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Associations of a healthy beverage pattern with all-cause and cause-specific mortality among US adults: a nationwide cohort study

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Abstract

Background Not all beverage items are necessarily beneficial for health, but the potential impact of an overall beverage pattern on health remains unknown. We aimed to examine associations of adherence to an overall healthy beverage pattern with all-cause and cause-specific mortality in a prospective cohort of US populations.

Methods We included 8,894 adults from the National Health and Nutrition Examination Survey (2001–2019), a nationally representative cohort of US populations. Dietary data were collected at baseline based on the 24-h recall dietary interview. Using the data, we calculated a healthy beverage score (HBS), where coffee, tea, and low-fat milk received positive scores, while alcohol, fruit juice, artificially sweetened beverages, sugar-sweetened beverages, and whole-fat milk received reverse scores. A higher HBS reflected a healthier beverage pattern. We used Cox proportional hazards models to calculate hazard ratios (HRs) and 95% confidence intervals (CIs) for the associations of HBS with mortality, adjusting for demographics, dietary and lifestyle factors, and medical history.

Results During a mean follow-up of 15.5 years, we recorded 2,363 all-cause deaths, including 761 cardiovascular disease (CVD) deaths, 511 cancer deaths, and 1,091 other deaths. Compared with the lowest quartile of HBS, the HRs and 95%CIs of the highest quartile of HBS were 0.79 (0.68, 0.92) for all-cause mortality, 0.75 (0.60, 0.95) for CVD mortality, 0.92 (0.70, 1.22) for cancer mortality, and 0.75 (0.58, 0.98) for other mortality. Inverse linear relationships of HBS with all-cause, and CVD mortality were observed using restricted cubic splines ($P_{non\text{-}linearity}$ >0.05). These results were consistent across subgroups predefined by age, sex, smoking status, dietary fiber consumption, hypertension, hyperlipidemia, daily energy intake, and Healthy Eating Index-2015. Results were robust in several sensitivity analyses.

Conclusions Greater adherence to HBS was associated with a substantially lower risk of all-cause, CVD and other mortality. These findings suggest that greater adherence to a healthy beverage pattern could benefit prevention of premature mortality.

Keywords Healthy beverage score, Mortality, Public health

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Introduction

Diet plays an important role in human health, and it is therefore important to evaluate various dietary intakes, such as beverage consumption, in relation to human health. Overwhelming evidence has indicated that different types of beverages have a distinct impact on human health [1–9]. Several meta-analyses of prospective cohorts have suggested that higher intakes of tea, coffee, and low-fat milk are associated with lower risks of several chronic diseases, including diabetes [1–3] and cardiovascular disease (CVD) [4–6], and mortality [7], while higher intakes of sugar-sweetened beverages (SSB), artificially sweetened beverages (ASB), and fruit juice are associated with higher risks of these chronic diseases [8] and mortality [9]. However, these previous prospective studies mainly focused on the associations of individual beverage items with health outcomes. Yet, humans generally do not consume single beverage items, and they consume a variety of beverages with complex combinations of nutrients that are likely to be interactive or synergistic [10]. Also, in these previous studies examining single beverage intake [1–9], it could be possible that the potential health impact of a single beverage may be too weak to detect, but the cumulative impacts of multiple beverages included in an overall beverage pattern may be sufficiently strong to be detectable [10]. Still importantly, an overall beverage pattern approach can be useful to inform dietary guidelines [10]. Given this, the role of beverages in health may be better described by an overall beverage pattern [10].

To date, few cohorts have examined the association of an overall beverage pattern with human health in general populations [11, 12]. In 2015, Duffey et al. created a healthy beverage index, including several commonly consumed drinks, and observed that greater adherence to this healthy beverage index was associated with lower levels of several key cardiometabolic disorders, such as hypertension, hyperlipidemia, and hyperglycemia in a cross-sectional analysis of US adults [11]. Very recently, a cohort analysis of Spanish populations has examined the association of a healthy beverage pattern with all-cause mortality and observed a beneficial association with all-cause mortality [12]. This is, so far, the only one prospective analysis of an overall beverage pattern with mortality in general population. However, in this Spanish cohort analysis, not all beverage items were given continuous scores to calculate a healthy beverage score (HBS), while dose-response relationships between these beverage items and mortality were previously observed [9, 13, 14]. The consumption of fruit juice, ASB, and alcohol was dichotomized and then combined with other beverages with continuous scores to create a continuous HBS in the Spanish study [12]. Also, importantly, this Spanish study did not examine the associations of a heathy beverage pattern with cause-specific mortality, e.g., CVD mortality, cancer mortality, and other mortality [12]. To address these knowledge gaps, we created an updated HBS by giving coffee and tea, and low-fat milk continuous positive scores, and alcohol, fruit juice, SSB, ASB, and whole-fat milk continuous reverse scores. We prospectively examined the associations of a healthy beverage pattern, assessed by this updated HBS with all-cause and cause-specific mortality in US adults from the National Health and Nutrition Examination Survey (NHANES), a nationally representative cohort of U.S. populations. We hypothesized that a higher HBS was associated with a lower risk of all-cause and cause-specific mortality.

Methods

Study design and participants

The NHANES has been conducted on an ongoing basis, with public-use data being released in two-year cycles since 1999, and it is sometimes referred to as continuous NHANES [15]. The sample for each two-year cycle is representative of the noninstitutionalized US population. The NHANES is administered by the National Center for Health Statistics (NCHS) at the Centers for Disease Control and Prevention (CDC). The NHANES usually collects questionnaire data through in-person interviews and performs health examinations in the Mobile Examination Center and collects specimens for laboratory tests. More details of the NHANES have been described elsewhere [15]. We used data from the NHANES linked mortality file, which links participants of the NHANES with death records in the National Death Index dataset through December 31, 2019. The research protocol received approval from the Ethics Review Board of the NCHS. Written informed consent from all participants was obtained by NHANES.

The baseline for this current analysis was set in 2001–2004, when all the beverage items to create an HBS were included as part of the 24-h recall dietary interview. Of the 21,161 participants from NHANES at the baseline, we excluded individuals who were aged < 18 years (n = 9,548), who did not have beverage data at baseline (n = 1,362), who were pregnant or breastfeeding (n = 639), who reported implausible daily energy intake (< 500 or > 3,500 kcal/d for women, and < 800 or > 4,200 kcal/d for men) (n = 706), or who did not have follow-up data (n = 12). Finally, we included 8,894 participants in the final analyses (Supplementary Fig. 1).

Dietary measurements

Dietary data were collected through 24-h dietary recall interviews. After initial 24-h dietary recall, a second-recall via telephone was conducted between 3 and 10 days later [15]. In-person interview took place in a private room at NHANES mobile examination center, using computer-assisted dietary interview system administered by NHANES interviewer [15].

To classify the specific types of coffee, tea, low-fat milk, whole-fat milk, fruit juice, ASB, and SSB, we linked NHANES dietary data to the United States Department of Agriculture (USDA) Food and Nutrient Database for Dietary Studies (FNDDS) and the Food Patterns Equivalents Database (FPED), and we only used the beverage data collected by the initial 24-h dietary recall, in line with the availability of FNDDS and FPED [16, 17]. For alcohol consumption, the intake data were available from NHANES and calculated as the average of the two dietary recalls. According to the approach by Rodríguez-Ayala et al. [12], we created an HBS, including coffee and tea, low-fat milk, whole-fat milk, fruit juice, ASB, SSB, and alcohol. Specifically, for healthier beverage items, including coffee and tea, low-fat milk, we gave a score of 1 to no consumption, and gave a score of 2, 3, and 4 to the lowest, second, and highest tertile of consumption, respectively. In contrast, for less healthier beverages, including whole-fat milk, fruit juice, ASB, SSB, and alcohol, we gave a score of 4 to no consumption, and a score of 3, 2, and 1 to the lowest, second, and highest tertile of consumption, respectively. We summed the individual score from each beverage to create an HBS, which theoretically ranged from 7 (lowest adherence) to 28 (highest adherence) (Supplementary Table 1). A higher HBS reflected a greater adherence to a healthy beverage pattern. Supplementary Table 2 presents the amount of individual beverage consumption across the quartiles of HBS.

Ascertainment of outcomes

The NHANES participant data were linked to the NCHS National Death Index (NDI), and mortality information was updated through December 31, 2019 [18]. All-cause mortality and cause-specific mortality, including CVD mortality, cancer mortality and other mortality, were our primary outcomes. The 10th revision of the International Classification of Diseases (ICD-10) was used to identify the underlying cause of death. For example, CVD deaths were determined by ICD-10 codes: I00-I09, I11, I13, I20-I51, and I60-I69. Cancer deaths were determined by ICD-10 codes: C00-C97 [19].

Assessment of covariates

Information on the demographical, lifestyle, social economical, and medical covariates, such as age, sex, education, race, income-poverty-ratio (PIR), body mass index (BMI), physical activity, medication use, smoking status, hypertension status, and hyperlipidemia status were obtained through home interviews and clinical examinations [15]. We also recorded prescribed medications to consider prevalent morbidity. Dietary covariates, including daily energy intake, dietary fiber consumption, fruit consumption, vegetable consumption, and meat consumption, were collected through 24-h dietary recall interviews [15]. Data on physical activity were extracted from the NHANES self-reported physical activity questionnaire. We assessed physical activity by calculating the total metabolic equivalent minutes per week (MET-minutes/week), which took into account the type, frequency, and duration of exercise performed each week, using the recommended MET values provided by NHANES for each exercise type. Physical activity (MET-minutes/week) = MET*weekly frequency*duration of each physical activity [20]. Healthy Eating Index-2015 (HEI-2015) was computed by summing scores for 13 vital dietary components, including nine adequacy components (total fruits, whole fruits, total vegetables, green and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids) and four moderation components (refined grains, sodium, added sugars, and saturated fats) [21].

Statistical analysis

In the statistical analysis, we accounted for the multistage sampling design of NHANES using the primary sampling unit and stratum variables and applied complex survey weights.

We calculated the follow-up time from baseline to the date of death, or the end of the follow-up. We used Cox proportional hazards models to examine the associations of adherence to the HBS and all-cause and cause-specific mortality. We adjusted for age and sex in model (1) We further adjusted for race, smoking, PIR, education level, BMI, hypertension, hyperlipidemia, number of medicines, daily energy intake, dietary fiber consumption, fruit consumption, vegetable consumption, meat consumption, and physical activity in model (2) We further tested the significance of linear trends by modelling the median value within each category of the HBS as a continuous variable and then examining the significance of this variable. To explore the dose-response relationship of the HBS with mortality, we fitted cubic spline regressions, where the same covariates in the primary analyses were adjusted.

We conducted stratified analyses predefined by several key risk factors, including age (< 50, ≥ 50 years), sex (male, female), smoking status (current, former and never), dietary fiber intake (≤ median, >median), daily energy intake (quartiles), hypertension (yes, no), hyperlipidemia (yes, no), and HEI-2015 (≤ median, >median). We examined the interaction impacts of HBS with risk factors by adding an interaction term of HBS and risk factor in the fully adjusted model. Given the potential for multiple testing, we set the statistical level for significance for these interactions at 0.006 (0.05/8 comparisons).

We also performed several sensitivity analyses to test the robustness of our study results based on fully adjusted models (model 2). First, we repeated the associations by excluding one component from the HBS at one time, to explore whether any beverage items mainly explained the associations. Second, we repeated the analyses by excluding individuals who died within the first 2 years of follow-up. Third, we repeated the analyses by excluding participants with prevalent CVD at baseline. Fourth, we examined the Pearson correction of HBS with an overall diet quality, assessed by HEI-2015, as well as additionally adjusted for HEI-2015 in replace of individual dietary factors, such as fruit intake, vegetable intake, and meat intake. Finally, we analyzed the associations of HBS with specific other mortality, such as mortality due to neurodegenerative disease, and kidney disease.

The missingness of covariates ranged from 0.1 to 28%, such as 0.1% for education, 3% for BMI, and 6% for PIR. Of which, only data on physical activity had a 28% missingness, and others had missingness less than 10%. We used the multiple imputation to impute the missing data of covariates [22]. We conducted statistical analyses using R version 4.4.2. $P<0.05$ was considered to indicate statistical significance, unless otherwise.

Results

Baseline characteristics

Table 1 presents the baseline characteristics of participants. Compared with participants in the lowest quartile of HBS, those in the highest quartile were older, and had less meat intake, lower daily energy intake, and higher diet quality.

Main results

During a mean follow-up of 15.5 years, we recorded 2,363 all-cause deaths, including 761 CVD deaths, 511 cancer deaths, and 1,091 other deaths. After adjusting for multivariable covariates, including demographics, lifestyle, dietary, and medical factors (Model 2), comparing with the participants in the lowest quartile of HBS, those in the highest quartile had a substantially lower risk of all-cause, CVD, and other mortality. The HRs and 95%CIs for comparing the highest with lowest quartile of HBS were 0.79 (0.68, 0.92) for all-cause mortality, 0.75 (0.60, 0.95) for CVD mortality, and 0.75 (0.58, 0.98) for

Table 1 Baseline characteristics of participants in the NHANES study by quartiles of the HBS

Characteristics	**Quartiles of the HBS**			
	Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**
HBS points	17.8 (1.4)	20.0 (0.0)	21.5 (0.5)	23.8 (0.9)
Participants (n)	3,344	1,282	2,467	1,801
Age (years)	39.7 (18.6)	48.3 (20.6)	53.1 (19.4)	58.7 (17.9)
Female (%)	43.3	54.5	53.6	55.9
BMI (kg/m^2)	27.8 (6.4)	28.1 (6.5)	28.4 (6.3)	28.0 (5.6)
Smoking status (%)				
Current	26.2	20.7	20.0	20.4
Former	22.1	26.1	29.4	34.0
Never	51.7	53.1	50.6	45.6
Race (%)				
Mexican American	24.5	23.9	16.4	8.7
Non-Hispanic Black	27.6	23.2	19.4	16.9
Non-Hispanic White	40.7	46.5	56.6	67.4
Other Hispanic	3.3	2.3	3.7	4.6
Other Race	3.8	4.2	3.9	2.5
Education level (%)				
Junior middle school and below	11.5	15.9	14.4	14.4
High school or equivalent	46.8	42.6	39.9	38.2
College or above	41.7	41.5	45.7	47.4
Total energy (Kcal/d)	2,313 (796)	1,941 (740)	1,882 (735)	1,757 (666)
HEI-2015	49.5 (12.0)	50.4 (13.6)	50.4 (13.2)	51.7 (13.6)
Hyperlipidemia (%)	63.6	68.1	70.5	76.0
Hypertension (%)	30.6	40.6	45.3	50.8
Vegetable consumption (servings/day)	1.5 (1.2)	1.5 (1.3)	1.5 (1.3)	1.6 (1.2)
Meat consumption (ounce/day)	2.1 (2.8)	1.8 (2.6)	1.7 (2.5)	1.7 (2.4)
Fruit consumption (servings/day)	1.4 (1.6)	1.2 (1.5)	1.0 (1.4)	0.9 (1.2)

Values are means (SD) or percentages (%)

HBS, Healthy Beverage Score; BMI, body mass index; HEI-2015, Healthy eating index-2015 other mortality (All P_{trend} <0.05) (Table 2). The HBS was not associated with cancer mortality, with HR and 95% CI of 0.92 (0.70, 1.22) for the highest vs. lowest quartile of HBS (Table 2).

A secondary analysis revealed that inverse linear relationships of HBS with all-cause and CVD mortality (Fig. 1). These results were consistent across risk factors predefined by age (< 50, ≥ 50 years), sex (male, female), smoking status (current, former, and never), dietary fiber intake (≤ median, >median), daily energy intake (quartiles), hypertension (yes, no), hyperlipidemia (yes, no), and HEI-2015 (≤ median, >median) (all $P_{interaction}$ >0.006, adjusted *P* value) (Supplementary Table 3).

Sensitivity analyses

Several sensitivity analyses demonstrated the robustness of the study results. We observed similar results when excluding deaths occurring within the first 2 years of follow-up; when excluding baseline CVD; when excluding any individual beverage item from HBS at a time; and when additionally adjusting for the HEI-2015 in replace of several specific dietary factors (Supplementary Tables 4–6, Supplementary Fig. 2). The correlation of HBS with HEI-2015 was 0.05 ($p < 0.001$). Finally, for several specific other mortality, we observed that a higher HBS was associated with a lower risk of mortality due to neurodegenerative diseases (Supplementary Table 7).

Discussion

Main findings

In this nationwide prospective cohort study of US adults, we observed that greater adherence to HBS were associated with a lower risk of all-cause, CVD, and other mortality, independent of established risk factors, including age, sex, educational level, race, PIR, BMI, physical activity, medication use, smoking status, hypertension, hyperlipidemia, daily energy intake, dietary fiber consumption, fruit consumption, vegetable consumption, and meat consumption. These associations were linear and robust in sensitivity analyses. These results were also consistent across several risk factors, including age, sex, smoking status, dietary fiber intake, daily energy intake, hypertension, hyperlipidemia, and HEI-2015.

Comparison with previous studies

Previous prospective cohort studies have mainly focused on the associations of intake of individual beverage items with mortality, and observed that tea and coffee are consistently associated with lower risks of mortality [23, 24], while SSB, ASB, and alcohol are generally associated with higher risks of mortality [13, 25]. However, people generally do not consume single beverage items, and the consumption of beverages may be correlated with each other. An increase in one beverage is more likely to be linked to a decrease in another beverage. Therefore, an overall beverage pattern may better reflect consumption of various

Table 2 Associations of healthy beverage score with all-cause and cause-specific mortality

	Quartiles of HBS				*P* for trend
	Quartile 1	Quartile 2	Quartile 3	Quartile 4	
All-cause mortality					
Cases/person-years	574/52,289	325/19,109	763/35,824	701/24,933	
Model 1	1 (ref)	0.79 (0.69, 0.91)	0.88 (0.76,1.02)	0.87 (0.75, 1.05)	0.15
Model 2	1 (ref)	0.82 (0.71, 0.95)	0.87 (0.75,1.02)	0.79 (0.68, 0.92)	0.006
CVD mortality					
Cases/person-years	176/52,289	105/19,109	244/35,824	236/24,933	
Model 1	1 (ref)	0.87 (0.71, 1.07)	0.83 (0.66, 1.03)	0.87 (0.71, 1.07)	0.28
Model 2	1 (ref)	0.90 (0.72, 1.11)	0.82 (0.65, 1.03)	0.75 (0.60, 0.95)	0.02
Cancer mortality					
Cases/person-years	131/52,289	61/19,109	164/35,824	155/24,933	
Model 1	1 (ref)	0.72 (0.46, 1.12)	1.01 (0.69, 1.46)	1.02 (0.75, 1.37)	0.65
Model 2	1 (ref)	0.73 (0.47, 1.14)	0.97 (0.66, 1.43)	0.92 (0.70, 1.22)	0.78
Other mortality					
Cases/person-years	267/52,289	159/19,109	355/35,824	310/24,933	
Model 1	1 (ref)	0.78 (0.62, 0.98)	0.83 (0.71, 0.97)	0.76 (0.66, 0.91)	0.13
Model 2	1 (ref)	0.81 (0.63, 1.04)	0.85 (0.65, 1.13)	0.75 (0.58, 0.98)	0.04

Data are HRs and 95% CIs

Model 1: Age (years), sex (male, female)

Model 2: Model 1 + race (non-Hispanic Black, non-Hispanic White, Mexican American, other Hispanic, other Races), smoking status (current, former, never smoker), PIR (continuous), education level (Junior middle school and below, High school or equivalent, College or above), BMI (kg/m^2; <18.5, 18.5–19.9, 20.0–24.9, 25.0–29.9 and ≥ 30.0), hypertension (yes/no), hyperlipidemia (yes/no), number of medicines (number), daily energy intake (kcal/day; quartiles), dietary fiber consumption (g/day; ≤median, >median), fruit consumption (serving/day; ≤median, >median), vegetable consumption (serving/day; ≤median, >median), meat consumption (ounce/day; ≤median, >median), physical activity (MET-minutes/week)

HBS, Healthy Beverage Score; PIR, income-poverty-ratio; BMI, body mass index; CVD, cardiovascular disease; MET, metabolic equivalent of task

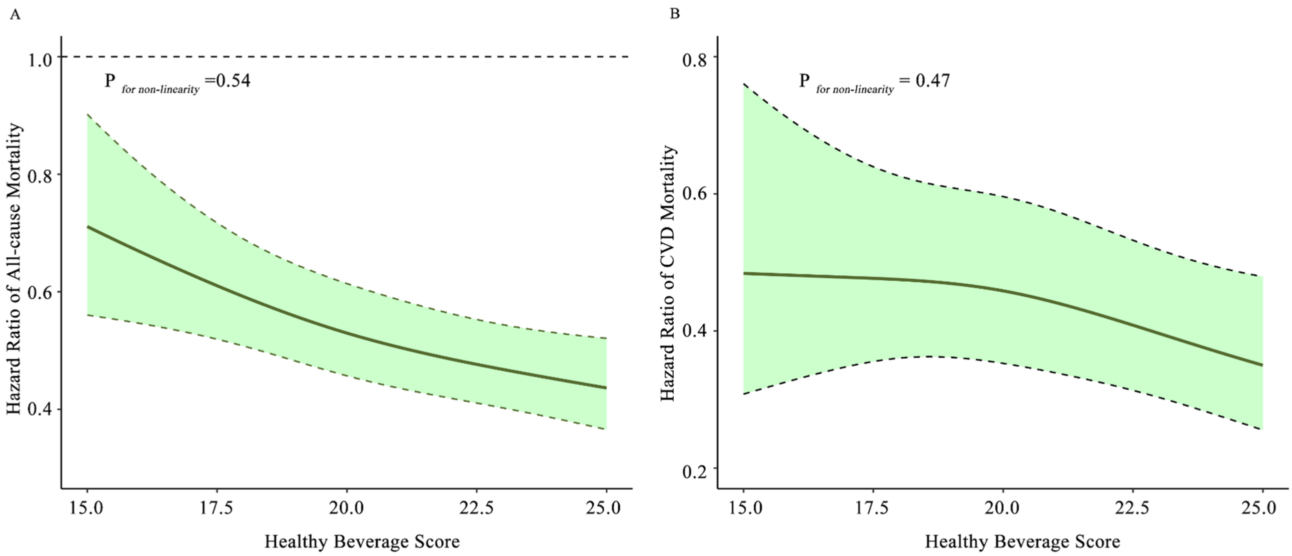

Fig. 1 Associations of the HBS with all-cause and CVD mortality using restricted cubic spines in the NHANES study. (**A**) Healthy beverage score and all-cause mortality; (**B**) Healthy beverage score and CVD mortality. Multivariable analyses were adjusted for age (years), sex (male, female), race (non-Hispanic Black, non-Hispanic White, Mexican American, other Hispanic, other Races), smoking status (current, former, never smoker), PIR (continuous), education level (Junior middle school and below, High school or equivalent, College or above), BMI (kg/m^2; <18.5, 18.5–19.9, 20.0–24.9, 25.0–29.9 and ≥ 30.0), hypertension (yes/no), hyperlipidemia (yes/no), number of medicines (number), daily energy intake (kcal/day; quartiles), dietary fiber consumption (g/day; ≤median, >median), fruit consumption (serving/day; ≤median, >median), vegetable consumption (serving/day; ≤median, >median), meat consumption (ounce/day; ≤median, >median), physical activity (MET-minutes/week). Solid line indicates HR and dashed lines indicate 95%CIs. HBS, Healthy Beverage Score; PIR, income-poverty-ratio; BMI, body mass index; CVD, cardiovascular disease; MET, metabolic equivalent of task

beverages [10]. Yet, to date, only one very recent cohort analysis of Spanish people has reported that compared with people in the lowest quartile of HBS, those in the highest quartile had a 28% lower all-cause mortality, but it did not examine the associations with cause-specific mortality [12]. Further, in the Spanish cohort study, the consumption of fruit juice, and ASB was dichotomized into "no consumption" vs. "any consumption", and alcohol consumption was dichotomized into "minor to moderate consumption" vs. "heavy consumption", which combined with other beverages with continuous scores to create a continuous HBS, although the dose-response relationships of these beverage items with mortality actually existed [9, 13, 26]. Therefore, the HBS in the Spanish cohort study could be further improved by giving continuous scores with gradients to all beverage items, including fruit juice, ASB, and alcohol according to the amounts consumed. Leveraging the rich data within the NHANES, we created an updated HBS by positively assigning continuous scores to tea and coffee, and low-fat milk, and reversely assigning continuous scores to fruit juice, ASB, SSB, alcohol, and whole-fat milk. We observed that compared with people in the lowest quartile of HBS, those in the highest quartile had a 21%, 25%, and 25% lower risk of all-cause, CVD, and other mortality, respectively. Our study is the first to report beneficial associations for an overall healthy beverage pattern and cause-specific mortality. In our study, the effect sizes of the beneficial associations of HBS with all-cause and cause-specific mortality were generally stronger than those of coffee, tea, and low-fat milk, individually. For example, a few very recent meta-analyses of prospective cohorts reported that compared with people with the lowest category of tea or coffee, those with the highest category had a 5–15% lower risk of all-cause and cause-specific mortality [23, 24]. Further, a short-term clinical trial reported that whole-fat milk did not adversely affect health conditions [27]. Therefore, we repeated the analyses by excluding whole-fat milk from HBS, and still observed similar results in our sensitivity. Actually, excluding each one of all these individual beverages (e.g., coffee and tea, low-fat milk, fruit juice, ASB, and SSB) from HBS at a time did not substantially change the associations, indicating that the beneficial associations were not mainly explained by any one specific beverage item, which supports the importance of recognizing an overall healthy beverage pattern.

Our present results were also consistent with those of recent meta-analyses examining associations of healthful dietary patterns, including Healthy Eating Index (HEI), Alternative Healthy Eating Index (AHEI), Dietary Approaches to Stop Hypertension (DASH) with mortality. For example, a meta-analysis of prospective cohorts by Schwingshackl et al. reported a 21–23% lower risk of all-cause and CVD mortality when comparing the highest with lowest HEI, AHEI, and DASH scores, similar to the effect size of the associations observed in our present study [28]. However, these previous dietary patterns mainly included solid foods and nutrients, and the HBS in our study only focused on commonly consumed beverages, and had a very low correlation with these previous dietary scores. Further, additional adjustment for HEI-2015 did not substantially change the results, and the results remained similar across different levels of HEI-2015, which suggested that adherence to a healthy beverage pattern may represent a viable alternative approach for a healthy lifestyle in addition to other popular healthful diets. Such findings might have an important public health implication. A healthy beverage pattern does not require a complete elimination of consumption of fruit juice, ASB, SSB, alcohol, and whole-fat milk, but instead, can be achieved in various ways (e.g., increasing tea or coffee intake and decreasing alcohol, ASB, or SSB intake), which increase the potential for population-wide health recommendations. Given this, our findings may help to inform dietary guidelines.

Possible interpretations

A healthy beverage pattern usually has more flavonoids, chlorogenic acid, lignans, quinides, trigonelline, vitamins, caffeine, and magnesium due to higher intake of tea and coffee [29, 30]. These components may benefit chronic diseases, such as diabetes, and CVD, resulting in lower mortality [31–41]. For example, the flavonoids, chlorogenic acid, lignans, quinides, trigonelline, and magnesium are associated with lower risks of obesity, diabetes and CVD, by impairing glucose absorption in the intestine via competitively inhibiting glucose-6-phosphate translocase and reducing sodium-dependent glucose transport in the brush border membrane vesicles [37]; by improving oxidative stress and inflammation because of their antioxidant properties [38]; by reducing liver glucose output [39]; by benefiting gut microbiome [40]; or by exhibiting either estrogenic or antiestrogenic effects [41]. Further, a healthy beverage pattern also encourages more consumption of low-fat milk, which is low in saturated fatty acid (SFA) and linked to lower risks of chronic diseases and mortality [42, 43]. On the other hand, due to less SSB, ASB, and full-fat milk, a healthy beverage pattern is less in added sugar, artificial sweeteners, and SFA, which are associated with lower risks of obesity, diabetes, and CVD, resulting in lower risks of mortality [44–46]. In addition, a healthy beverage pattern is also lower in fruit juice and alcohol. Fruit juice is linked to higher risks of diabetes [14], probably due to its moderately high glycaemic index (50–80) [47]. High amount of alcohol intake is associated with higher risks of chronic diseases and mortality, while low and moderate alcohol intake is not linked to risk [13, 48]. However, we did not observe a significant association between HBS and cancer mortality. This could be explained by the fact that cancer mortality is less susceptible to an overall beverage pattern, which could be mainly influenced by a complex interplay of multiple factors such as dietary intake, lifestyle, genetics, environmental pollution, and treatments [49]. Further, a variety of cancers have distinct pathogenic mechanisms and risk factors, which may also contribute to the null association observed of HBS with total cancer mortality [50]. Further studies are needed to examine the associations of HBS with more specific cancer mortality.

Strengths and limitations of the study

Strengths of our study include its prospective design, the use of nationally representative data, and the first investigation of an overall healthy beverage pattern with cause-specific mortality.

However, several limitations should be considered. First, beverage consumption was only assessed at baseline and not re-evaluated during follow-up, which could lead to measurement errors and misclassification. Second, water consumption was not included in this study. Water is generally recommended as a safe beverage for hydration. As it does not contain energy, macronutrients, or micronutrients, its consumption is considered free for the general population. Third, our analyses were conducted within US adults, which limits the generalizability of our findings to populations of other countries. More high-quality studies in other countries or regions (e.g., Asian countries) are needed. Finally, residual confounders cannot be ruled out due to the nature of observational study.

Conclusions

In this study of US adults, we observed that greater adherence to HBS was associated with lower risks of all-cause, CVD, and other mortality. These findings suggest that greater adherence to a healthy beverage pattern may benefit prevention of premature mortality.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-025-01179-5.

Supplementary Material 1

Author contributions

Z.C. conceived the study. Y.F. and H.W. analyzed the data. Z.C., and Y.F. provided statistical expertise. K.W., Z.L., B.T., Q.L., and F.O. performed a thorough repetition and validation of the statistical analysis. Z.C. wrote the first draft of the article. Z.C., Y.F., H.W., K.W., Z.L., B.T., Q.L., and F.O. contributed to the interpretation of the results and revision of the manuscript for important intellectual content and approved the final version of the manuscript. Z.C. is the guarantor. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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Data availability
For detailed information regarding input data sources and to download the data used in these analyses, please visit the National Health and Nutrition Examination Survey (NHANES) database at: https://www.cdc.gov/nchs/nhanes/.

Declarations

Ethics approval and consent to participate
The Ethics Review Board of the National Center for Health Statistics (NCHS) granted approval for the survey protocol. The written informed consent form was obtained from all participants.

Competing interests
The authors declare no competing interests.

Clinical trial number
Not applicable.

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