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Sweetened beverage consumption and risk of cardiovascular mortality: A systematic review and meta-analysis

Akshaya Srikanth Bhagavathula [a], Jamal Rahmani [b], Kota Vidyasagar [c], Wubshet Tesfaye [d], Jagdish Khubchandani [e,*]

[a] Department of Social and Clinical Pharmacy, Faculty of Pharmacy at Hradec Kralove, Charles University, Hradec Kralove, Czech Republic
[b] Department of Community Nutrition, Student Research Committee, Faculty of Nutrition and Food Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[c] Department of Pharmaceutical Sciences, University College of Pharmaceutical Sciences, Hanamkonda 506009, Telangana, India
[d] Health Research Institute, University of Canberra, Canberra, Australian Capital Territory, Australia
[e] Department of Public Health Sciences, College of Health and Social Services, New Mexico State University, Las Cruces, NM, 88003, USA

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ABSTRACT

Background and aims: Several studies have reported the association of sweetened beverages (SB) with cardiovascular disease. However, the relationship between SB and cardiovascular mortality has not been clearly established. This systematic review and meta-analysis investigated the association between SB consumption and cardiovascular mortality.
Methods: PubMed/MEDLINE, Web of Science, and Embase were systematically searched up to July 31, 2021, for prospective cohort studies investigating this association in adults. Pooled relative risks (RRs) and 95% confidence intervals (CIs) were used to assess the strength of association between SB: sugar-sweetened beverages (SSB)/artificial-sweetened beverages (ASB) exposure and cardiovascular mortality.
Results: A total of eight cohort studies comprising 1.2 million participants exposed to SB, reported 15,831 (1.2%) cases of cardiovascular mortality with a median follow-up of 12.2 years. Consuming at least one glass (250 ml) of SB per day (RR: 1.06; 95% CI: 1.00−1.12, $P < 0.001$) or ≥2 glasses per day (RR: 1.24; 95% CI: 1.16−1.31, $P < 0.001$) was significantly associated with increased risk of cardiovascular mortality. SSB and ASB intake of ≥2 glasses per day increased the risk of cardiovascular mortality by 21% (RR:1.21, 95% CI: 1.09−1.33, $P < 0.001$) and 33% (RR: 1.33, 95% CI: 1.12−1.55, $P < 0.001$), respectively.
Conclusions: Our findings reveal that high SSB and ASB consumption are associated with an increased risk of cardiovascular mortality. Policymakers and public health practitioners should work on multi-sectoral strategies to reduce the consumption of sweetened beverages around the world and among all population groups.

1. Introduction

The global non-alcoholic beverage market and consumption have exploded since the beginning of the 21st century. This market is expected to grow and cross USD 1 trillion in sales and consumption by the next decade, with high income countries dominating the per capita consumption rates [1,2]. Along with the growth in non-alcoholic beverage consumption, professional organizations, scholars, and public health advocacy groups have expressed profound concerns about the health effects of these beverages [3–5]. For example, sweetened beverages (SBs) have received wide attention for their strong association with obesity, resulting in public health actions, such as soda tax, calorie labels, and major awareness campaigns to reduce SB consumption [4–6]. Besides the strong evidence of the association between SB and weight gain, studies have also highlighted the risk of diabetes, metabolic syndrome, chronic kidney disease, stroke, and cardiovascular disease (CVD) with greater SB consumption [7–9]. Despite the plethora of research on the potential health impacts of SBs on health and wellbeing, there is little evidence on the association

* Corresponding author.
E-mail addresses: akshaypharmd@gmail.com (A.S. Bhagavathula), mojtaba.rah91@gmail.com (J. Rahmani), vidyasagarkota2@gmail.com (K. Vidyasagar), Wubshet.Tesfaye@canberra.edu.au (W. Tesfaye), jagdish@nmsu.edu (J. Khubchandani).

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between the consumption of SBs and the risk of cardiovascular mortality. In addition to the lack of studies, exposure measurement could pose challenges due to the variety of SBs available for the general public (e.g., artificial vs. low sugar vs. no sugar) [6,7]. Theoretically, it seems plausible that the adverse cardiovascular outcomes associated with SB consumption could impact life expectancy. However, the few reviews and meta-analyses conducted on this topic have not provided exhaustive information on the risk of CVD mortality associated with sugar-sweetened beverages (SSB) and artificial-sweetened beverages [10,11]. For instance, recent dose-response studies have focused mostly on the risk of all-cause mortality and cancer mortality (along with CVD mortality) w among consumers of SB and 100% fruit juice [10,11]. However, there is a dearth of evidence to show a consistent and robust association between SB consumption and cardiovascular mortality. Thus, the purpose of this study was to comprehensively assess and assimilate all evidence on SB consumption and cardiovascular mortality via a systematic review and meta-analysis.

2. Methods

2.1. Search strategy

This systematic review and meta-analysis were performed according to the Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) guidelines [12]. PubMed/MEDLINE, Web of Science, and Embase were systematically searched using a combination of MeSH and free-text terms for relevant prospective cohort studies published up to July 31, 2021. Detailed information of the search terms used to identify the articles is shown in Supplemental Table 1. Repeated hand searches were also conducted to examine references from relevant studies. All the references were stored in the EndNote library (version X9, for Windows, Thomson Reuters, Philadelphia, PA, USA), and duplicates were removed. The detailed steps of the literature search are depicted in Fig. 1.

2.2. Study selection criteria

Only studies with the following characteristics were included: (1) population-based prospective cohorts; (2) conducted among adult (≥18 years) population; (3) investigated the SBs consumption, such as sugar-sweetened beverages (SSB) and artificial-sweetened beverages (ASB), by Food Frequency Questionnaire (FFQs) or The Diet History Questionnaire (DHQs); (4) indicated a definite outcome for cardiovascular mortality; (5) evaluated the association between SB consumption and risk of cardiovascular mortality by the effect sizes of odds ratios (ORs), relative risks or risk ratios (RRs), or hazard ratios (HRs) with 95% confidence intervals (CI); (6) published in English. Daily consumption of at least one glass or serving (250 ml) of SB was considered the lowest-threshold and two or more glasses (serving) as the highest-threshold.

We excluded the following articles: (1) unrelated publications, duplicate studies, grey literature, including book chapters, letters, and commentaries; (2) in-vitro, animal, and cell culture studies; (3) review articles; (4) publications that did not meet the inclusion criteria based on the title or abstract and with irrelevant outcomes reported. If multiple articles based on the same cohort were published, we chose the one with more informative reporting. Four authors (ASB, JR, KVS, and WT) independently conducted the systematic literature search, screened the titles and abstracts, and performed a full-text review. Any potential disagreements during the review process were resolved by consensus with the senior author (JK).

2.3. Data Extraction & quality of evidence

The following data were extracted from the eligible studies: first author's details, year of publication, country, study design, the name of the cohort study, sample size, number of cases, follow-up years, assessment method, population characteristics (mean age and gender), measurement of SB consumption at baseline, number of cases with CVD, variables adjusted for analysis and outcome of interest with 95% CIs for the overall consumption of SB, SSB or ASB category. The Newcastle-Ottawa Scale (NOS) [13] was used to assess the overall quality of included studies (Supplementary Table 2). The NOS consists of three sections: selection, comparability, and outcomes. Each section was assigned a maximum of four, two, and three points, respectively. According to NOS, scores of 0–3, 4–6, and 7–9 indicated poor, fair, and high quality, respectively.

2.4. Statistical analysis

Pooled measures were calculated as the inverse variance-weighted mean of the logarithm of RR, with corresponding 95% CI, to assess the strength of association between SB exposure and cardiovascular mortality. The DeSirmonian and Laird random-effect model (REM) was adopted as the pooling method [14]. The data were pooled to calculate the effect size using the inverse-variance weighted (fixed effect) model when risk estimates were provided separately. However, we used the highest quartile of SB intake in the adjusted multivariate hazard models to describe the consumption of two or more glasses/day when the data were provided in quartiles. The potential sources of heterogeneity across the studies were explored using Cochran's Q test and I^2 statistics [15]. Heterogeneity between the studies was assessed using I^2 values of 0%, 25%, 50%, and 75%, representing no, low, moderate, and high heterogeneity, respectively. Subgroup analysis with the random-effect model was conducted on the following factors: median age (<55 or ≥55 years), continent (North America, Europe, or Asia), sample size (<100,000 or ≥100,000), method of assessment (FFQ or DHQ), years of follow-up (<10 years or ≥10 years), and the number of patients with CVD in the study population (<10,000 or ≥10,000). Publication bias was visually explored by funnel plots and confirmed statistically by Egger's weighted regression test and Begg's rank test [16]. All statistical analyses were performed using STATA software, version 16.1 MP (Stata Corp, College Station, Texas, USA). All reported probabilities (*P*-values) were two-sided, and a *P*-value of less than 0.05 was considered statistically significant.

3. Results

3.1. Characteristics of included studies

The search strategy identified 6042 records: 2225 from PubMed/MEDLINE, 536 from Web of Science, and 3281 from Embase. After eliminating duplicates and irrelevant records, eight unique prospective cohorts were included in the systematic review and meta-analysis [16–23]. The process of the literature search is shown in Fig. 1.

The characteristics of the eight included prospective cohort studies are shown in Table 1. Out of these studies, five studies were conducted in the United States [16–19,23], one each in Sweden [22] and Singapore [21], whereas one study [20] was conducted in 10 European countries. In total, 1,252,547 healthy adult subjects participated in these studies. There were more female than male participants, with one exclusively female cohort [19]. The mean age of the participants was 55.6 ± 6.77 years, and the median follow-up period was 12.2 years (range: 3–28 years). Dietary intakes were assessed by a validated FFQ and DHQ [16–23]. Six studies reported the exposure of SB (both SSB and ASB) [17,18,20–23], and one each

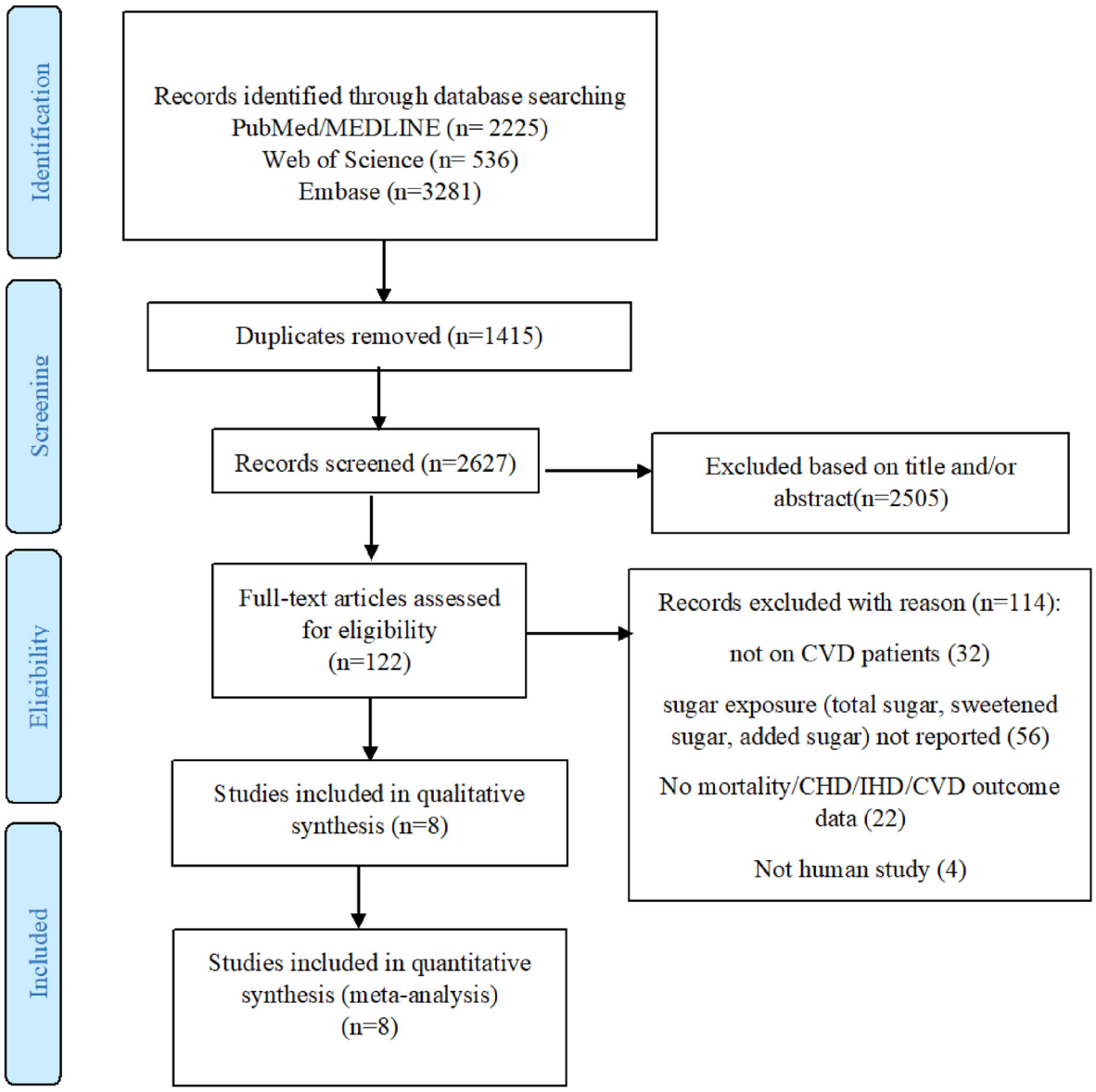

Fig. 1. Flow chart of studies included.

evaluated exclusively on SSB [16] and ASB [19]. All studies adjusted for at least four of the important primary confounding variables. Overall, the incidence of CVD was observed in 200,015 subjects, with 1.2% mortality (n = 15,831). Supplemental Table 2 shows the NOS scores for the included studies. The average NOS score was 8.75. Thus, all the included studies were considered high quality with a low risk of bias according to the NOS scale.

3.2. Sweetened beverage consumption and cardiovascular mortality

Figs. 2 and 3 show the relation of SB consumption, both the low and the high exposure, with cardiovascular mortality risk. Seven studies examined the association between SB consumption (lower-threshold) and risk of cardiovascular mortality [16,18–23]. These studies were conducted in the USA (n = 5), Europe (n = 2), and Singapore (n = 1). All the studies adjusted for at least four confounders, while four studies effect estimates were adjusted for energy intake [16,18,20,23]. Overall, consumption of at least one glass (250 ml) of SB per day was associated with increased cardiovascular mortality (RR: 1.06; 95% CI: 1.00–1.12, $P < 0.001$), with moderate heterogeneity ($I^2 = 49.9\%$; $P_{\text{heterogeneity}} = 0.06$).

Five cohort studies [17–20,22] providing the data points of higher category of SB consumption (≥2 glasses per day) were included in the meta-analysis of cardiovascular mortality, reporting 11,278 cases of cardiovascular mortality among 772,140 participants. The pooled RR for the association between high SB consumption and risk of cardiovascular mortality was 1.24 (95% CI: 1.16–1.31), with no evidence of significant heterogeneity ($I^2 = 28.8\%$, $P_{\text{heterogeneity}} = 0.23$).

3.3. Sugar-sweetened beverage consumption and cardiovascular mortality

Five prospective cohort studies [16–18,20,22] comprising 748,046 subjects, and 10,359 (1.3%) cardiovascular deaths had a median follow-up of 13.4 years. The results of both highest (median ~ 2 glasses or servings/day) and lowest threshold (at least 250 ml or one glass/

Table 1
Characteristics of studies included for review.

Author	Country/	Study Period	Design	Sample size (CVD)	Sex	Diet Measures	Mean age	Follow-up (years)	Exposure	CVD mortality	Adjusted
Barrington et al. [17]	USA	2000–2008	Prospective	69582	M/W	FFQ		8	SSB	1066	age, sex, race, marital status, education, BMI, medication use, past medical history, physical activity, alcohol intake, smoking, family history of CVD, energy intake,
Collin et al. [18]	USA	2003–2013	Prospective	13440	M/W	FFQ	63.6	–	SB	168	age, sex, education, income, region, smoking, physical activity, energy intake, BMI, hypertension, dyslipidemia.
Malik et al. [19]	USA	1980–2014	Prospective	164534 (7896)	M/W	FFQ	59.08	NHS:34 HPFS:28	SSB/ASB	4197	Age. smoking, alcohol, postmenopausal hormone use, activity, diabetes, family history, BMI, food intake, energy intake
Massvar-Rahmani et al. [20]	USA	1993–1998	Prospective	93676 (61178)	W	FFQ	65	3	ASB	1985	Smoking, alcohol, MET, HEI
Mullee et al. [21]	10 EU	1992–2000	Prospective	451743 (9106)	M/W	DHQ/FFQ	50.8	16.4	SSB/ASB	1027	BMI, Physical, Education, Alcohol, smoking, OCP, menopause, total energy intake, meat intake, age, sex
Odegaard et al. [22]	Singapore	1993–1998	Prospective	52584 (3097)	M/W	FFQ	54	5	SB	81	age, sex, dialect, education, year of interview,
Ramne et al. [23]	Sweden	1991–2014	Prospective	48747 (24272)	M/W	Modified diet history, FFQ	53.1	14	SSB/ASB	3901	age, sex, race, marital status, education, income, BMI, drugs use, smoking
Tasevska et al. [24]	USA	1995–2008	Prospective	353751 (11444)	M/W	DHQ	61.3	13	SSB/ASB	3406	age, BMI, education, smoking, race, energy intake, vegetables, alcohol, chronic diseases, saturated fat, family history of cancer, intake of meat and total fat

[a]mean follow-up time; M/W: men/women, CVD: cardiovascular disease, DHQ: The Diet History Questionnaire, FFQ: Food frequency questionnaire, OCD: oral contraceptive pills, BMI: body mass index, MET: metabolic equivalent of task, HEI: Healthy Eating Index, SB: sweetened beverages, SSB: sugar sweetened beverages, ASB: artificial sweetened beverages.

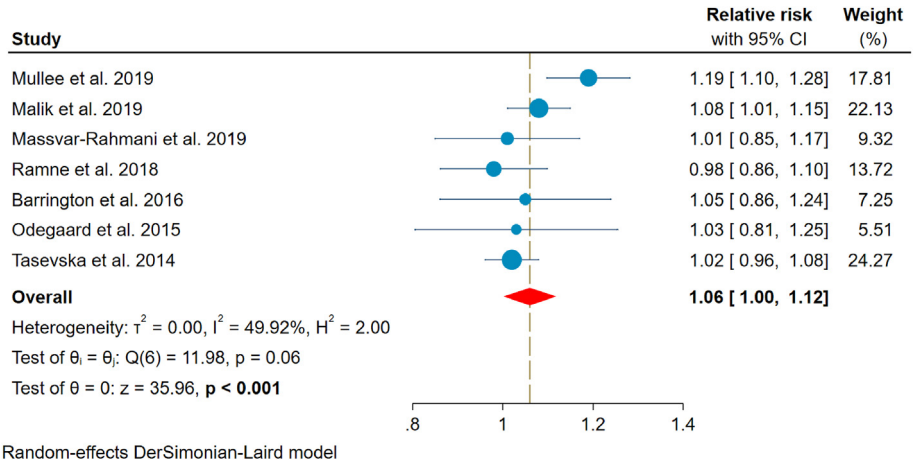

Fig. 2. Sweetened beverages consumption of 1 glass (250 ml/day) and risk of cardiovascular mortality [17,19–24].

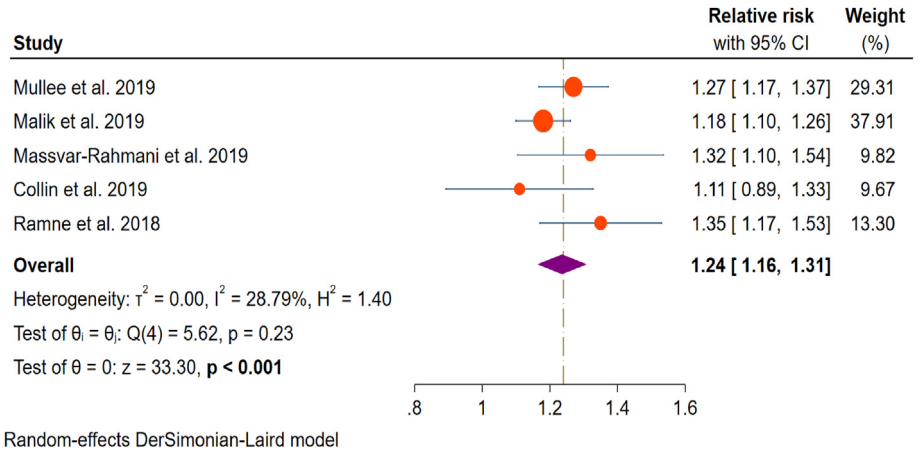

Fig. 3. Sweetened beverages consumption of 2 or more glasses/day and risk of cardiovascular mortality [18–21,23].

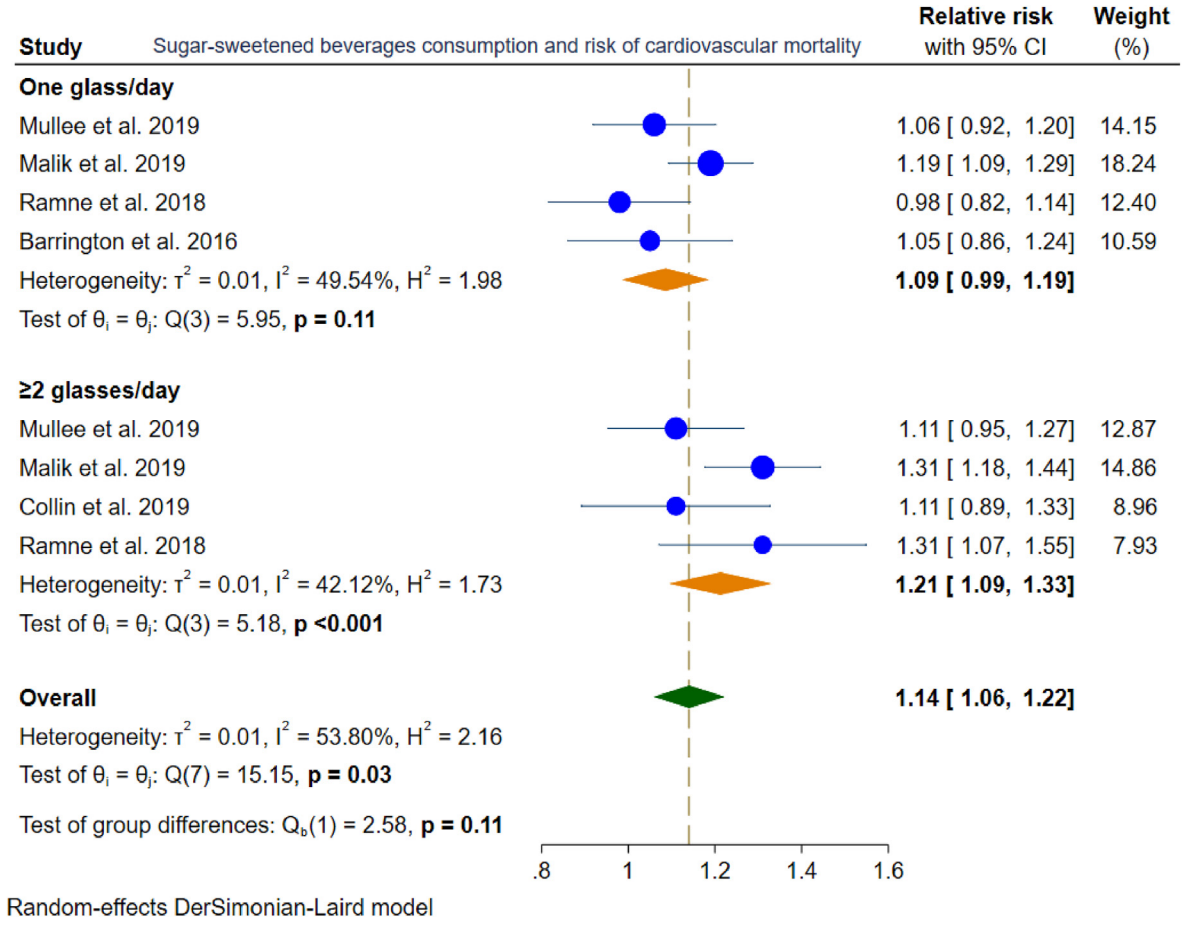

Fig. 4. Sugar-sweetened beverages consumption and risk of cardiovascular mortality [17–19,21,23].

day) consumption of SSB and risk of cardiovascular mortality are shown in Fig. 4. Overall, the pooled analysis showed an association between consumption of SSB and increased risk of cardiovascular mortality (RR: 1.14, 95% CI: 1.06–1.22, $P < 0.001$) with moderate heterogeneity ($I^2 = 53.8\%$, $P_{\text{heterogeneity}} = 0.11$). The RR (95% CI), comparing those consuming at least one glass or serving per day of SSB versus rare or non-consumers, was 1.09 (0.99–1.19) for cardiovascular mortality. We found a significant association of higher consumption of SSB of ≥2 glasses per day (compared with rare or none) with cardiovascular mortality with RR of 1.21 (95% CI: 1.09–1.33, $P < 0.001$, $I^2 = 42.1\%$). Moderate heterogeneity was detected between lower and higher levels.

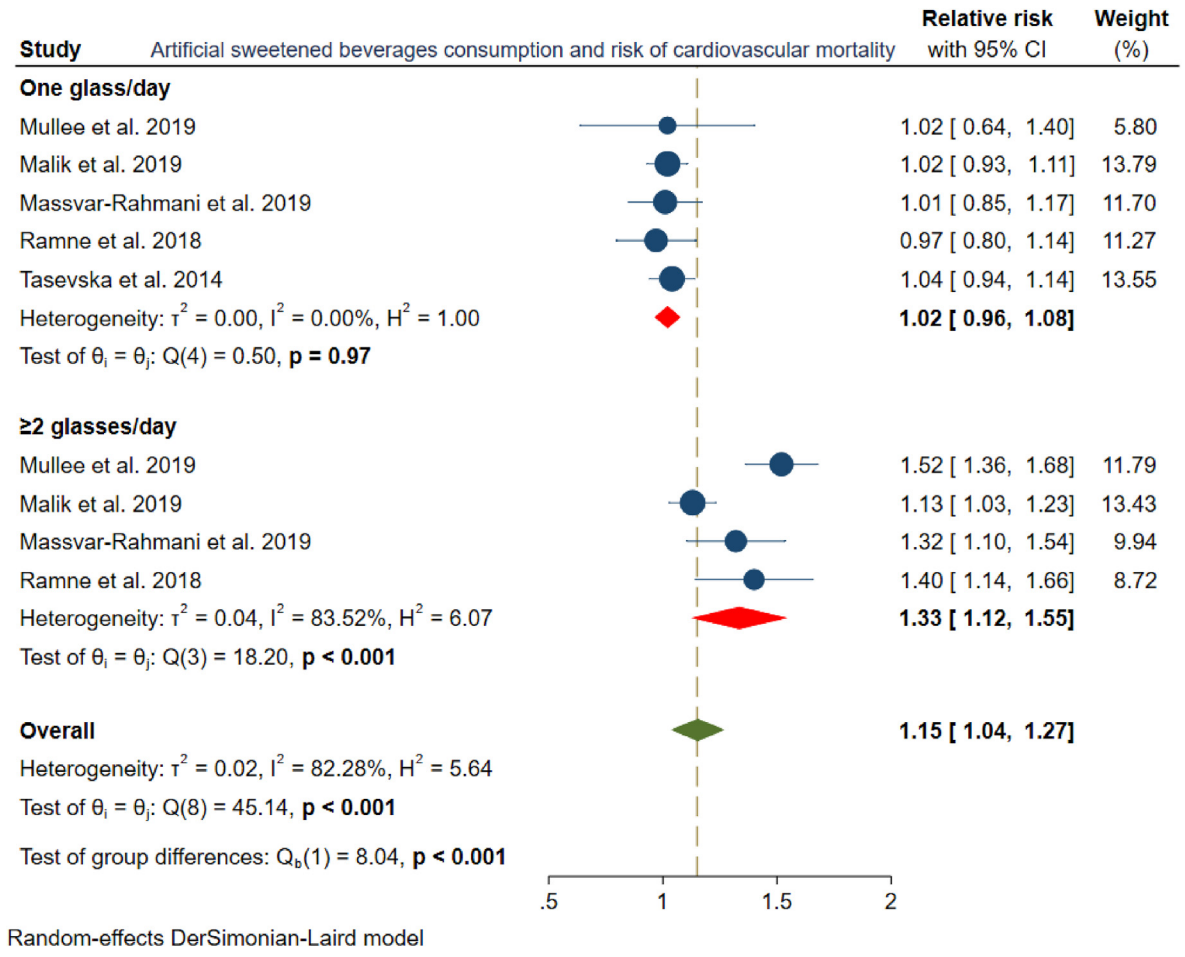

Fig. 5. Artificial sweetened beverages consumption and risk of cardiovascular mortality [19–21,23,24].

3.4. Artificially sweetened beverage consumption and cardiovascular mortality

Five studies provided the data for ASB consumption and risk of cardiovascular mortality [18–20,22,23]. Fig. 5 shows the relationship of daily consumption of ASB with cardiovascular mortality. Overall, daily consumption of ASB was associated with significant increased risk of cardiovascular mortality (RR: 1.15, 95% CI: 1.04–1.27, $P < 0.001$), with high heterogeneity ($I^2 = 82.3\%$, $P_{heterogeneity} < 0.001$). Compared with rare or non-users, the lowest intake of ASB of one glass or serving (250 ml) per day was not associated with increased cardiovascular mortality (RR: 1.02, 95% CI: 0.96–1.08, $P = 0.970$, $I^2 = 0.0\%$). However, four studies identified the association between higher ASB consumption (2 or more glasses or serving/day compared to rare or none) and cardiovascular mortality [18–20,22]. Also, we found that higher consumption of ASB resulted in a statistically significant higher risk of cardiovascular mortality with RR (95% CI) of 1.33 (1.12–1.55, $P < 0.001$), and high heterogeneity ($I^2 = 83.5\%$)

3.5. Subgroup analysis

Subgroup analysis was performed to search for the potential sources of heterogeneity. The test for heterogeneity thus indicated that variations in results across the ASB consumption group were not solely due to chance. It was expected because studies were conducted in different countries, on different populations, age groups, and methods such as the assessment of ASB consumption differed by study. The detailed results of subgroup analyses of SB, SSB, and ASB consumption and risk of CVD mortality are summarized in Table 2.

3.6. Risk of bias

The funnel plots, Egger's test, and Begg's tests showed no evidence of significant small-study effect for the analysis between cardiovascular mortality and the consumption of SB (For one serving: Egger's test $P = 0.645$, Begg's test $P = 0.763$, and for two or more servings: Egger's test $P = 0.582$, Begg's test $P = 1.000$), overall SSB consumption (Egger's test $P = 0.833$, Begg's test $P = 1.000$), and ASB (Egger's test $P = 0.544$, Begg's test $P = 0.251$), respectively (Supplementary figures: a-d).

4. Discussion

This systematic review and meta-analysis synthesize the available evidence on the association between SB consumption and risk of cardiovascular mortality from prospective observational studies. To the best of our knowledge, this is one of the few reviews to examine the association between ASB or SSB consumption and the risk of cardiovascular mortality. Also, the inclusion of new studies [16,18–20,22] published since the last review [23] strengthens the

Table 2
Subgroup analysis of sweetened beverages consumption and risk of cardiovascular mortality.

Subgroup	Consumption 1 glass per day				Consumption 2 or more glass per day			
	No. of studies	Relative risk (95% CI)	I^2	$P_{heterogeneity}$	No. of studies	Relative risk (95% CI)	I^2	$P_{heterogeneity}$
1. Sweetened beverages								
Median age				0.67				0.56
<55 years	2 studies	1.09 (0.88–1.29)	86.7%		2 studies	1.26 (1.15–1.37)	29.1%	
≥55 years	5 studies	1.04 (1.00–1.08)	0.0%		3 studies	1.21 (1.10–1.33)	29.8%	
Countries				0.91				0.08
USA	4 studies	1.04 (1.00–1.09)	0.0%		3 studies	1.19 (1.12–1.26)	0.0%	
Europe	2 studies	1.09 (0.88–1.29)	0.0%		2 studies	1.29 (1.20–1.38)	0.0%	
Asia	1 study	1.03 (0.81–1.25)	–		–	–	–	
Sample size				0.17				0.57
<100,000	4 studies	1.01 (0.93–1.09)	0.0%		3 studies	1.27 (1.12–1.41)	34.4%	
≥100,000	3 studies	1.09 (1.00–1.18)	78.6%		2 studies	1.22 (1.13–1.31)	45.3%	
Assessment method				0.55				0.56
FFQ	5 studies	1.05 (1.00–1.10)	0.0%		4 studies	1.23 (1.13–1.33)	35.9%	
DHQ	2 studies	1.10 (0.93–1.27)	89.2%		1 study	1.27 (1.17–1.37)	0.0%	
Years of follow-up				0.54				0.39
<10 years	3 studies	1.03 (0.92–1.13)	0.0%		1 study	1.32 (1.10–1.54)	–	
≥10 years	4 studies	1.07 (0.99–1.15)	73.9%		3 studies	1.24 (1.15–1.33)	47.1%	
Unspecified	–	–	–		1 study	1.11 (0.89–1.33)	–	
CVD patients				0.50				0.80
<10,000	4 studies	1.08 (0.99–1.17)	63.4%		3 studies	1.24 (1.15–1.33)	47.1%	
≥10,000	2 studies	1.02 (0.96–1.07)	0.0%		2 studies	1.22 (1.01–1.42)	44.7%	
Unspecified	1 study	1.05 (1.00–1.12)	–		–	–	–	
2. Sugar-sweetened beverages								
Median age				0.16				0.09
<55 years	2 studies	1.03 (0.92–1.13)	0.0%		3 studies	1.16 (1.04–1.27)	4.8%	
≥55 years	2 studies	1.14 (1.02–1.27)	40.1%		1 study	1.31 (1.18–1.44)	–	
Countries				0.16				0.77
USA	2 studies	1.14 (1.02–1.27)	40.1%		2 studies	1.23 (1.04–1.42)	57.7%	
Europe	2 studies	1.03 (0.92–1.13)	0.0%		2 studies	1.19 (1.00–1.38)	46.9%	
Sample size				0.16				0.94
<100,000	2 studies	1.01 (0.89–1.13)	0.0%		2 studies	1.20 (1.01–1.40)	32.2%	
≥100,000	2 studies	1.14 (1.01–1.26)	54.9%		2 studies	1.21 (1.02–1.41)	72.5%	
Assessment method				0.78				0.14
FFQ	3 studies	1.09 (0.95–1.23)	0.0%		3 studies	1.26 (1.14–1.38)	20.9%	
DHQ	1 study	1.06 (0.92–1.20)	–		1 study	1.11 (0.95–1.27)	0.0%	
Years of follow-up				0.73				0.33
<10 years	1 study	1.05 (0.86–1.24)	0.0%		–	–	–	
≥10 years	2 studies	1.09 (0.96–1.22)	63.8%		3 studies	1.24 (1.10–1.38)	50.4%	
Unspecified	–	–	–		1 study	1.11 (0.89–1.33)	–	
CVD patients				0.73				0.33
<10,000	3 studies	1.09 (0.96–1.22)	63.8%		3 studies	1.24 (1.10–1.38)	50.4%	
≥10,000	–	–	–		1 study	1.11 (0.89–1.33)	–	
Unspecified	1 study	1.05 (0.86–1.24)	–		–	–	–	
3. Artificial sweetened beverages								
Median age				0.58				**0.01**
<55 years	2 studies	0.98 (0.82–1.14)	0.0%		2 studies	1.49 (1.35–1.62)	0.0%	
≥55 years	3 studies	1.03 (0.97–1.09)	0.0%		2 studies	1.20 (1.02–1.38)	59.1%	
Countries				0.58				**0.01**
USA	3 studies	1.03 (0.97–1.09)	17.3%		2 studies	1.20 (1.02–1.38)	59.1%	
Europe	2 studies	0.98 (0.82–1.14)	0.0%		2 studies	1.49 (1.35–1.62)	0	
Sample size				0.59				0.88
<100,000	2 studies	0.99 (0.87–1.11)	0.0%		2 studies	1.35 (1.19–1.52)	0.0%	
≥100,000	3 studies	1.03 (0.96–1.09)	0.0%		2 studies	1.32 (0.94–1.70)	94.1%	
Assessment method				0.63				**0.03**
FFQ	3 studies	1.01 (0.94–1.08)	0.0%		3 studies	1.25 (1.08–1.43)	62.3%	
DHQ	2 studies	1.04 (0.94–1.13)	0.0%		1 study	1.52 (1.36–1.68)	–	
Years of follow-up				0.89				0.90
<10 years	1 study	1.01 (0.85–1.17)			1 study	1.32 (1.10–1.54)	–	
≥10 years	4 studies	1.02 (0.96–1.08)	0.0%		3 studies	1.34 (1.06–1.62)	88.8%	
CVD patients				0.71				0.90
<10,000	3 studies	1.01 (0.93–1.09)	0.0%		3 studies	1.34 (1.06–1.62)	88.8%	
≥10,000	2 studies	1.03 (0.95–1.11)	0.0%		1 study	1.32 (1.10–1.54)	0.0%	

CI: confidence interval; USA: United States of America; FFQ: food frequency questionnaire; DHQ: Diet History Questionnaire; CVD: cardiovascular disease.

evidence on the cardiovascular risk implications of SB consumption and thus better inform implications for public health practice and health promotion education.

Our findings suggest that SB consumption is associated with an increased risk of cardiovascular mortality, which increases with the level of consumption in a dose-response manner. While one glass of SB per day was associated with a modest increase risk of mortality, the use of two or more glasses was associated with a 24% increase in mortality risk. The reported risk of cardiovascular mortality with SSB consumption is comparable to previous reports [23,25]. Furthermore, evidence shows a link between SSBs and a higher risk of all-cause mortality. At the same time, ASB is associated with total

and cardiovascular mortality at high intake levels, mainly in women [18]. Evidence also suggests an association of SSBs consumption with increased risk of diabetes and metabolic syndrome [26] and certain types of cancers [27]. This could explain the potential pathway from SB consumption to cardiovascular mortality (i.e., greater consumption leading to weight gain and insulin resistance resulting in vascular disease culminating in a higher risk of cardiovascular mortality). Based on the current evidence, national and international organization recommend limiting intake of SBs and the US and Canadian Dietary Guidelines and WHO recommended reducing dietary intake of free sugar to less than 10% of total energy intake [28]. A meta-analysis of studies evaluating SB taxes found that taxation resulted in decrease in beverage consumption, sales, and purchase [29]. Moreover, in 2018, the UK implemented a tiered taxation on SSBs, based on sugar content (£0.24 per liter containing ≥8 mg of total sugar per 100 ml and £0.18 per liter <8 g total sugar per 100 ml) [30].

One notable finding of this review is that the risk of cardiovascular mortality increases as the level of consumption increases. Specifically, consuming multiple (≥2) glasses of SSB and ASB per day was associated with a 21% and 33% mortality risk due to cardiovascular causes, respectively. Likewise, recent research has found an association between the use of these beverages with the risk of chronic kidney disease, obesity, obesity-related cancers, type 2 diabetes, hypertension, and all-cause mortality to be dose-dependent [8,31,32]. These findings, in sum, suggest that SB consumption is not only associated with cardiovascular mortality but also other chronic diseases and all-cause mortality, and the risk is likely to be related to the level of consumption. Therefore, it is imperative to consider SB intake and consumption level carefully to reduce detrimental health outcomes.

Interestingly, compared to people who do not or rarely consume ASB beverages, it was only the consumption of multiple glasses of ASB beverages that led to a significant increase in cardiovascular mortality (33%); using a single glass or serving was not a significant predictor of cardiovascular mortality. On the contrary, compared with non-users, SSB consumption was associated with increased cardiovascular mortality irrespective of the level of daily consumption. However, there was a cumulative risk from 14% in people taking one or more glasses of SSB to 21% in those using two or more glasses per day. These findings have important practical implications in terms of providing nutritional guidance on the advisable level of intake of such drinks to reduce potential health impacts and associated risk of mortality due to cardiovascular incidents. Although further evidence is required to understand better the differential health consequences based on the SB types, our findings suggest that the use of ASB and SSB may have different health implications.

The subgroup analyses revealed that in studies with more than ten years of follow-up duration, there is an 11% and 34% increased risk of cardiovascular mortality with two or more glasses of SSB and ASB consumption, respectively. This finding indicates that duration of exposure could be one of the modulating factors between SB consumption and cardiovascular outcomes. Another important factor identified in the subgroup analyses was the method of assessment for beverage consumption. The consumption of SB was associated with cardiovascular mortality risk only in studies using the FFQ questionnaire to assess the beverage intake. Although the FFQ, as a self-reported questionnaire, could give a less accurate estimate of beverage consumption or other dietary intakes, evidence shows a good correlation between FFQ and DHQ as a predictor of nutrient intake [33]. It is also important to understand that among the included studies, only two studies used the DHQ questionnaire as opposed to the FFQ, which may limit the conclusion that can be drawn regarding the predictive validity of the DHQ on cardiovascular mortality. The sample size of the populations included, their median age and country of study also contributed to variations in the mortality outcome.

The findings of this meta-analysis demonstrate the need for effective interventions to reduce the consumption of SB for lowering the potential risk of cardiovascular mortality. Given the role health risk perception plays in regulating SB consumption [34], interventions that focus on the behavioral drivers of their use and other unhealthy lifestyles are important to reduce the grave risk due to the consistent and excessive consumption of these drinks. Mainly, understanding the link between health risk perception and intention to reduce the consumption of these beverages is important in dictating the nature of interventions that can be successful in this regard [35–37]. Intentions, habits, and environmental cues play a significant role in predicting self-regulatory behavior in the use of these beverages [36,37]. Thus, designing successful interventions requires an adequate understanding of these factors. Additionally, applying appropriate predictive models to identify highly likely users of SB can help prevent or reduce their consumption.

This meta-analysis included all prospective studies constituting a total of 1.2 million people to examine the relationship between consumption of SB and risk of cardiovascular mortality. Also, the inclusion of many studies of high quality based on the risk of bias assessment is another strength of this work. In the same vein, given that the evidence source for this meta-analysis is entirely observational studies, it is difficult to infer causal associations between beverage consumption and cardiovascular mortality due to differences in the definitions of SSBs or ASBs, and variations in the SB consumption quantities. Also, some of the participants' behaviors recorded in these observational studies may not consider the change in behavior over time by participants, which may limit the accuracy of the consumption level of SB. The inconsistent use of the dietary intake assessment tool may also limit the generalizability of these findings, as most of the studies relied on the FFQ as opposed to DHQ.

5. Conclusions

Sweetened beverages (SB) have received much attention from public health scholars, practitioners, and policy advocates for their detrimental effects on body weight. Many studies also indicate the influence of SB on cardiovascular and metabolic health. Our study provides strong evidence on the long-term impact of SB consumption. In this review of eight prospective cohort studies consisting of more than 1 million individuals exposed to SB, cardiovascular mortality was heightened for a sizable proportion of individuals after more than a decade of follow-up. These results bolster the argument about the damaging health effects of SB. While the public may not be concerned much about body weight, the increased risk of cardiovascular mortality due to SB consumption should be conveyed in public health promotion and awareness campaigns. Future studies should also include more extended follow-up periods, delineate effects of SB by types, and population-specific adverse effects of SB. Public health messaging for the link between SB, obesity, CVD, and mortality risk should be more clearly communicated to the general public.

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Declaration of competing interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this paper.

Appendix A. Supplementary data

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