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# Sodium, added sugar and saturated fat intake in relation to mortality and CVD events in adults: Canadian National Nutrition Survey linked with vital statistics and health administrative databases

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## Abstract

This study aimed to determine whether higher intakes of Na, added sugars and saturated fat are prospectively associated with all-cause mortality and CVD incidence and mortality in a diverse population. The nationally representative Canadian Community Health Survey-Nutrition 2004 was linked with the Canadian Vital Statistics – Death Database and the Discharge Abstract Database (2004–2011). Outcomes were all-cause mortality and CVD incidence and mortality. There were 1722 mortality cases within 115 566 person-years of follow-up (median (interquartile range) of 7·48 (7·22–7·70) years). There was no statistically significant association between Na density or energy from saturated fat and all-cause mortality or CVD events for all models investigated. The association of usual percentage of energy from added sugars and all-cause mortality was significant in the base model with participants consuming 11·47 % of energy from added sugars having 1·34 (95 % CI 1·01, 1·77) times higher risk of all-cause mortality compared with those consuming 4·17 % of energy from added sugars. Overall, our results did not find statistically significant associations between the three nutrients and risk of all-cause mortality or CVD events at the population level in Canada. Large-scale linked national nutrition datasets may not have the discrimination to identify prospective impacts of nutrients on health measures.

**Key words:** **Nutrients of public health concern: CVD: National nutrition survey: Health administrative databases**

Traditionally, studies on the association between Na, saturated fat, and sugar intake and all-cause mortality or CVD events have been prospective cohort studies of middle-aged or older adults[1–3]. Some major limitations of previous studies include the use of single FFQ[4], sample selection bias or lack of generalisability, random and systematic measurement errors[5], and using dichotomised dietary exposure data (linearity assumption). The latter is critical because these nutrients, particularly Na, are generally consumed more than the standard recommended amounts in Canada[6] and the USA[7].

To our knowledge, no previous study globally has examined the association of Na, added sugar and saturated fat with CVD incidence and mortality using large-scale nationally representative nutrition surveys linked with health administrative databases (particularly with regard to CVD outcomes). The concept of a dose–response relationship between nutrients and mortality or CVD events needs further elucidation, especially in countries following Western-type dietary patterns. This is important as nutrition policymakers may-face barriers in policy development because of mixed messages coming from research studies.

**Abbreviations:** CCHS, Canadian Community Health Survey; CVSD, Canadian Vital Statistics – Death Database; DAD, Discharge Abstract Database; HR, hazard ratio; NCI, National Cancer Institute.

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Herein, we present results on the association between Na, added sugars and saturated fat with both all-cause mortality and CVD events using the large scale national nutrition survey (Canadian Community Health Survey-Nutrition 2004 (CCHS-Nutrition 2004)) that is linked at the individual level to health administrative databases, the Canadian Vital Statistics – Death Database (CVSD) and Discharge Abstract Database (DAD) (2004–2011). Our secondary goal was to evaluate whether such large-scale linked national nutrition datasets are discriminatory enough to tease out the prospective impacts of nutrients on objective health measures (i.e., all-cause mortality and CVD mortality and incidence) and whether other foods and nutrients that are highly correlated with Na, added sugars and saturated fat can modify the relationship between these three nutrients and health outcomes. This study addresses potential limitations of previous research using a national-level survey, using outcomes linked to health administrative rather than self-reported data, using repeated 24-h recalls rather than FFQ, addressing dietary misreporting and by conducting sensitivity modelling.

## Methods

### Study population and design

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving research study participants were approved by the Ottawa Health Science Network Research Ethics Board. Data were collected under the authority of the Statistics Act of Canada and were analysed and accessed at Statistics Canada. Written or verbal informed consent was obtained from all subjects/patients. Additional details on each dataset can be found in the online Supplementary Materials.

*The Canadian Community Health Survey-Nutrition 2004.* In 2004–2005, Statistics Canada conducted the cross-sectional, multistage and complex CCHS-Nutrition 2004 collecting data from Canadians (> 0 years). In total, 35 107 respondents were sampled and appropriately weighted to represent > 98 % of the community-dwelling Canadian population (response rate = 76·5 %). Additional details on CCHS-Nutrition 2004 have been previously published[8]. Briefly, dietary data were collected using 24-h dietary recalls through the modified version of the United States Department of Agriculture's Automated Multiple Pass Method[9–11]. Each recall included all foods and beverages consumed the previous day (midnight to midnight). Nutrient compositions of consumed foods and beverages were then analysed using Health Canada's Canadian Nutrient File[12]. All respondents completed one 24-h dietary recall and about 30 % completed a second recall. The second day of dietary recalls was used to estimate usual intake distribution to account for day-to-day variation in intakes that can be applied to the entire survey sample using the National Cancer Institute's (NCI) method[13,14]. Added sugars, which are not available in the food composition database used (Canadian Nutrient File-supplement 2001b), were estimated using a method proposed by Brisbois *et al.* in which food groups were categorised as containing either added or naturally occurring sugars[15]. Na intakes from foods and beverages and from salt added to recipes or at the table were captured in this study. Data on socio-demographic and lifestyle characteristics, and health conditions were collected and imputed when missing. Out of 16 212 participants, 2019 (12·45 %) had missing data on at least one of the key variables. Missing data were assumed to occur at random, an assumption which was tested and confirmed as all imputed variables showed similar distribution to before imputation. Weight and height were measured in-person but in the event it was self-reported, a correction factor was used to determine BMI[16]. A correction factor was applied to 4620 participants (28·5 %) with missing measured BMI and non-missing self-reported BMI (online Supplementary Materials).

*a) Canadian Community Health Survey-Nutrition 2004 linked to the Canadian Vital Statistics – Death Database .* Of the CCHS-Nutrition 2004 participants, 89·33 % (*n* 29 897) agreed to share and link their survey information with federal and provincial administrative databases. A detailed description of the linked cohort data and linkage methodology has been published[17]. Data from CCHS-Nutrition 2004 were linked to the CVSD up to 31 December 2011 to ascertain mortality. In total, 1753 death records were identified in the database. Cause of death was coded using the WHO International Classification of Diseases (online Supplementary Table S1). Figure 1 presents the study flow. After exclusions, the final sample comprised of 16 212 adults (representing: 22 898 880 Canadians). In this analytical sample, 1722 mortality cases were recorded in 115 566 person-years of follow-up (median (interquartile range) of 7·5 (7·2–7·7) years). To address potential confounding, we removed respondents with pre-existing heart disease, diabetes and cancer, leaving 13 473 respondents (*n* 4076 (1739 males and 2337 females) with second day dietary recalls). In sensitivity analyses, the sample was limited to participants ≥ 45 to ≤ 80 years (*n* 8079).

*b) Canadian Community Health Survey-Nutrition 2004 linked to Discharge Abstract Database.* CCHS-Nutrition 2004 was linked to the DAD to ascertain CVD events (incident cases resulting in hospitalisation). The DAD includes discharges from all Canadian acute care hospitals. Hospital discharge records from 2004–2011 were used. In total, 12 643 adults with 3624 second day dietary recalls (excluding Quebec) were available with demographic, administrative and hospital discharge data, after excluding those with heart diseases at baseline (Fig. 1). Additional exclusion of participants with baseline cancer and diabetes resulted in 11 546 adults. Sensitivity analyses limited the sample to participants ≥ 45 to ≤ 80 years (*n* 6017 adults). During follow-up, 567 incident CVD cases and deaths due to CVD were identified.

### Estimating usual intakes of Na, added sugars and saturated fat

Both days of 24-h dietary recall were used. To handle outliers for energy (kJ (kcal)), Na density (g/4184 kJ (1000 kcal)), percentage of total energy from added sugar and from saturated fat, we

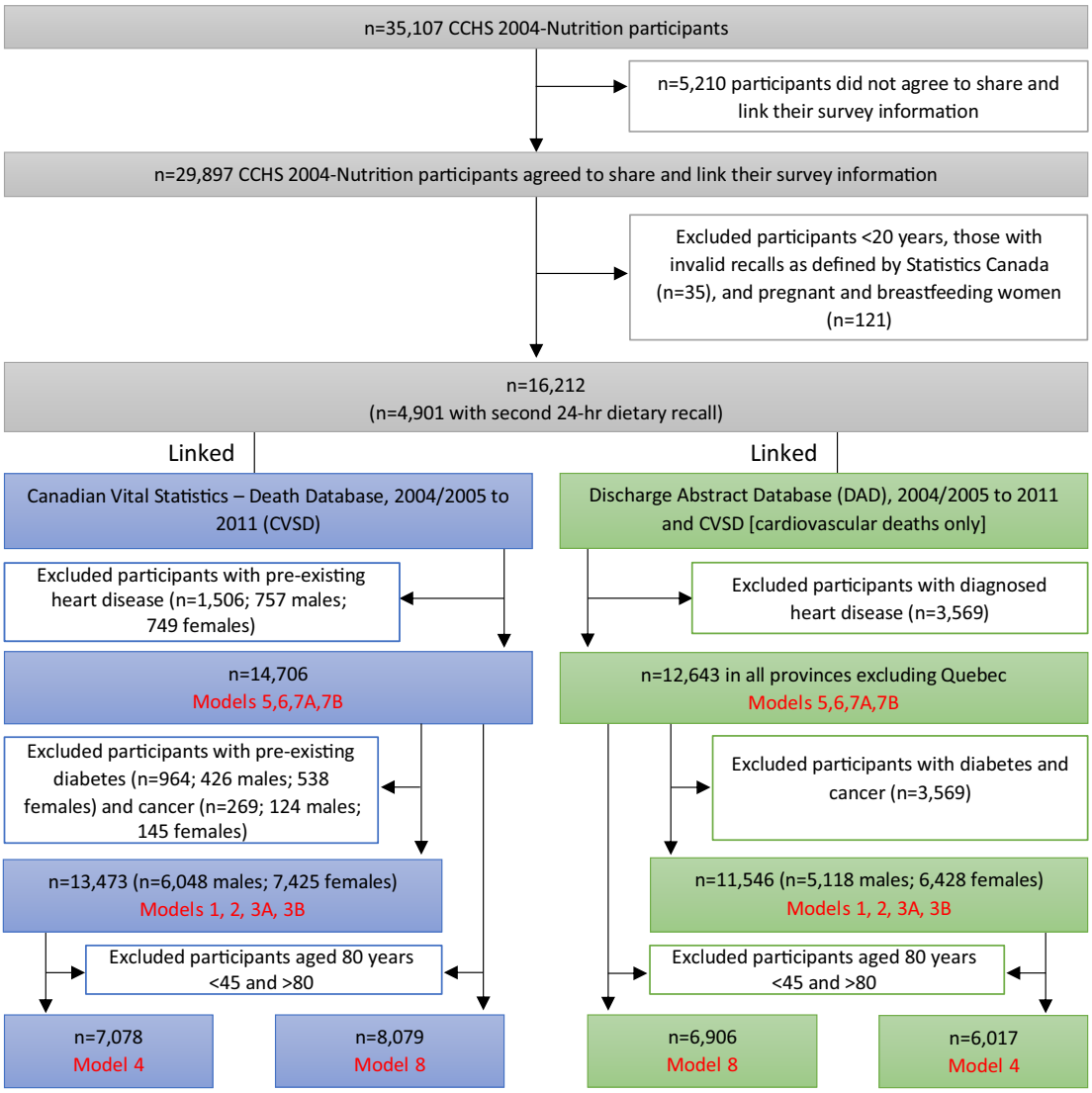


**Fig. 1.** Study flow – analytical sample of Canadian adults in Canadian Community Health Survey (CCHS)-Nutrition Linked to Canadian Vital Statistics – Death Database (CVSD) and Discharge Abstract Database (DAD), 2004/2005 to 2011.

used the BOXCOX_SURVEY macro provided by the NCI to find the best Box-Cox transformation to normality based on the first day of dietary recall[18]. After transforming the data, we winsorised any observations that fell below *quartile 1 − 3 × interquartile range* or above *quartile 3 + 3 × interquartile range* (< 0·5 % of records) by replacing them with the next closest value before back-transforming all observations to their original scale.

The NCI method for estimating usual dietary intake was used to ascertain long-term dietary exposure[13,19]. Non-linear mixed-effects models were used to estimate the mean and distribution of usual intake for energy and the nutrients under investigation[13]. To examine nutrient–disease associations with correction for measurement error, regression calibration was performed as part of the NCI model[20]. We estimated a bivariate distribution for energy and each nutrient (e.g. added sugar in grams) to find percentiles of the ratio between the two (percentage of energy from added sugar). The percentiles were then used for regression[20]. All NCI method steps were bootstrapped 500 times using the bootstrap resampling weights provided by Statistics Canada to account for complex sampling design.

We assessed additional models to further evaluate the impact of random measurement error, by including the first 24-h recall data only (i.e. not removing random measurement error) (online Supplementary Table S2).

### *Dietary misreporting (addressing systematic measurement error)*

Participants' energy intake was compared with their estimated energy requirements, calculated using the participant's age, sex, physical activity level (i.e. sedentary, low active, active, very active) and measured weight and height (using the Institute of Medicine factorial equations). Having an energy intake < 70, > 142 and 70–142 % of estimated energy requirement was flagged as under-reporting, over-reporting and plausible reporting, respectively[21]. Misreporting status was used for estimation

of usual intake distribution and for ascertaining diet–disease relationships to help improve precision of results (see online Supplementary Materialsfor additional details)[21,22].

### Covariate definition

Covariates were selected *a priori*, based on previous literature, and nutrients were treated as continuous exposures[23,24]. Sequence of dietary recall (first or second day) and day of the week (weekend or weekday) were the main covariates in all models (for usual intake distributions). In addition, other covariates used in the sensitivity analyses included baseline age (continuous), sex, education (less than secondary school graduation, secondary school graduation, some post-secondary, post-secondary graduation), smoking status (never, current < 20 cigarettes/d, current ≥ 20 cigarettes/d, former and those with ≥ 100 lifetime cigarettes), misreporting (under-reporter, plausible-reporter and over-reporter), physical activity (daily metabolic equivalent of task: ≥ 3, 1·5 ≤ to < 3, < 1·5), BMI (underweight, normal weight, overweight, obesity), alcohol consumption (over the past 12 months: 0 drinks; less than 1–3 times/month; 1–3 times/week; 4–7 times/week, binge drinker (i.e. ≥ 5 drinks 1 or more times/week)), racial group (White, Black, Korean/Chinese/Filipino/Japanese/South East Asian, West Asian/South Asian/Arab, Multiple ethnicity/Others) and self-reported hypertension (yes/no). We also adjusted for the Healthy Eating Index-2010 score (from 0 to 100) minus the score for the nutrient under study, to ensure that the nutrient–disease associations were not influenced by other dietary confounders.

Findings are presented for males and females combined (sex used as a covariate in all models). The sex-stratified analyses resulted in convergence error during the bootstrapping procedure, which confirmed lack of power.

### Statistical analysis

We tested for linearity of nutrient–disease associations by adapting the residual method for energy adjustment. We estimated weighted regression-calibrated values for the usual intake of all three nutrients using Box-Cox transformation with $\lambda = 1$, 1·5, 2, 2·5 and 3 (functional form)[20]. The residuals of weighted regressions from each Box-Cox transformation compared using a *t* test. All nutrient–disease associations were approximately linear ($\lambda = 1$) except for the association between added sugar and all-cause mortality ($\lambda = 2{\cdot}5$) and added sugar and CVD events ($\lambda = 3$). Weighted Cox proportional hazards regression models were used to estimate the hazard ratio (HR) and 95 % CI for all-cause mortality and incident CVD events. Cox proportional hazards assumptions were checked using weighted Schoenfeld residual variables plotted against time to event variables. No departure from proportionality of hazards over time was found. Further, interaction terms of person-time and dietary factors were not significant, which additionally confirms proportionality of hazards assumption. A weighted Cox proportional hazards model was conducted to calculate a HR for the association of usual intake of nutrients with all-cause mortality and incident CVD events. All 95 % CI for HR were estimated from CV after 500 bootstrap runs. Adjusted HR were estimated by comparing mid-values of the quintiles (i.e. percentiles 10, 30, 50, 70 and 90) of nutrient intake, with quintile 1 as reference. The base model was adjusted for age and sex only. We re-ran analyses removing the first year of follow-up, and results were materially the same; thus, models based on the full dataset were retained as recommended elsewhere[25]. We also tested for the interaction of all nutrients with hypertension in weighted Cox models.

All analyses were conducted with R 3.4.0 and SAS Version 9.4 (SAS Institute) and were weighted using Statistics Canada's sample survey weights. Variance estimates were calculated with the bootstrap technique to account for the complex sampling design of CCHS-Nutrition 2004[26].

## Results

The weighted mean and bootstrapped standard errors of the estimated usual intake values for all nutrients examined were similar among males and females. In the base model, males had slightly higher percentage of energy as added sugars (10·27 (SD 0·24) *v.* 9·59 (SD 0·20)), slightly lower values for Na density (1504·60 (SD 17·47) *v.* 1523·34 (SD 13·14) mg/4184 kJ (1000 kcal)) and similar percentage of energy as saturated fat (10·19 (SD 0·12) *v.* 10·20 ± 0·12) than females.

Tables 1 and 2 present the weighted and multivariable-adjusted HR and bootstrapped 95 % CI of all-cause mortality and CVD events according to the mid-point of quintiles of usual intake. In the base model, among adults with no self-reported diabetes, cancer or heart disease (*n* 13 473), there was a consistent, though not significant, association between Na density and all-cause mortality (HR: 1·25; 95 % CI 0·86, 1·83) for comparison of the 90th *v.* 10th percentile of usual intake (276·35 unit difference) (Table 1). For CVD events, a 310·34 unit difference in Na density resulted in a HR of 1·48 (95 % CI 0·85, 2·60) (Table 2). The association of usual percentage of energy from added sugars and all-cause mortality was statistically significant in the base model with participants consuming 11·47 % of energy from added sugars having 1·34 (95 % CI 1·01, 1·77) times higher risk of all-cause mortality compared with those consuming 4·17 % of energy from added sugars (Table 1). The association of usual percentage of energy from saturated fats and all-cause mortality was not statistically significant (HR: 1·23; 95 % CI 0·88, 1·72) (Table 1). The association was weaker after adding confounders (models 1–3), and stronger after restricting the sample to those ≤ 45 to ≥ 80 years (models 4 and 8) (Tables 3 and 4). Generally, adding the Healthy Eating Index-2010 score as a covariate did not change the HRs, though none of the sensitivity models was statistically significant. For the association of the percentage of energy from added sugars and saturated fat with all-cause mortality, there was a significant interaction for hypertension (models 3b and 7b) and therefore models including both normotensive and hypertensive tended to be slightly protective, despite being non-significant (Table 3).

When using only the first 24-h dietary recall, the HR approximated 1·00 for all the models tested, confirming that measurement error in dietary intake weakens diet–disease relationships (online

**Table 1.** Weighted and multivariable-adjusted hazard ratios (HR) and bootstrapped 95 % CI of all-cause mortality according to mid-point of quintiles of usual intake of Na density, percentage of energy from added sugars and percentage of energy from saturated fat, Canadian adults in Canadian Community Health Survey-Nutrition linked to Canadian Vital Statistics – Death Database (CVSD), 2004/2005 to 2011

| | Mid-value of the quintiles of estimated usual intakes* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10th percentile | 30th percentile | | 50th percentile | | 70th percentile | | 90th percentile | |
| Characteristic | | HR | 95 % CI | HR | 95 % CI | HR | 95 % CI | HR | 95 % CI |
| Usual Na density, mg/4184 kJ (1000 kcal), median score† | 1379·03 | 1460·95 | | 1510·98 | | 1563·97 | | 1655·38 | |
| Base model‡,§ | 1·00 (Reference) | 1·07 | 0·96, 1·20 | 1·11 | 0·93, 1·34 | 1·16 | 0·90, 1·50 | 1·25 | 0·86, 1·83 |
| Model 1‡,‖ | 1·00 (Reference) | 1·05 | 0·93, 1·19 | 1·09 | 0·89, 1·33 | 1·13 | 0·85, 1·49 | 1·19 | 0·79, 1·80 |
| Model 2‡,¶ | 1·00 (Reference) | 1·06 | 0·93, 1·19 | 1·09 | 0·89, 1·34 | 1·13 | 0·85, 1·51 | 1·20 | 0·80, 1·81 |
| Model 3a‡,** | 1·00 (Reference) | 1·05 | 0·93, 1·19 | 1·09 | 0·89, 1·34 | 1·13 | 0·85, 1·51 | 1·20 | 0·79, 1·83 |
| Model 3b: normotensive‡,†† | 1·00 (Reference) | 1·06 | 0·91, 1·22 | 1·10 | 0·86, 1·39 | 1·14 | 0·81, 1·60 | 1·21 | 0·73, 1·98 |
| Model 3b: hypertensive‡,†† | 1·00 (Reference) | 1·05 | 0·89, 1·25 | 1·09 | 0·82, 1·45 | 1·13 | 0·76, 1·68 | 1·19 | 0·66, 2·13 |
| Usual percentage of energy from added sugar, %† | 4·17 | 6·23 | | 7·73 | | 9·25 | | 11·47 | |
| Base model ($\lambda = 2{\cdot}5$)‡, § | 1·00 (Reference) | 1·04 | 1·00, 1·09 | 1·10 | 1·00, 1·20 | 1·17 | 1·01, 1·37 | 1·34 | 1·01, 1·77 |
| Model 1 ($\lambda = 2{\cdot}5$)‡,‖ | 1·00 (Reference) | 1·02 | 0·98, 1·06 | 1·04 | 0·95, 1·14 | 1·07 | 0·91, 1·25 | 1·14 | 0·85, 1·53 |
| Model 2 ($\lambda = 2{\cdot}5$)‡,¶ | 1·00 (Reference) | 1·02 | 0·98, 1·06 | 1·04 | 0·95, 1·13 | 1·07 | 0·91, 1·25 | 1·12 | 0·84, 1·51 |
| Model 3a ($\lambda = 2{\cdot}5$)‡, ** | 1·00 (Reference) | 1·02 | 0·97, 1·06 | 1·03 | 0·94, 1·13 | 1·06 | 0·90, 1·24 | 1·12 | 0·83, 1·50 |
| Model 3b ($\lambda = 2{\cdot}5$): normotensive‡,†† | 1·00 (Reference) | 1·01 | 0·96, 1·06 | 1·02 | 0·92, 1·14 | 1·04 | 0·86, 1·25 | 1·08 | 0·76, 1·53 |
| Model 3b ($\lambda = 2{\cdot}5$): hypertensive‡,†† | 1·00 (Reference) | 1·02 | 0·95, 1·10 | 1·05 | 0·90, 1·22 | 1·09 | 0·83, 1·43 | 1·18 | 0·71, 1·95 |
| Usual percentage of energy from saturated fat, %† | 7·30 | 8·38 | | 9·13 | | 9·89 | | 11·14 | |
| Base model‡,§ | 1·00 (Reference) | 1·06 | 0·96, 1·16 | 1·10 | 0·94, 1·30 | 1·15 | 0·92, 1·45 | 1·23 | 0·88, 1·72 |
| Model 1‡,‖ | 1·00 (Reference) | 1·02 | 0·89, 1·17 | 1·04 | 0·83, 1·30 | 1·05 | 0·77, 1·44 | 1·08 | 0·68, 1·69 |
| Model 2‡,¶ | 1·00 (Reference) | 1·02 | 0·89, 1·17 | 1·03 | 0·82, 1·30 | 1·05 | 0·76, 1·43 | 1·07 | 0·68, 1·68 |
| Model 3a‡,** | 1·00 (Reference) | 1·02 | 0·89, 1·17 | 1·04 | 0·83, 1·31 | 1·05 | 0·77, 1·45 | 1·08 | 0·68, 1·71 |
| Model 3b: normotensive‡,†† | 1·00 (Reference) | 0·98 | 0·85, 1·14 | 0·97 | 0·76, 1·25 | 0·97 | 0·68, 1·37 | 0·95 | 0·57, 1·57 |
| Model 3b: hypertensive‡,†† | 1·00 (Reference) | 1·10 | 0·89, 1·35 | 1·17 | 0·83, 1·66 | 1·25 | 0·77, 2·03 | 1·38 | 0·69, 2·77 |

* Weighted and multivariable-adjusted HR are calculated using regression calibration (Cox proportional hazards model) and the 95 % CI calculated by bootstrapping the usual intake estimating models B = 500 times at each step. $\lambda = 1$ unless otherwise specified.
† Weighted and error-adjusted usual intake median of the nutrients.
‡ Unweighted *n* 13 473 with 4076 second day of 24-h dietary recalls (941 unique cases of all-cause mortality).
§ Base model (20 ≤ age group): adjusted for baseline age (continuous) and sex.
‖ Model 1 (20 ≤ age group): base model covariates in addition to education (less than secondary school graduation; secondary school graduation; some post-secondary; post-secondary graduation), smoking (daily and occasional smoker with 20 ≤ cigarettes/d; daily/occasional smoker with < 20 cigarettes/d; former daily/occasional smoker and those who smoked ≥ 100 in lifetime; never smoked), misreporting (under-reporter, plausible-reporter and over-reporter), alcoholic beverage consumption (did not drink alcohol in the past 12 month; drank alcohol in the past 12 month for < once a month/once a month/2–3 times a month; drank alcohol in the past 12 month for once a week/2–3 times a week; drank alcohol in the past 12 months for 4–6 times a week/every day OR intense drinking: drank 2–3times a week/4–6 time a week/every day with the frequency of having five or more drinks being once/week/more than once a week), physical activity (daily energy expenditure ≥ 3; 1·5 ≤ daily energy expenditure < 3; and 0 ≤ daily energy expenditure < 1·5), BMI categories (underweight, normal weight, overweight, obesity), racial group (White, black, Korean/Chinese/Filipino/Japanese South East Asian, West Asian/South Asian/Arab, Multiple ethnicity/Others).
¶ Model 2 (20 ≤ age group): model 1 covariates in addition to the Healthy Eating Index (HEI) 2010 score[48] minus the nutrient (Na, added sugar or saturated fat depending on the model being evaluated).
** Model 3a (20 ≤ age group): model 2 covariates in addition to hypertension (yes/no).
†† Model 3b (20 ≤ age group): model 2 covariates in addition to hypertension (yes/no) interaction. Significant interaction for added sugars and saturated fat ($P < 0{\cdot}0001$).

Supplementary Table S2). Intake distributions using single dietary recall were wider (e.g. 841·6–2293·9 for Na density), resulting in larger CI when reporting results at mid-point of quintiles.

## Discussion

This article reports the first results from a nationally representative cohort of Canadian adults, using the CCHS-Nutrition 2004 linked to the CVSD and the DAD. A significant association between increased Na density, percentage of energy from added sugars and saturated fat with all-cause mortality and CVD risk among Canadian adults was not found. However, the non-significant association observed for the relationship of these nutrients with disease and mortality does not undermine the well-established association between Na intake and blood pressure and the potential health benefits of reducing these nutrients at the population level[6,27].

Epidemiological research and randomised clinical trials have shown the association of high Na intake with increased hypertension risk[28–30], though the association of Na intake with CVD endpoints has been inconsistent. Similar to our research, several studies have shown non-significant results[31–34], while others have reported inverse[35–37] or positive[32,38–43] associations. Several factors may explain the inconsistent findings, including differences in ascertainment of CVD events, analytical methods, dietary assessment techniques and handling of measurement errors and not considering the confounding effects of other dietary components. The shorter follow-up period of our study, as well as a tighter range of Na intakes (Canadians generally overconsume Na at the population level) has been

**Table 2.** Weighted and multivariable-adjusted hazard ratios (HR) and bootstrapped 95 % CI of CVD events (incidence and deaths) according to mid-point of quintiles of usual intake of Na density, percentage of energy from added sugars and percentage of energy from saturated fat, Canadian adults in Canadian Community Health Survey-Nutrition linked to Canadian Vital Statistics – Death Database (CVSD) and Discharge Abstract Database (DAD), 2004/2005 to 2011

| | Mid-value of the quintiles of estimated usual intakes* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10th percentile | 30th percentile | | 50th percentile | | 70th percentile | | 90th percentile | |
| Characteristic | | HR | 95 % CI | HR | 95 % CI | HR | 95 % CI | HR | 95 % CI |
| Usual Na density, mg/4184 kJ (1000 kcal), median score† | 1352·36 | 1442·8 | | 1499·2 | | 1560·5 | | 1662·7 | |
| Base model‡,§ | 1·00 (Reference) | 1·12 | 0·95, 1·32 | 1·20 | 0·92, 1·57 | 1·30 | 0·89, 1·90 | 1·48 | 0·85, 2·60 |
| Model 1‡,‖ | 1·00 (Reference) | 1·11 | 0·93, 1·32 | 1·19 | 0·89, 1·58 | 1·27 | 0·85, 1·92 | 1·43 | 0·78, 2·60 |
| Model 2‡,¶ | 1·00 (Reference) | 1·11 | 0·93, 1·34 | 1·19 | 0·88, 1·60 | 1·28 | 0·84, 1·96 | 1·44 | 0·77, 2·67 |
| Model 3a‡,** | 1·00 (Reference) | 1·11 | 0·92, 1·33 | 1·18 | 0·88, 1·60 | 1·27 | 0·83, 1·94 | 1·43 | 0·76, 2·69 |
| Model 3b: normotensive‡,†† | 1·00 (Reference) | 1·16 | 0·93, 1·44 | 1·28 | 0·89, 1·83 | 1·41 | 0·85, 2·34 | 1·65 | 0·79, 3·45 |
| Model 3b: hypertensive‡,†† | 1·00 (Reference) | 1·00 | 0·82, 1·23 | 1·01 | 0·72, 1·41 | 1·01 | 0·62, 1·63 | 1·01 | 0·50, 2·03 |
| Usual percentage of energy from added sugar, %† | 4·42 | 6·64 | | 8·14 | | 9·60 | | 11·87 | |
| Base model (λ = 3) ‡,§ | Reference | 0·99 | 0·93, 1·06 | 0·98 | 0·85, 1·13 | 0·97 | 0·75, 1·25 | 0·93 | 0·56, 1·56 |
| Model 1 (λ = 3)‡,‖ | 1·00 (Reference) | 0·99 | 0·92, 1·06 | 0·97 | 0·82, 1·15 | 0·95 | 0·70, 1·28 | 0·90 | 0·49, 1·65 |
| Model 2 (λ = 3) ‡,¶ | 1·00 (Reference) | 0·99 | 0·92, 1·06 | 0·97 | 0·83, 1·15 | 0·95 | 0·71, 1·29 | 0·91 | 0·49, 1·66 |
| Model 3a (λ = 3) ‡,** | 1·00 (Reference) | 0·99 | 0·92, 1·06 | 0·97 | 0·82, 1·15 | 0·95 | 0·70, 1·29 | 0·90 | 0·48, 1·66 |
| Model 3b (λ = 3): normotensive‡,†† | 1·00 (Reference) | 0·94 | 0·86, 1·03 | 0·87 | 0·71, 1·08 | 0·78 | 0·53, 1·14 | 0·61 | 0·28, 1·31 |
| Model 3b (λ = 3): hypertensive‡,†† | 1·00 (Reference) | 1·07 | 0·96, 1·19 | 1·17 | 0·92, 1·49 | 1·33 | 0·86, 2·05 | 1·76 | 0·73, 4·24 |
| Usual percentage of energy from saturated fat, %† | 7·19 | 8·19 | | 8·92 | | 9·65 | | 10·8 | |
| Base model‡,§ | 1·00 (Reference) | 1·01 | 0·91, 1·13 | 1·02 | 0·85, 1·23 | 1·04 | 0·80, 1·34 | 1·05 | 0·72, 1·54 |
| Model 1‡,‖ | 1·00 (Reference) | 0·97 | 0·83, 1·12 | 0·94 | 0·72, 1·23 | 0·92 | 0·63, 1·34 | 0·89 | 0·52, 1·52 |
| Model 2‡,¶ | 1·00 (Reference) | 0·97 | 0·83, 1·12 | 0·94 | 0·72, 1·23 | 0·92 | 0·63, 1·34 | 0·89 | 0·52, 1·52 |
| Model 3a‡,** | 1·00 (Reference) | 0·97 | 0·83, 1·13 | 0·95 | 0·73, 1·25 | 0·93 | 0·64, 1·36 | 0·90 | 0·52, 1·56 |
| Model 3b: normotensive‡,†† | 1·00 (Reference) | 0·97 | 0·80, 1·19 | 0·95 | 0·67, 1·36 | 0·94 | 0·57, 1·54 | 0·91 | 0·44, 1·86 |
| Model 3b: hypertensive‡,†† | 1·00 (Reference) | 1·03 | 0·83, 1·27 | 1·05 | 0·72, 1·52 | 1·07 | 0·63, 1·81 | 1·10 | 0·52, 2·35 |

* Weighted and multivariable-adjusted HR are calculated using regression calibration (Cox proportional hazards model) and the 95 % CI calculated by bootstrapping the usual intake estimating models B = 500 times at each step. λ = 1 unless otherwise specified.
† Weighted and error-adjusted usual intake median of the nutrients.
‡ Unweighted *n* 11 546 with 3313 second day of 24-h dietary recalls.
§ Base model (20 ≤ age group): adjusted for baseline age (continuous) and sex.
‖ Model 1 (20 ≤ age group): base model covariates in addition to education (less than secondary school graduation; secondary school graduation; some post-secondary; post-secondary graduation), smoking (daily and occasional smoker with 20 ≤ cigarettes/d; daily/occasional smoker with < 20 cigarettes/d; former daily/occasional smoker and those who smoked ≥ 100 in lifetime; never smoked), misreporting (under-reporter, plausible-reporter and over-reporter), alcoholic beverage consumption (did not drink alcohol in the past 12 month; drank alcohol in the past 12 month for < once a month/once a month/2–3 times a month; drank alcohol in the past 12 month for once a week/2–3 times a week; drank alcohol in the past 12 months for 4–6 times a week/every day OR intense drinking: drank 2–3times a week/4–6 time a week/every day with the frequency of having five or more drinks being once/week/more than once a week), physical activity (daily energy expenditure ≥ 3; 1·5 ≤ daily energy expenditure < 3; and 0 ≤ daily energy expenditure < 1·5), BMI categories (underweight, normal weight, overweight, obesity), racial group (White, black, Korean/Chinese/Filipino/Japanese South East Asian, West Asian/South Asian/Arab, Multiple ethnicity/Others).
¶ Model 2 (20 ≤ age group): model 1 covariates in addition to the Healthy Eating Index (HEI) 2010 score[48] minus the nutrient (Na, added sugar or saturated fat depending on the model being evaluated).
** Model 3a (20 ≤ age group): model 2 covariates in addition to hypertension (yes/no).
†† Model 3b (20 ≤ age group): model 2 covariates in addition to hypertension (yes/no) interaction.

shown to contribute to lack of significant association between Na intake and CVD risk[32]. In line with our study, an earlier analysis of the National Health and Nutrition Examination Survey (NHANES) data demonstrated a modest positive but non-significant association between CVD mortality and Na intake among normotensive but not hypertensive adults, possibly explained by lower Na intake among hypertensive adults[23] (79·11 units lower in our research). In another NHANES study, a modest but insignificant association between CVD mortality and Na consumption was attributed to using only the first 24-h dietary recall[36].

The association with all-cause mortality and added sugars, whereby participants consuming 11·47 % of energy content as added sugars had 1·34 times higher risk of all-cause mortality compared with those who consumed 4·17 % of energy as added sugars, lost statistical significance upon adding confounders. For CVD events, a non-significant inverse association was observed between percentage of energy from added sugars and saturated fat for almost all but hypertensive adults. This is in line with the randomised clinical trials that have shown the cholesterol-lowering benefit of replacing saturated fat with linoleic acid, even though this has not been shown to lower the risk of all-cause or CHD mortality[44]. Furthermore, the food sources of saturated fats may play a role in the risk of CVD with recent research showing a higher risk associated with consuming saturated fats from red meat and butter and a lower risk from fish, cheese and yogurts[45]. Additionally, saturated fat intakes in this study were in line with dietary

**Table 3.** Sensitivity analyses: weighted and multivariable-adjusted hazard ratios (HR) and bootstrapped 95 % CI of all-cause mortality according to mid-point of quintiles of usual intake of Na density, percentage of energy from added sugars and percentage of energy from saturated fat, Canadian adults in Canadian Community Health Survey-Nutrition linked to Canadian Vital Statistics – Death Database (CVSD), 2004/2005 to 2011

| | Mid-value of the quintiles of estimated usual intakes* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10th percentile | 30th percentile | | 50th percentile | | 70th percentile | | 90th percentile | |
| Characteristic | | HR | 95 % CI | HR | 95 % CI | HR | 95 % CI | HR | 95 % CI |
| Usual Na density, mg/4184 kJ (1000 kcal), median score† | 1311·82 | 1436·11 | | 1527·7 | | 1624·66 | | 1786·06 | |
| Model 4‡,§ | 1·00 (Reference) | 1·09 | 0·95, 1·25 | 1·16 | 0·91, 1·47 | 1·24 | 0·87, 1·75 | 1·38 | 0·81, 2·33 |
| Median score | 1337·53 | 1446·25 | | 1514·61 | | 1592·82 | | 1717·09 | |
| Model 5‖,¶ | 1·00 (Reference) | 1·02 | 0·92, 1·13 | 1·03 | 0·87, 1·22 | 1·04 | 0·81, 1·34 | 1·06 | 0·74, 1·54 |
| Model 6‖,** | 1·00 (Reference) | 1·02 | 0·92, 1·14 | 1·04 | 0·87, 1·23 | 1·05 | 0·82, 1·35 | 1·08 | 0·74, 1·56 |
| Model 7a: normotensive‖,†† | 1·00 (Reference) | 1·03 | 0·92, 1·15 | 1·05 | 0·87, 1·27 | 1·07 | 0·82, 1·41 | 1·11 | 0·74, 1·67 |
| Model 7b: hypertensive‖,†† | 1·00 (Reference) | 1·01 | 0·87, 1·17 | 1·01 | 0·78, 1·30 | 1·02 | 0·71, 1·46 | 1·02 | 0·60, 1·76 |
| Median score | 1304·44 | 1439·56 | | 1538·61 | | 1645·08 | | 1825·96 | |
| Model 8‡‡,§§ | 1·00 (Reference) | 1·07 | 0·95, 1·20 | 1·12 | 0·91, 1·36 | 1·17 | 0·88, 1·57 | 1·28 | 0·82, 1·99 |
| Usual percentage of energy from added sugar, %† | 3·64 | 5·54 | | 6·80 | | 8·24 | | 10·34 | |
| Model 4 ($\lambda = 2{\cdot}5$) ‡,§ | 1·00 (Reference) | 1·02 | 0·98, 1·06 | 1·05 | 0·97, 1·14 | 1·09 | 0·95, 1·25 | 1·17 | 0·90, 1·53 |
| Median score | 3·88 | 5·97 | | 7·55 | | 9·19 | | 11·52 | |
| Model 5 ($\lambda = 2{\cdot}5$)‖,¶ | 1·00 (Reference) | 1·02 | 0·98, 1·06 | 1·04 | 0·95, 1·13 | 1·07 | 0·92, 1·25 | 1·13 | 0·86, 1·50 |
| Model 6 ($\lambda = 2{\cdot}5$) ‖,** | 1·00 (Reference) | 1·02 | 0·98, 1·06 | 1·04 | 0·95, 1·13 | 1·07 | 0·92, 1·24 | 1·13 | 0·85, 1·49 |
| Model 7a ($\lambda = 2{\cdot}5$): normotensive‖,†† | 1·00 (Reference) | 1·01 | 0·96, 1·01 | 1·01 | 0·92, 1·05 | 1·03 | 0·86, 1·12 | 1·05 | 0·75, 1·23 |
| Model 7b ($\lambda = 2{\cdot}5$): hypertensive‖,†† | 1·00 (Reference) | 1·03 | 0·97, 1·09 | 1·07 | 0·94, 1·21 | 1·12 | 0·89, 1·40 | 1·24 | 0·81, 1·88 |
| Median score | 22·21 | 5·32 | | 6·68 | | 8·11 | | 10·14 | |
| Model 8 ($\lambda = 2{\cdot}5$) ‡‡ | 1·00 (Reference) | 1·02 | 0·99, 1·06 | 1·05 | 0·98, 1·13 | 1·09 | 0·96, 1·24 | 1·17 | 0·92, 1·48 |
| Usual percentage of energy from saturated fat, %† | 6·61 | 8·11 | | 9·11 | | 10·04 | | 11·50 | |
| Model 4‖‖ | 1·00 (Reference) | 1·08 | 0·91, 1·27 | 1·13 | 0·85, 1·50 | 1·18 | 0·80, 1·74 | 1·27 | 0·73, 2·21 |
| Median score | 7·00 | 8·30 | | 9·17 | | 10·03 | | 11·35 | |
| Model 5‖,¶ | 1·00 (Reference) | 1·02 | 0·91, 1·15 | 1·04 | 0·85, 1·26 | 1·05 | 0·80, 1·38 | 1·07 | 0·72, 1·59 |
| Model 6‖,** | 1·00 (Reference) | 1·02 | 0·91, 1·15 | 1·03 | 0·85, 1·26 | 1·05 | 0·79, 1·38 | 1·07 | 0·72, 1·58 |
| Model 7a: normotensive‖,†† | 1·00 (Reference) | 0·97 | 0·85, 1·11 | 0·95 | 0·76, 1·19 | 0·93 | 0·68, 1·27 | 0·90 | 0·58, 1·41 |
| Model 7b: hypertensive‖,†† | 1·00 (Reference) | 1·12 | 0·94, 1·33 | 1·21 | 0·91, 1·60 | 1·30 | 0·88, 1·93 | 1·46 | 0·83, 2·57 |
| Median score | 6·68 | 8·14 | | 9·09 | | 10·00 | | 11·43 | |
| Model 8‡‡,§§ | 1·00 (Reference) | 1·06 | 0·91, 1·22 | 1·09 | 0·86, 1·39 | 1·13 | 0·81, 1·58 | 1·19 | 0·74, 1·91 |

* Weighted and multivariable-adjusted HR are calculated using regression calibration (Cox proportional hazards model) and the 95 % CI calculated by bootstrapping the usual intake estimating models B = 500 times at each step. $\lambda = 1$ unless otherwise specified.

† Weighted and error-adjusted usual intake median of the nutrients.

‡ Unweighted *n* 7078 with 2058 second day of 24-h dietary recalls (580 unique cases of all-cause mortality).

§ Model 4 (45 ≤ age group ≤ 80 years): adjusted for baseline age (continuous) and sex; in addition to education (less than secondary school graduation; secondary school graduation; some post-secondary; post-secondary graduation), smoking (daily and occasional smoker with 20 ≤ cigarettes/d; daily/occasional smoker with < 20 cigarettes/d; former daily/occasional smoker and those who smoked ≥ 100 in lifetime; never smoked), misreporting (under-reporter, plausible-reporter and over-reporter), alcoholic beverage consumption (did not drink alcohol in the past 12 month; drank alcohol in the past 12 month for < once a month/once a month/2–3 times a month; drank alcohol in the past 12 month for once a week/2–3 times a week; drank alcohol in the past 12 months for 4–6 times a week/every day OR intense drinking: drank 2–3 times a week/4–6 time a week/every day with the frequency of having five or more drinks being once/week/more than once a week), physical activity (daily energy expenditure ≥ 3; 1·5 ≤ daily energy expenditure < 3; and 0 ≤ daily energy expenditure < 1·5), BMI categories (underweight, normal weight, overweight, obesity), racial group (White, black, Korean/Chinese/Filipino/Japanese South East Asian, West Asian/South Asian/Arab, Multiple ethnicity/Others), and Healthy Eating Index (HEI) 2010 score minus the nutrient (Na, added sugar or saturated fat depending on the model being evaluated).

‖ Unweighted *n* 14 706 with 4448 second day of 24-h dietary recalls.

¶ Model 5 (20 ≤ age group): adjusted for baseline age (continuous) and sex; in addition to education (less than secondary school graduation; secondary school graduation; some post-secondary; post-secondary graduation), smoking (daily and occasional smoker with 20 ≤ cigarettes/d; daily/occasional smoker with < 20 cigarettes/d; former daily/occasional smoker and those who smoked ≥ 100 in lifetime; never smoked), misreporting (under-reporter, plausible-reporter and over-reporter), alcoholic beverage consumption (did not drink alcohol in the past 12 month; drank alcohol in the past 12 month for < once a month/once a month/2–3 times a month; drank alcohol in the past 12 month for once a week/2–3 times a week; drank alcohol in the past 12 months for 4–6 times a week/every day OR intense drinking: drank 2–3 times a week/4–6 time a week/every day with the frequency of having five or more drinks being once/week/more than once a week), physical activity (daily energy expenditure ≥ 3; 1·5 ≤ daily energy expenditure < 3; and 0 ≤ daily energy expenditure < 1·5), BMI categories (underweight, normal weight, overweight, obesity), racial group (White, black, Korean/Chinese/Filipino/ Japanese South East Asian, West Asian/South Asian/Arab, Multiple ethnicity/Others), in addition to diabetes and cancer as covariates, only heart disease is removed in this dataset.

** Model 6 (20 ≤ age group): model 5 covariates in addition to Healthy Eating Index (HEI) 2010 score minus the nutrient (Na, added sugar or saturated fat depending on the model being evaluated).

†† Model 7 (20 ≤ age group): model 6 covariates in addition to hypertension (yes/no) interaction. Significant interaction for added sugars and saturated fat ($P < 0{\cdot}0001$).

‡‡ Unweighted *n* 8079 with 2355 second day of 24-h dietary recalls.

§§ Model 8 (45 ≤ age group ≤ 80 years): model 6 covariates with age restriction.

‖‖ Unweighted *n* 13 473 with 4076 second day of 24-h dietary recalls (941 unique cases of all-cause mortality).

guidance (up to around the 90th percentile) recommending a maximum 10 % of energy intake from saturated fats, which may have further contributed to the lack of association found[46].

Although our multivariate models were adjusted for a list of *a priori* identified confounders in sensitivity analyses, the possibility of residual confounding due to other dietary factors cannot be ignored. It is likely that the observed effect of Na may be

**Table 4.** Sensitivity analyses: weighted and multivariable-adjusted hazard ratios (HR) and bootstrapped 95 % CI of CVD events (incidence and deaths) according to mid-point of quintiles of usual intake of Na density, percentage of energy from added sugars and percentage of energy from saturated fat, Canadian adults in Canadian Community Health Survey-Nutrition linked to Discharge Abstract Database (DAD) and Canadian Vital Statistics – Death database (CVSD), 2004/2005 to 2011

| | Mid-value of the quintiles of estimated usual intakes* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10th percentile | 30th percentile | | 50th percentile | | 70th percentile | | 90th percentile | |
| Characteristic | | HR | 95 % CI | HR | 95 % CI | HR | 95 % CI | HR | 95 % CI |
| Usual Na density, mg/4184 kJ (1000 kcal), median score† | 1252·57 | 1400·5 | | 1507·7 | | 1615·2 | | 1795·7 | |
| Model 4‡,§ | 1·00 (Reference) | 1·15 | 0·94, 1·40 | 1·27 | 0·90, 1·78 | 1·40 | 0·86, 2·28 | 1·66 | 0·80, 3·43 |
| Median score | 1313·42 | 1429·8 | | 1504·2 | | 1589·2 | | 1728·9 | |
| Model 5‖,¶ | 1·00 (Reference) | 1·06 | 0·91, 1·22 | 1·10 | 0·86, 1·39 | 1·14 | 0·81, 1·61 | 1·22 | 0·73, 2·05 |
| Model 6‖,** | 1·00 (Reference) | 1·06 | 0·91, 1·23 | 1·09 | 0·86, 1·40 | 1·14 | 0·80, 1·62 | 1·22 | 0·72, 2·07 |
| Model 7a: normotensive‖,†† | 1·00 (Reference) | 1·11 | 0·93, 1·33 | 1·19 | 0·89, 1·60 | 1·28 | 0·84, 1·96 | 1·46 | 0·77, 2·78 |
| Model 7b: hypertensive‖,†† | 1·00 (Reference) | 0·96 | 0·81, 1·15 | 0·94 | 0·70, 1·27 | 0·92 | 0·60, 1·40 | 0·88 | 0·46, 1·67 |
| Median score | 1251·22 | 1407·7 | | 1525·4 | | 1639·6 | | 1844·1 | |
| Model 8‡‡,§§ | 1·00 (Reference) | 1·10 | 0·94, 1·28 | 1·17 | 0·89, 1·55 | 1·25 | 0·85, 1·85 | 1·41 | 0·78, 2·57 |
| Usual percentage of energy from added sugar, %† | 3·77 | 5·85 | | 7·29 | | 8·82 | | 10·88 | |
| Model 4 ($\lambda = 3$) ‡,§ | 1·00 (Reference) | 0·99 | 0·93, 1·05 | 0·98 | 0·86, 1·12 | 0·96 | 0·74, 1·24 | 0·93 | 0·56, 1·53 |
| Median score | 3·80 | 6·45 | | 8·52 | | 10·58 | | 13·74 | |
| Model 5‖,¶ | 1·00 (Reference) | 0·88 | 0·75, 1·04 | 0·80 | 0·60, 1·07 | 0·72 | 0·47, 1·10 | 0·62 | 0·34, 1·15 |
| Model 6‖,** | 1·00 (Reference) | 0·88 | 0·74, 1·04 | 0·80 | 0·59, 1·07 | 0·72 | 0·47, 1·10 | 0·62 | 0·33, 1·15 |
| Model 7a: normotensive‖,†† | 1·00 (Reference) | 0·81 | 0·67, 0·97 | 0·68 | 0·48, 0·95 | 0·57 | 0·35, 0·93 | 0·44 | 0·22, 0·90 |
| Model 7b: hypertensive‖,†† | 1·00 (Reference) | 1·05 | 0·83, 1·33 | 1·09 | 0·71, 1·66 | 1·13 | 0·61, 2·07 | 1·19 | 0·49, 2·91 |
| Median score | 2·99 | 5·49 | | 7·42 | | 9·30 | | 11·97 | |
| Model 8‡‡,§§ | 1·00 (Reference) | 0·86 | 0·72, 1·01 | 0·76 | 0·56, 1·02 | 0·67 | 0·44, 1·03 | 0·57 | 0·31, 1·04 |
| Usual percentage of energy from saturated fat, %† | 6·25 | 7·67 | | 8·79 | | 9·82 | | 11·38 | |
| Model 4‡,§ | 1·00 (Reference) | 0·91 | 0·76, 1·09 | 0·85 | 0·61, 1·17 | 0·79 | 0·50, 1·25 | 0·72 | 0·37, 1·38 |
| Median score | 6·96 | 8·08 | | 8·94 | | 9·74 | | 10·98 | |
| Model 5‖,¶ | 1·00 (Reference) | 0·97 | 0·84, 1·11 | 0·94 | 0·74, 1·20 | 0·92 | 0·66, 1·30 | 0·89 | 0·54, 1·46 |
| Model 6‖,** | 1·00 (Reference) | 0·97 | 0·84, 1·11 | 0·94 | 0·74, 1·20 | 0·92 | 0·65, 1·29 | 0·89 | 0·54, 1·45 |
| Model 7a: normotensive‖,†† | 1·00 (Reference) | 0·94 | 0·79, 1·12 | 0·91 | 0·67, 1·22 | 0·87 | 0·57, 1·33 | 0·82 | 0·44, 1·50 |
| Model 7b: hypertensive‖,†† | 1·00 (Reference) | 1·03 | 0·86, 1·23 | 1·05 | 0·76, 1·44 | 1·07 | 0·68, 1·68 | 1·10 | 0·58, 2·10 |
| Median score | 6·56 | 7·85 | | 8·80 | | 9·70 | | 11·01 | |
| Model 8‡‡,§§ | 1·00 (Reference) | 0·90 | 0·76, 1·05 | 0·83 | 0·62, 1·10 | 0·76 | 0·51, 1·14 | 0·68 | 0·39, 1·20 |

* Weighted and multivariable-adjusted HR are calculated using regression calibration (Cox proportional hazards model) and the 95 % CI calculated by bootstrapping the usual intake estimating models B = 500 times at each step. $\lambda = 1$ unless otherwise specified.

† Weighted and error-adjusted usual intake median of the nutrients.

‡ Model 4 (45 ≤ age group ≤ 80 years): adjusted for baseline age (continuous) and sex; in addition to education (less than secondary school graduation; secondary school graduation; some post-secondary; post-secondary graduation), smoking (daily and occasional smoker with 20 ≤ cigarettes/d; daily/occasional smoker with < 20 cigarettes/d; former daily/occasional smoker and those who smoked ≥ 100 in lifetime; never smoked), misreporting (under-reporter, plausible-reporter and over-reporter), alcoholic beverage consumption (did not drink alcohol in the past 12 month; drank alcohol in the past 12 month for < once a month/once a month/2–3 times a month; drank alcohol in the past 12 month for once a week/2–3 times a week; drank alcohol in the past 12 months for 4–6 times a week/every day OR intense drinking: drank 2–3 times a week/4–6 time a week/every day with the frequency of having five or more drinks being once/week/more than once a week), physical activity (daily energy expenditure ≥ 3; 1·5 ≤ daily energy expenditure < 3; and 0 ≤ daily energy expenditure < 1·5), BMI categories (underweight, normal weight, overweight, obesity), racial group (White, black, Korean/Chinese/Filipino/ Japanese South East Asian, West Asian/South Asian/Arab, Multiple ethnicity/Others), and Healthy Eating Index (HEI) 2010 score minus the nutrient (Na, added sugar or saturated fat depending on the model being evaluated).

§ Unweighted *n* 6017 with 1666 second day of 24-h dietary recalls.

‖ Unweighted *n* 12 643 with 3624 second day of 24-h dietary recalls.

¶ Model 5 for CVD (20 ≤ age group): adjusted for baseline age (continuous) and sex; in addition to education (less than secondary school graduation; secondary school graduation; some post-secondary; post-secondary graduation), smoking (daily and occasional smoker with 20 ≤ cigarettes/d; daily/occasional smoker with < 20 cigarettes/day; former daily/occasional smoker and those who smoked ≥ 100 in lifetime; never smoked), misreporting (under-reporter, plausible-reporter and over-reporter), alcoholic beverage consumption (did not drink alcohol in the past 12 month; drank alcohol in the past 12 month for < once a month/once a month/2–3 times a month; drank alcohol in the past 12 month for once a week/2–3 times a week; drank alcohol in the past 12 months for 4–6 times a week/every day OR intense drinking: drank 2–3 times a week/4–6 time a week/every day with the frequency of having 5 or more drinks being once/week/more than once a week), physical activity (daily energy expenditure ≥ 3; 1·5 ≤ daily energy expenditure < 3; and 0 ≤ daily energy expenditure < 1·5), BMI categories (underweight, normal weight, overweight, obesity), racial group (White, black, Korean/Chinese/Filipino/ Japanese South East Asian, West Asian/South Asian/Arab, Multiple ethnicity/Others), in addition to diabetes as covariate, only heart disease is removed in this dataset.

** Model 6 for CVD (20 ≤ age group): model 5 for CVD covariates in addition to Healthy Eating Index (HEI) 2010 score minus the nutrient (Na, added sugar or saturated fat depending on the model being evaluated).

†† Model 7 for CVD (20 ≤ age group): model 6 for CVD covariates in addition to hypertension (yes/no) interaction.

‡‡ Unweighted *n* 6906 with 1914 second day of 24-h dietary recalls.

§§ Model 8 for CVD (45 ≤ age group ≤ 80 years): model 6 for CVD covariates with age restriction.

mediated through consumption of high Na 'foods', which have other dietary components that may work synergistically to impact health outcomes[47]. Similarly, added sugars and saturated fats are present in a variety of food items that have been associated with increased energy intake and unhealthy dietary patterns[47,48]. The addition of Healthy Eating Index score as a confounder may not have accounted for the complexity of nutrient–disease relationships. For instance, simultaneously

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increasing intake of fruits and vegetables and reducing intake of fast foods, carbonated drinks and solid fats result in greater health benefits than restricting a single nutrient[1–3,47].

This study has several strengths. This is the first time nationally representative nutrition surveys were linked with health administrative databases at the population level in Canada with individual level data for Na, added sugars and saturated fat. More than 23 % of participants in our study provided a second day of dietary recall, which is higher than the 8 % used by well-known NHANES studies on the topic[23,24]. The use of the NCI method for handling random measurement error allowed for the calculation of usual intakes while adjusting for several confounding factors in sensitivity analyses[13,19,20,49]. Dietary recalls are more prone to random error (but less biased) than FFQ[50] and can benefit from methods for estimating usual intakes[20,49]. In addition, adjusting for systematic error due to misreporting was a unique consideration, which to the best of our knowledge was neglected in previous studies.

There are several limitations of this research, which may in part explain the lack of statistical significance observed. Lack of power was the first issue we encountered; despite being a large-scale national nutrition survey the mortality rate was lower than the national rate and CVD was not captured for the province of Quebec. Corroborating measurements for self-reported nutrients were not available (e.g. Na estimates from urine collection). The risk-lowering properties of medications (e.g. anti-hypertensives, blood sugar and cholesterol-lowering medications) were unaccounted for. An estimation method was used to determine added sugar levels, which is required given that added sugar contents are not available in the national food composition database and added and naturally occurring sugars are chemically indistinguishable from one another. However, this approach may have resulted in misclassification of added sugar contents for food categories that contain a combination of both naturally occurring and added sugar (e.g. cereals, milk)[15]. Measurement error in food composition tables is well known and depends on the nutrient under study and highlights the need for continuous improvement in accuracy of these databases. There were also limitations common to national nutrition surveys which need rigorous modelling exercises to be handled, and the assumption that intakes are the same before and after the time of survey. Additional changes in time-varying covariates after baseline could also have occurred with changes in diet and other risk factors (e.g. smoking, exercise, alcohol, chronic disease). While the causal association would not change, the absolute burden could change. For example, increasing intakes of added sugars, which as of 2015 sit at around 11·1 % of total energy in Canada, would likely result in an increased burden[52]. Results should be interpreted considering the observational longitudinal design of this research and shorter follow-up period, similar to other observational studies[23,24].

### *Conclusion*

Using a nationally representative nutrition survey linked with health administrative databases, our results did not show a significant association between Na density, added sugars or saturated fat, when considered in isolation, with mortality and CVD events. Focusing on single nutrients in epidemiological studies (national nutrition surveys linked with outcomes) may yield inconsistent and marginal results which have been attributed to interactions and cumulative effects amongst foods and nutrients[53]. An important future direction for evaluating the association of single nutrients or dietary factors with risk of morbidity and mortality is examining whether there is an association in controlled settings and testing the attribution of other unaccounted dietary factors[54]. An important conclusion in terms of data usability is that linked national nutrition surveys may not have enough discriminatory ability to tease out the prospective impacts of nutrients on objective health measures, even though accounting for measurement error strengthened the models, and that any such policy in this area should be tested and evaluated using alternative sources.

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There are no conflicts of interest.

## Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S000711452200099X

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