represent major marketing brands. Notably SSB consumption globally continues to rise as shown in a recent cross-national analysis of 75 countries [2], from 36 litres (L) per person per year in 1997 to 43L in 2010.

In 2014 WHO proposed a reduction in their 2002 recommendation, which was to maintain intake of free sugars below 10 percent of total energy and which had been shown to be well substantiated in a recent systematic review [3], with a more ambitious "ideal" target of 5% from free sugars. This would be equivalent to 25 g/day for women and 35 g/day for men within a typical 1900 Kcal and 2600 Kcal diet respectively.

The issue that is key is whether high SSB consumers add these energy containing beverages into their diet (energy addition) rather than balancing intake with a parallel decrease in other food and/or beverages. Without energy compensation, high intake of SSBs would be expected to drive a positive energy balance and so promote weight gain [1].

Negative health effects of SSB have not only been linked with obesity, but also with diabetes and metabolic syndrome [4, 5]. The consumption of >5 servings/week of all of the types of beverages analyzed in the PREDIMED study was associated with an increased risk of metabolic syndrome and some of its components. Findings from a meta-analysis of prospective cohort studies found that individuals consuming 1–2 servings of SSB each day had a 26 % greater risk of developing type 2 diabetes than those with no or very low consumption [6].

Soft drink overconsumption is also considered to be a major public health concern with implications for cardiovascular diseases. This follows a number of studies performed both in animals and humans suggesting that chronic consumption of refined sugars, especially fructose, can contribute to cardiovascular dysregulation, and the onset of arterial hypertension [7, 8]. Very high fructose consumption have been associated with increased triglyceride levels, visceral fat, blood pressure, resistance to the hypoglycemic action of insulin, and decreased levels of HDL-cholesterol. These variations, individually and together, have been associated with an increased risk of cardiovascular disease [9].

Accumulating evidence on the mental effects has also entered public health discussions. Sodium benzoate, a common antimicrobial agent used in popular beverages for preservation purposes [10], has recently been linked to attention deficit hyperactivity disorder (ADHD). Subjects presenting ADHD report higher intakes of beverages containing benzoates, which are mainly artificially fruit-flavoured carbonated beverages, teas, Italian sodas, coffee drinks containing syrups and other popular sodas, particularly diet brands [11]. In several cross-sectional studies, frequent drinking of sweetened beverages is also associated with higher prevalence of depression, suicidal thoughts and acts, and other mental stress [12].

Caffeine contained in sweet beverages pull more water out of your body than they provide [13]. Caffeine, along with artificial sugar, can aggravate the digestive system causing inflammation, dehydration or an imbalance in good bacteria [14]. However, constipated individuals report lower consumption of sweetened, carbonated and non-carbonated beverages [15].

2. Aim

This topic is of high public health importance because the exposure and the outcome are highly prevalent. Therefore, the present paper attempts to detect whether soft drink consumption displaces water consumption in a representative population sample. Also, determine any association between increased sugary drinks consumption and body weight and adiposity, or other diseases.

3. Methods

3.1. Design

Cross-sectional study.

3.2. Sample size

A total of 2496 subjects aged 13–94 years were randomly recruited. They were facilitated, through an online platform, a self-administered survey. Therefore a simple, quick survey to answer (less than 5 min), on issues related to soft drink consumption was designed. Participation involved answering a questionnaire of specific and easy questions about the consumption of cola or sugary drinks, physical activity performed and related diseases.

3.3. Inclusion criteria

- Men and women, ages 13–94 years old
- Sufficient level of understanding to conceive their participation in the study
- Acceptance and voluntary participation.

3.4. Exclusion criteria

Participants who did not complete questionnaires correctly.

3.5. Variables and study factors

The survey was translated, by native and bilingual professionals, into six languages: Spanish, Chinese, English, French, German and Portuguese. Subjects from several different countries participated in the study: Germany, Austria, Belgium, Bulgaria, Rumania, Croatia, Spain, France, Italy, Portugal, Switzerland, Morocco, Argentina, Bolivia, Brazil, Colombia, Ecuador, Peru, Uruguay, Venezuela, Mexico, Guatemala, Honduras, El Salvador, Costa Rica, Nicaragua, Dominican Republic, Canada, EEUU, Philippines, China and Taiwan.

The questionnaire was designed to investigate about the consumption of sugary drinks and their relationship with the development of impact diseases.

The following information on demographics factors was collected: age, sex, country of residence and of birth, and level of education. Height and weight were specified as anthropometric data. BMI was calculated from body weight and height with the Quetelet index [16]. In order to establish overweight and obesity cut offs, the BMI values were compared to the established by the Spanish Society for the Study of Obesity or according to the World Health Organization [17].

The type, days and time a week of physical activity performed was included as part of habits factors.

Data on which type of soft drinks (sugary, zero/light, none) and how often (never, monthly, weekly or daily) did they usually consume them and in which quantity (in millilitres), was also compiled. The duration of the consumption was also asked. The questionnaire items on beverages included: cola soft drinks, other sugary drinks, besides cola (lemon and orange drinks, soda, industrial juices, sport drinks and tea-based sugary drinks) and water. The questionnaire was an adaption of the Beverage Intake Questionnaire from Hedrick et al. [18]. Finally, participants were asked to select, from a drop-down list, which diseases do they suffer and if they are on medication for any of them. Diseases included in the drop-down list were: overweight or obesity, cardiovascular disease, diabetes type I or type II, cancer, osteoporosis, osteopenia, bone problems; arthrosis, arthritis or rheumatoid disease, asthma, chronic hay fever, food allergy; gastritis, heartburn, reflux; flatulence, bad digestion, belching; diarrhoea; constipation (1 deposition each 3 days or more), allergy to pollen, pet hair, dust, fungus, humidity, mites, etc.; erosion of the enamel of the teeth, caries, gingivitis; bipolar, schizophrenia, ADHD, obsessive-compulsive disorder, bulimia, anorexia, anxiety, depression . . .

3.6. Statistical analysis

Questionnaire responses were analysed using the Statistical Package for the Social Sciences (SPSS) version 21. Frequency, percentage and other descriptive statistics were used to describe and summarise data.

Parametric statistical tests, such as t-student, ANOVA and non-parametric, were used to analyze the differences between the means of two groups of quantitative variables, with a p value <0.05 considered significant and a 95% confidence interval. Levene's test was used to assess the assumption that variances of the populations from which different samples are drawn are equal or parametric.

4. Results

4.1. Response rate

A total of 2496 surveys were returned. All surveys were eligible for inclusion in the study. Of total participants, 833 were men and 1659 women, with a mean age of 35.37 ± 14.26 years. The baseline characteristics of participants are summarized in Table 1.

Results obtained from items related to sugar-sweetened beverages and water consumption are presented in Table 2. There was no difference in results in subjects of different countries.

There is a negative correlation between variables 'drinking water' and 'consumption of cola soft drinks' (Spearman correlation –0.79, $p = 0.01$). The more cola soft drinks are consumed; less water is drunk and vice versa. Comparing all soft drinks (sugary or sugar free cola and others) with water consumption, there is a poor negative correlation, and a regression of –0.36, not statistically significant $p = 0.69$.

There is statistically significant difference ($p < 0.001$) in BMI, between those who consume 0–3 cans of cola per week and those consuming 4–6 and >7 cans/week. However, there is no difference between those who consume 4–6 and >7 cans/week. Therefore, those who consumed 0–3 cans a week have a lower BMI than those

Table 1
Descriptive statistics of the participants

	Total ($n = 2496$) Mean ± SD	Males ($n = 833$) Mean ± SD	Females ($n = 1659$) Mean ± SD
Age (years)	35.37 ± 14.26	35.33 ± 14.55	35.42 ± 14.12
Weight (kg)	67.69 ± 15.34	77.66 ± 12.67	62.72 ± 14.08
Height (cm)	166.94 ± 9.21	175.18 ± 7.33	162.79 ± 7
BMI (Kg/m^2)	24.18 ± 4.72	25.41 ± 4.69	23.56 ± 4.61
Physical activity (days/week)	1.98 ± 1.59	1.75 ± 1.55	2.04 ± 1.61
Physical activity (hours/week)	2.38 ± 2.5	2.03 ± 1.91	2.47 ± 2.6
	N (%)	N (%)	N (%)
Study level			
– No studies	2 (0.1)	0	2 (0.1)
– Primary studies	674 (27)	261 (31.3)	412 (24.8)
– Secondary studies	1454 (58.3)	460 (55.2)	991 (59.7)
– Tertiary studies	365 (14.6)	111 (13.3)	254 (15.3)

Table 2
Consumption of water, cola and/or sugary drinks

	Total ($n = 2496$) Mean ± SD	Males ($n = 833$) Mean ± SD	Females ($n = 1659$) Mean ± SD
Water (ml/day)	1437.43 ± 1337.3	1511.28 ± 1096.96	1399 ± 1442.93
Cola soft drinks (ml/day)	238.98 ± 406.29	252.54 ± 416.97	232.77 ± 401.13
Cola soft drinks (cans/week)	1.96 ± 5.37	1.9 ± 5.01	2 ± 5.55
Soft drinks, different from cola* (ml/day)	175.71 ± 877.65	189.62 ± 919.37	169.13 ± 857.14
Soft drinks, different from cola* (cans/week)	0.81 ± 2.78	0.85 ± 2.52	0.79 ± 2.9
Duration of consumption (years)			
– Cola soft drinks	14.57 ± 11.87	16.54 ± 12.53	13.76 ± 11.49
– Soft drinks, different from cola*	12.35 ± 23.57	15.08 ± 34.25	11.21 ± 17.13
	N (%)	N (%)	N (%)
Cola soft drinks			
Cans/week			
– 0–3 cans	2113 (85.9)	724 (88.8)	1385 (84.3)
– 4–6 cans	60 (2.4)	12 (1.5)	48 (2.9)
– ≥7 cans	288 (11.7)	79 (9.7)	209 (12.7)
Type			
– No consumption	1429 (57.3)	469 (56.3)	956 (57.6)
– Sugar-sweetened	561 (22.5)	230 (27.6)	331 (20)
– Zero/Light	506 (20.3)	134 (16.1)	372 (22.4)
Frequency of consumption			
– Never	1261 (50.5)	426 (51.1)	831 (50.1)
– Monthly	405 (16.2)	92 (11)	313 (18.9)
– Weekly	454 (18.2)	157 (18.8)	297 (17.9)
– Daily	376 (15.1)	158 (19)	218 (13.1)
*Sugary drinks, besides cola**			
Cans/week			
– 0–3 cans	2320 (93.6)	776 (94.3)	1540 (93.3)
– 4–6 cans	55 (2.2)	22 (2.7)	33 (2)
– ≥7 cans	103 (4.2)	25 (3)	78 (4.7)
Type			
– No consumption	1631 (65.3)	559 (67.1)	1068 (64.4)
– Sugar-sweetened	622 (24.9)	213 (25.6)	409 (24.7)
– Zero/Light	243 (9.7)	61 (7.3)	182 (11)
Frequency of consumption			
– Never	1593 (63.8)	549 (65.9)	1040 (62.7)
– Monthly	416 (16.7)	115 (13.8)	301 (18.1)
– Weekly	317 (12.7)	101 (12.1)	216 (13)
– Daily	170 (6.8)	68 (8.2)	102 (6.1)

*Lemon and orange drinks, soda, industrial juices, sport drinks, tea-based sugary drinks.

who consume >7 cans of cola a week. There is also statistically significant difference between the duration of the consumption of cola soft drinks ($p < 0.001$) and BMI.

Same analysis was made with soft drinks, different from cola. P-value = 0.02, so there were statistically significant differences between BMI of drinkers of soft drinks different from cola, depending on the number of cans consumed weekly. *Post-hoc* analysis differs between cola soft drinks and soft drinks different from cola. There are statistically significant differences between those taking 3 or less cans a week and those who take more than 6; however, no differences were found between these two groups and those who consumed 4–6 cans/week. Therefore, BMI is lower among those who consumed 0–3 cans weekly of soft drinks different from cola, than those consuming >7 cans/week. There is also statistically significant difference between the duration of the consumption of soft drinks, different from cola ($p = 0.001$) and BMI.

Chi-square was performed to evaluate if there is greater presence of disease among people who drink more cola soft drinks. Same groups, dividing people for their weekly cans consumption, were used. The only diseases which showed a p-value <0.05 were gastritis ($p < 0.001$), constipation ($p < 0.001$) and mental illness ($p = 0.003$), so the number of people with these 4 diseases was different than expected. On the contrary, no statistically significant differences ($p > 0.05$) were observed for cardiovascular disease, diabetes type I and II, cancer, osteoporosis, arthritis or rheumatoid disease, asthma or chronic hay fever, food allergy, flatulence, diarrhoea, allergy to pollen or similar and teeth-enamel erosion or gingivitis.

5. Discussion

5.1. SSB and weight gain

The controversy as to whether there is a causal role between high consumption of energy-containing SSB and high rates of weight gain and obesity has been rigorously debated over several decades. Support for an association between the two comes from large observational studies [19], but demonstrating causation, a step which arguably is required in order to provide sufficient strength of evidence to promote major national and international public policy initiatives, has been more difficult and the debate remains ongoing. Further controversy is leant to the topic through widespread discussion as to the role that the beverage industry may have played in building the scientific evidence [20] and whether this should be of concern to the scientific community [21].

In our attempt to detect whether soft drink consumption displaced water consumption, we observed such association. The higher consumption of SSB, less water was drunk. In Fresan et al. [22] study replacing one sugar-sweetened soda beverage with one serving of water per day at baseline was related to a lower incidence of obesity.

A cross-national study of 75 countries found that each 1% rise in soft drink consumption was associated with an additional 4.8% overweight adults and 2.3% cases of obesity [2]. There is some evidence that we may regulate badly, at least in the short-term, when faced with “liquid energy/calories” such that energy-containing beverages may evoke weaker appetite and compensatory dietary responses than solid food [23]. Hence they may increase total intake when added “ad libitum” into a typical diet [24].

A meta-analysis of available longitudinal data indicates that children consuming one SSB each day are 55% more likely to be overweight compared to those with limited consumption [3]. A longitudinal study of 548 school children, showed that with each 200 ml/day of SSB consumed increases 1.6 times the risk of obesity and BMI by 0.24 kg/m2. Another prospective study of 19 months, 548 school children indicated that for each serving of SSB there was an increase of 0.18 kg/m2 in BMI [25].

Malik et al. [26] concluded that one additional serve of SSB was associated with a 0.05–0.06 unit increase in BMI in children and 0.12–0.22 kg additional weight gain in adults, as assessed over a one year period. Mattes et al. [27] conducted a meta-analysis of randomised clinical trials in which it was shown that the addition of SSBs in the form of soft drinks caused a dose-dependent increase in weight gain. Removing SSBs from the diet of overweight individuals was shown to prevent further weight gain and/or promote greater weight loss than their lean counterparts.

In regard to our results, they show similar findings. Increasing BMI is directly proportional to the number of cans of soda consumed per week. Those who consumed 0–3 cans/week had a lower BMI than those who consumed >7 cans/week.

Even more recent evidence in the SUN Cohort suggests that replacing 1 glass of SSB by 1 glass (200 ml) of water per day was associated with a lower incidence of new obesity cases (OR 0.85; 95% CI 0.75–0.97) [22]. The portion size also matters: when the amount of SSB intake is analysed, it has been seen a positive correlation between overweight and a larger consumption of soft drinks. Over a 14-years follow-up cohort of 6947 young African women, a higher frequency of SSBs intake was associated with an increased obesity incidence as well [28]. These are not isolated examples: Tucker et al. also found in a 4-year follow-up study that US healthy women that consumed SSBs gained significantly more weight (2.68 ± 5.14 kg) than those who consumed artificially-sweetened drinks (-0.05 ± 4.40 kg) or no soft drinks (0.50 ± 5.05 kg) [29].

In a meta-analysis of 3 different cohorts in Denmark ($n = 4765$), when looking for interactions between soft drinks intake and a genetic predisposition to obesity, a significant link between an annual weight gain and SSBs intake was found [30].

Thus, the results of our study are consistent with a plausible physiological mechanism, that consumption of sugar-sweetened drinks could lead to obesity because of imprecise and incomplete compensation for energy consumed in liquid form.

Notable in the absence of a relationship has been the large NHANES data set in more than 38,000 US adults aged 20–74 years, where no significantly association between obesity risk and SSB consumption pattern has been found, such that those who reported frequently consuming SSB did not have either a higher BMI or greater obesity rates than those who were self reported infrequent consumers [31].

5.2. SSB and diabetes mellitus

In case of type 2 diabetes, consumption of sugary drinks (>336 ml) was associated with an increased risk of DM2 OR = 1.52 (95% CI 1.26 to 1.83), adjusting for energy intake and BMI [32]. Moreover Fagherazzi et al. [33] showed, on Italian women, that consumption of >359 ml of SSB presented a HR 1.34 (95% CI 1.05 to 1.71) to increased risk of type 2 diabetes. A similar situation was observed in the study cohort ($n = 40,389$ men) by Koning et al. [34], in which the consumption of sugary drinks >1 serving/day presents a risk (Hazard Ratio) of 1.67 (95% CI: 1.31–2.13).

A longitudinal study that followed over 8 years 91,249 women, those who consumed ≥1 serving/day of SSB, had twice as likely as those who consumed <1 serving per month of SSB of developing diabetes [35]. Malik et al. [18] in another recent meta-analysis indicated that the consumption of 334 ml/day of SSB was associated with an increased risk of diabetes RR = 1.25 (95% CI 1.10 to 1.42). No such results were found in our analysis.

5.3. SSB and metabolic syndrome and cardiovascular disease

There is increasing evidence that higher SSB consumption increases cardiovascular risk by contributing to the development of hypertension, dyslipidemia, inflammation, coronary heart disease, and stroke [36].

In over 88,000 women in the Nurses' Health Study followed for 24 years, it was found that those who consumed ≥2 servings/day of SSBs had a 35% greater risk of coronary heart disease compared with infrequent consumers [37]. Additional adjustment for potential mediating factors (including BMI, total energy intake, and incident diabetes) attenuated the association, but it remained statistically significant, suggesting that the effect of SSBs may not be entirely mediated by these factors.

Recent evidence has also emerged linking intake of SSBs to increased risk of stroke. Among 84,085 women and 43,371 men in the Harvard cohorts followed for 28 and 22 years, respectively, ≥1 SSB serving/day was associated with a 16% increased risk of total stroke compared with no servings [38].

Velasquez-Melendez et al. [39] also found a correlation between a higher intake of SSBs and a higher risk of metabolic syndrome (OR 1.95; 95%CI 1.60–2.38), almost doubling the risk compared with nonconsumers, even after adjustment for physical activity and other toxic habits. Our results did not find association between SSB an increased risk of cardiovascular disease.

5.4. SSB and osteoporosis

A cross-sectional study in Mexico with 328 women of reproductive age associated SSB consumption with the risk of osteopenia or osteoporosis OR = 11,186 (95% CI 5.7 to 21.6; $p = 0.001$).

Cross-sectional studies in children and adolescents have associated the consumption of SSB with low bone mineral density (BMD).

Tucker et al. evaluated 1413 women from the Framingham Osteoporosis Study, indicating that colas are associated with low BMD (adjusted for confounding variables such as low intake calcium) and that caffeine decreases liable BMD. Caffeine and phosphoric acid present in colas increases urinary calcium; high in phosphorus and low in calcium diets lead to complexes reduce serum calcium, the stimulation of parathyroid hormone (PTH), which causes bone resorption [40]. However it has been suggested that the amount of phosphoric acid present in colas is insufficient to cause this imbalance [35].

Our results did not find association between SSB an increased risk of osteoporosis.

Of course, observational data such as ours can provide evidence only of an association and says nothing of causation.

How strong is this evidence [41], and if there is a causative relationship with SSB, whether this may be a consequence of the sweet nature of sugary carbohydrate beverages, the high energy content, or simply the food form remains under debate [42].

5.5. Limitations

There are several limitations to the interpretation of our findings. First, our study was observational in nature and cannot prove causality. Although we attempted to control for the effects of the major identified predictors of obesity, sugar-sweetened drink consumption could be a marker for unrecognised factors that affect body weight. Second, for logistical reasons, we used indirect measures of obesity (BMI). Although this measure is in widespread use, and provide a good estimate of adiposity in children, we cannot fully control for changes in body composition over time, resulting, for example, from puberty or fitness training.

The study was not specifically designed with a nutrition focus and it remains possible that there are other important elements of diet which we have not been able to control for.

6. Conclusion

In our study an association between consumers of soda and obesity and gastritis, constipation and mental illness was observed. Soft drinks consumers could displace water consumption. The role that energy-containing beverages may play in the development of overweight and obesity remains highly controversial; nevertheless studies suggest that it is an important point to improve as a public health measure. Longer-term randomized clinical trials which have introduced or removed SSB within the diet tend to support this causative relationship with weight gain, but certainly not all studies do.

Conflict of interests and source of funding

The authors have disclosed that they have no significant relationships with, or financial interest in, any commercial companies pertaining to this article.

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