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Estimates of the current and future burden of cancer attributable to low fruit and vegetable consumption in Canada

Abbey E. Poirier[a], Yibing Ruan[a], Lauren A. Hebert[a], Xin Grevers[a], Stephen D. Walter[b], Paul J. Villeneuve[c], Darren R. Brenner[a,d], Christine M. Friedenreich[a,d,*], on behalf of the ComPARe Study Team[1]

[a] Department of Cancer Epidemiology and Prevention Research, CancerControl Alberta, Alberta Health Services, Calgary, Alberta, Canada
[b] Department of Health Research Methods, Evidence, and Impact, McMaster University, Hamilton, Ontario, Canada
[c] Department of Health Sciences, Carleton University, Ottawa, Ontario, Canada
[d] Departments of Oncology and Community Health Sciences, Cumming School of Medicine, University of Calgary, Calgary, Alberta, Canada

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ABSTRACT

Low fruit and vegetable consumption is associated with colorectal cancer and may be associated with lung, breast, bladder, pancreatic, ovarian, liver, stomach, esophageal, head and neck cancers. We estimated the current attributable and future avoidable burden of cancer associated with low fruit and vegetable consumption in Canada. Using data on cancer incidence, exposure prevalence and risk effects, we estimated the population attributable risk (PAR) for cancers associated with low fruit and vegetable consumption as well as the future avoidable burden. The prevalence of fruit and vegetable consumption was projected to 2032 and cancer incidence was projected to 2042 to estimate the future potential impact fraction of cancer attributable to low fruit and vegetable consumption. Based on estimates from the Canadian Community Health Survey, the prevalence of low fruit (< 4 servings/day) and vegetable (< 4 servings/day) consumption in the Canadian population was 80.5% and 86.6%, respectively. The PARs for colorectal cancer associated with low fruit and vegetable consumption were 6.1% (1, 371 cases) and 2.2% (487 cases), respectively. For all incident cancers in 2015, 0.7% and 0.3% were attributable to low fruit and vegetable consumption, respectively. An increase of one serving/week of fruit could prevent 20,710 colorectal cancer cases cumulatively by 2042, and the same increase in vegetable consumption could prevent 10,185 cases. Although more research on the association between fruit and vegetable consumption and cancer risk is needed, our results demonstrate that with reasonable increases in current fruit and vegetable consumption by Canadians, over 30,000 colorectal cancer cases could be prevented by 2042.

1. Introduction

Low vegetable consumption is classified by the World Cancer Research Fund (WCRF) as having a probable casual association with colorectal cancer (World Cancer Research Fund, 2018; World Cancer Research Fund/American Institute for Cancer Research, 2007). In addition, recent meta-analyses have shown significant associations between low vegetable consumption and cancers of the oral cavity,

* Corresponding author at: Department of Cancer Epidemiology and Prevention Research, CancerControl Alberta, Alberta Health Services, Holy Cross Centre, Box ACB, 2210 2nd St SW, Calgary, Alberta T2S 3C3, Canada.

E-mail addresses: AbbeyE.Poirier@albertahealthservices.ca (A.E. Poirier), Christine.Friedenreich@albertahealthservices.ca (C.M. Friedenreich).

[1] Additional members of the ComPARe study team: Eduardo Franco, Gerald Bronfman Department of Oncology, Division of Cancer Epidemiology, McGill University, Montréal, Québec, Canada nada; Will King, Department of Public Health Sciences, Queen's University, Kingston, Ontario, Canada; Paul Demers, Occupational Cancer Research Centre, Toronto, Ontario, Canada; Prithwish De, Cancer Care Ontario, Toronto, Ontario, Canada; Leah Smith, Canadian Cancer Society, Toronto, Ontario, Canada; Elizabeth Holmes, Canadian Cancer Society, Toronto, Ontario, Canada; Dylan O'Sullivan, Department of Public Health Sciences, Queen's University, Kingston, Ontario, Canada; Karena Volesky, Gerald Bronfman Department of Oncology, Division of Cancer Epidemiology, McGill University, Montréal, Québec, Canada; Zeinab El-Masri, Cancer Care Ontario, Toronto, Ontario, Canada; Robert Nuttall, Health Quality Council of Ontario, Toronto, Ontario, Canada; Mariam El-Zein, Gerald Bronfman Department of Oncology, Division of Cancer Epidemiology, McGill University, Montréal, Québec, Canada; Tasha Narain, Department of Public Health Sciences, Queen's University, Kingston, Ontario, Canada; Priyanka Gogna, Department of Public Health Sciences, Queen's University, Kingston, Ontario, Canada.

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Table 1
Relative risks of cancers associated with low fruit and vegetable consumption.

Exposure	Cancer site	Intake level	Relative risk (95% confidence interval)	
			Men	Women
Fruit	Lung[a]	100 g/day	0.94 (0.89–0.99)	0.95 (0.92–0.99)
	Colorectum[b]	100 g/day	0.97 (0.94–0.99)	0.97 (0.94–0.99)
	Breast[c]	200 g/day	–	0.94 (0.89–1.00)
	Bladder[d]	1 serving/day increment	0.98 (0.96–1.00)	0.98 (0.96–1.00)
	Pancreas[e]	Highest consumption	0.81 (0.68–0.96)	0.77 (0.64–0.92)
	Stomach[f]	100 g/day	0.98 (0.94–1.02)	0.98 (0.94–1.02)
	Esophagus[g,k]	100 g/day	0.84(0.75–0.94)	0.84(0.75–0.94)
Vegetable	Lung[a]	80 g/day	0.96 (0.92–1.00)	0.96 (0.92–1.00)
	Colorectum[b]	100 g/day	0.98 (0.96–0.99)	0.98 (0.96–0.99)
	Bladder[d]	1 serving/day increment	0.97 (0.94–1.00)	0.97 (0.94–1.00)
	Pancreas[e]	Highest consumption	0.76 (0.69–0.83)	0.76 (0.69–0.83)
	Ovary[h]	Highest consumption	–	0.89 (0.81–0.99)
	Liver[i]	Highest consumption	0.78(0.62–0.99)	0.78(0.62–0.99)
	Esophagus[g,l]	100 g/day	0.89 (0.80–0.99)	0.89 (0.80–0.99)
	Head and neck[j]	80 g/day	0.69 (0.50–0.98)	0.86 (0.55–1.39)

[a] Estimates from Vieira and colleagues (Vieira et al., 2016).
[b] Estimates from WCRF/AICR CUP: Colorectal Cancer 2011 report (World Cancer Research Fund, 2015).
[c] Estimates from Aune and colleagues (Aune et al., 2012).
[d] Estimates from WCRF/AICR CUP: Bladder Cancer 2015 report (World Cancer Research Fund, 2016b).
[e] Estimates from Wu and colleagues (Wu et al., 2016).
[f] Estimates from WCRF/AICR CUP: Stomach Cancer 2016 report (World Cancer Research Fund International/American Institute for Cancer Research, 2016). Risk is only present if consumption is < 1 serving/day. Therefore the RR for stomach cancer was converted to 1.18 for 0–1 servings and 1.00 for ≥1 servings.
[g] Estimates from WCRF/AICR CUP: Esophageal Cancer 2016 report (World Cancer Research Fund, 2016a).
[h] Estimates from Hu and colleagues (Hu et al., 2015).
[i] Estimates from Luo and colleagues (Luo et al., 2015).
[j] Estimates from Boeing and colleagues (Boeing et al., 2006).
[k] Squamous cell esophageal cancer.
[l] Adenocarcinoma esophageal cancer.

esophagus, larynx and pharynx (World Cancer Research Fund/American Institute for Cancer Research, 2018), bladder (World Cancer Research Fund, 2016b), pancreatic, ovarian (Hu et al., 2015) and liver cancers (Luo et al., 2015). Low consumption of fruit is classified as having a probable causal association with colorectal cancer (World Cancer Research Fund, 2018). Lung, stomach, esophageal (World Cancer Research Fund, 2018), breast, bladder (World Cancer Research Fund, 2016b), and pancreatic (Wu et al., 2016) cancers have also been shown in meta-analyses to be associated with low fruit consumption. Potential mechanisms explaining these associations include antioxidant effects, an increased activity of detoxifying enzymes, the action of micronutrients, prevention of nutrient deficiency, and a stimulated immune system (Grundy et al., 2016; Key, 2011; World Cancer Research Fund, 2007). Fibre found in non-starchy vegetables and fruit helps to increase stool bulk which in turn increases the transit speed of food through the colon and may thus reduce the absorption of carcinogens in the colon (Key et al., 2004; La Vecchia, 2001).

Previous research has estimated the burden of disease attributable to low fruit and vegetable consumption on both national and global levels (Grundy et al., 2016, 2017; Lock et al., 2005; Nagle et al., 2015; Parkin and Boyd, 2011). The proportion of cancer attributable to low fruit and vegetable consumption was estimated on a global scale (Lock et al., 2005), and separately in the United Kingdom (Parkin and Boyd, 2011), Australia (Nagle et al., 2015) and the Canadian province of Alberta (Grundy et al., 2016). However, to date, such estimates do not exist for Canada. In addition, previous reports did not consider the projected future burden of cancer attributable to low fruit and vegetable consumption. By estimating the future burden of cancer attributable to low fruit and vegetable consumption, we will be able to better understand the proportion of cancer that could be prevented in the future if changes in behaviour through interventions were made now.

Given the previously reported positive associations between low fruit and vegetable consumption and cancer risk, estimating the proportion of cancer in Canada attributable to low consumption could help inform cancer prevention initiatives. As part of the larger Canadian Population Attributable Risk of Cancer Study (ComPARe) (Brenner et al., 2018), the aims of this paper were to estimate the proportion of incident cancer cases in 2015 that were attributable to low fruit and vegetable consumption, and to estimate the proportion of cancer that could be prevented by 2042 if fruit and vegetable consumption behaviours were modified.

2. Methods

Details of the methods used herein have been published previously (Brenner et al., 2018), and a brief summary of the overall methods is included in this supplement. Levels of fruit and vegetable consumption in Canada; risk estimates for the associations between low consumption and cancer; and cancer incidence data (details in methods summary; (Brenner et al., 2019)) were used to estimate the attributable and avoidable burden of cancer in Canada. Low fruit consumption and low vegetable consumption as separate entities will be hereafter be referred to as low fruit and vegetable consumption for simplicity.

2.1. Current population attributable burden of cancer

2.1.1. Latency period

As previously described (Brenner et al., 2018), to account for a latency period between the time fruit and vegetable consumption was reported and cancer diagnosis, historical exposure prevalence data were used. Data on fruit and vegetable consumption were obtained from the 2003 Canadian Community Health Survey (CCHS) and cancer incidence data for 2015 from the Canadian Cancer Registry leading to a 12-year latency period.

2.1.2. Risk estimates

We obtained the most current relative risk (RR) estimates from the International Agency for Research on Cancer (IARC) monographs

(Tomatis et al., 1978), WCRF reports (World Cancer Research Fund, 2015; World Cancer Research Fund, 2016a, b; World Cancer Research Fund International/American Institute for Cancer Research, 2016), and large published meta-analyses (Aune et al., 2012; Boeing et al., 2006; Hu et al., 2015; Luo et al., 2015; Vieira et al., 2016; Wu et al., 2016) (Table 1). The Meta-analyses of Observational Studies in Epidemiology (MOOSE) guidelines (Stroup et al., 2000) were used to assess the quality of meta-analyses when they were used as a source for risk estimates.

2.1.3. Prevalence of exposure

The exposure prevalence data for fruit and vegetable consumption in Canada were obtained from the 2003 CCHS. The CCHS, a biennial cross-sectional, population-based survey conducted by Statistics Canada, focused on health status, health care utilization and health determinants in the Canadian population (Béland, 2002; Statistics Canada, 2016). The CCHS includes five questions on fruit and vegetable consumption (Supplementary Table 1). Potatoes were not considered a vegetable, as a reduced cancer risk has been observed only for non-starchy vegetables. Participants were asked, in separate questions, to record how many times they consumed fruits and vegetables per day, per week or per month, depending on frequency. Two derived variables were generated to record how many times per day the participants consumed fruits and vegetables. We approximated a ‘one time per day’ as ‘one serving per day’, and defined a serving of fruit as equivalent to 100 g and one serving of vegetables as 80 g (Canadian Food Inspection Agency, 2018; World Cancer Research Fund/American Institute for Cancer Research, 2007). The World Cancer Research Fund recommends a minimum consumption of 400 g (4–5 servings) of non-starchy vegetables and fruit each day to protect against cancer (World Cancer Research Fund, 2018). Therefore, we used four or more servings/day of fruits or vegetables as the reference consumption level and generated four lower consumption categories: 0 to < 1, 1 to < 2, 2 to < 3, and 3 to < 4 servings/day. The lower limit of each consumption range was taken as the consumption level for that category and was used to correspond to the appropriate RR.

2.1.4. Statistical analysis

To estimate the current attributable burden of cancers associated with low fruit and vegetable consumption, the PAR equation (Levin, 1953) was used:

$$\mathrm{PAR} = \frac{\sum_x \mathrm{P_x}(\mathrm{RR_x} - 1)}{1 + \sum_x \mathrm{P_x}(\mathrm{RR_x} - 1)}$$

where P_x is the proportion of the population with a consumption category x (the four consumption categories described above) and RR_x is the RR for low consumption in that category. We assumed that the RRs for fruit and vegetable consumption have a log-linear exposure-response relationship, and calculated RR separately for each consumption category (x) using the following equation:

$$\mathrm{RR_x} = \mathrm{RR}^{\mathrm{S_{ref}} - \mathrm{S_x}}$$

where RR represents the RR for a deficit of 1 serving per day of fruit or vegetable consumption, $\mathrm{S_{ref}}$ represents the reference serving level (i.e., ≥4 servings/day), and $\mathrm{S_x}$ represents the serving level for category x.

To estimate the total number of cancer cases attributable to low fruit and vegetable consumption, PAR estimates were multiplied by the site-specific cancer incidence according to age, sex and region in 2015. To estimate the total proportions of cancer attributable to low fruit and vegetable consumption, the age-sex-specific attributable cases were combined for each cancer site and divided by the total number of observed cancer cases at that site for both men and women, individually and combined. Monte Carlo simulation methods were used to estimate the corresponding 95% Confidence Intervals (95% CIs). (Brenner et al., 2018).

2.2. Future avoidable burden of cancer

2.2.1. Prevalence of exposure projections

To project the future prevalence of each fruit and vegetable consumption category, we used CCHS data from 2000, 2003, 2007, and 2011. We used a multinomial logistic regression model to project the future prevalence of fruit consumption over time:

$$\ln \frac{\Pr(Y_i = x)}{\Pr(Y_i = K)} = \beta_0 + \beta_1 Year$$

in which x indicates one of the four low consumption categories, and K indicates the referent category.

For the projection of vegetable consumption, we used a method similar to the one used for projecting physical inactivity prevalence (Friedenreich et al., 2019). In brief, we fitted the prevalence in consumption categories assuming a decreasing trend using either a log-linear model ($\ln \mathrm{P}_x = \beta_0 + \beta_1 Year$) or log-log model ($\ln \mathrm{P}_x = \beta_0 + \beta_1 \ln(Year)$), and selected the model with the higher R-squared value. We fitted the prevalence odds in consumption categories with an increasing trend using either a linear model ($\frac{P}{1-P} = \beta_0 + \beta_1 Year$) or linear-log model ($\frac{P}{1-P} = \beta_0 + \beta_1 \ln(Year)$), and selected the model with a higher R-squared value. Although latency periods depend on the cancer site, we assumed a latency period of 10 years, based on findings from cohort studies on fruit and vegetable intake and cancer outcomes (Boeing et al., 2006; Riboli and Norat, 2003). The prevalence in each region was projected to year 2032. Our projection estimates for all of Canada and each province are shown in Supplementary Fig. 1.

2.2.2. Cancer incidence projections

We refer the reader to detailed (Brenner et al., 2018) and brief (Brenner et al., 2019) descriptions of the methods used to estimate future proportions and rates of cancer incidence.

2.2.3. Counterfactual scenarios

Various counterfactual scenarios were considered to estimate the proportion of cancer cases in Canada that could be avoided in the future. The interventions were selected to represent hypothetical or evidence-based scenarios for the exposure distribution of fruit and vegetable, in which the proportion of ‘exposed’ individuals across the population is changed. The counterfactual scenarios applied were: 1) an increase of one and 2) two servings/day of fruit and vegetable consumption and 3) a 50% reduction in the prevalence of individuals consuming a low amount of fruit and vegetables by 2032. The first two counterfactual scenarios were based on evidence that interventions designed to increase fruit and vegetable consumption in adults can result in increases of 1.5 servings/day (Pomerleau et al., 2005). These counterfactual scenarios assume that no other changes to diet have occurred.

2.2.4. Estimation of potential impact fractions

We used the RR shift method (Barendregt and Veerman, 2010) to estimate the counterfactual intervention effects on fruit and vegetable consumption:

$$\mathrm{PIF} = \frac{\sum_c \mathrm{P_c RR_c} - \sum_c \mathrm{P_c RR_c^*}}{\sum_c \mathrm{P_c RR_c}}$$

where P_c is the projected prevalence in counterfactual category c of fruit or vegetable consumption, RR_c is the RR for that category, and $RR_c{}^*$ is the RR for category c after a counterfactual intervention.

Ethics approval was granted for this project by the Health Research Ethics Board of Alberta - Cancer Committee (HREBA.CC-14-0220_REN4).

Table 2
Prevalence of fruit and vegetable consumption in Canada.

Sex	Age (years)	Fruit consumption prevalence (%)[a] (95% confidence interval)				
		0–1 serving/day	1–2 servings/day	2–3 servings/day	3–4 servings/day	≥4 serving/day
Men	20–34	20.3 (19.1–21.5)	25.3 (24.1–26.5)	21.8 (20.6–23.0)	11.5 (10.6–12.5)	18.5 (17.4–19.7)
	35–44	21.0 (19.8–22.2)	29.0 (27.5–30.5)	21.9 (20.7–23.1)	11.7 (10.7–12.6)	13.7 (12.7–14.8)
	45–64	20.7 (19.7–21.6)	28.6 (27.6–29.7)	23.0 (22.0–24.0)	12.5 (11.7–13.4)	12.1 (11.4–12.9)
	≥65	13.8 (12.9–14.7)	24.7 (23.6–25.9)	25.6 (24.4–26.9)	13.8 (12.8–14.7)	11.5 (10.5–12.4)
	All	19.6 (19.1, 20.2)	27.2 (26.6, 27.9)	22.8 (22.2, 23.4)	12.2 (11.8, 12.7)	14.2 (13.7, 14.7)
Women	20–34	14.6 (13.7–15.5)	23.0 (21.9–24.1)	24.0 (22.8–25.1)	16.1 (15.1–17.1)	20.7 (19.7–21.7)
	35–44	16.4 (15.3–17.6)	24.1 (22.8–25.4)	24.2 (22.9–25.5)	17.2 (15.9–18.4)	16.9 (15.8–18.1)
	45–64	14.2 (13.4–14.9)	24.1 (23.2–25.1)	24.0 (23.1–24.9)	18.0 (17.2–18.8)	17.3 (16.5–18.1)
	≥65	9.0 (8.3–9.7)	21.1 (20.1–22.0)	26.2 (25.2–27.2)	19.6 (18.7–20.6)	16.6 (15.7–17.4)
	All	13.9 (13.4, 14.3)	23.3 (22.7, 23.8)	24.4 (23.9, 25.0)	17.6 (17.1, 18.1)	18.0 (17.5, 18.5)
All	20–34	17.4 (16.7–18.2)	24.2 (23.3–25.0)	22.9 (22.1–23.7)	13.8 (13.1–14.5)	19.6 (18.8–20.4)
	35–44	18.7 (17.9–19.5)	26.6 (25.6–27.6)	23.0 (22.1–23.9)	14.4 (13.6–15.2)	15.3 (14.5–16.1)
	45–64	17.4 (16.8–18.0)	26.4 (25.6–27.1)	23.5 (22.8–24.2)	15.3 (14.7–15.9)	14.8 (14.2–15.3)
	≥65	11.1 (10.5–11.6)	22.7 (21.9–23.4)	26.0 (25.2–26.8)	17.1 (16.4–17.7)	14.3 (13.7–15.0)
	All	16.7 (16.3, 17.0)	25.2 (24.8, 25.6)	23.6 (23.2, 24.0)	15.0 (14.6, 15.3)	16.1 (15.8, 16.5)

Vegetable consumption prevalence (%)[a] (95% confidence interval)								
Sex	Age (years)	0 serving/day	0–1 serving/day	1–2 servings/day	2–3 servings/day	3–4 servings/day	4–5 servings/day	≥5 servings/day
Men	20–34	1.3 (0.9–1.7)	24.2 (23.0–25.4)	39.0 (37.6–40.4)	18.4 (17.3–19.5)	8.6 (7.8–9.5)	3.3 (2.8–3.8)	2.6 (2.2–3.0)
	35–44	0.7 (0.5–1.0)	20.7 (19.5–21.8)	40.1 (38.6–41.6)	21.2 (19.9–22.4)	9.0 (8.0–9.9)	3.0 (2.4–3.5)	2.8 (2.3–3.3)
	45–64	0.5 (0.4–0.7)	17.4 (16.5–18.2)	38.3 (37.1–39.4)	24.5 (23.5–25.6)	10.0 (9.3–10.7)	3.8 (3.3–4.3)	2.4 (2.0–2.8)
	≥65	0.6 (0.4–0.8)	13.1 (12.2–14.0)	32.3 (31.0–33.6)	24.5 (23.3–25.7)	11.6 (10.7–12.5)	4.2 (3.6–4.7)	3.0 (2.5–3.5)
	All	0.8 (0.7, 0.9)	19.4 (18.9, 20.0)	38.0 (37.3, 38.7)	22.0 (21.4, 22.6)	9.6 (9.2, 10.0)	3.5 (3.3, 3.8)	2.6 (2.4, 2.9)
Women	20–34	0.4 (0.3–0.6)	14.2 (13.2–15.2)	32.1 (30.9–33.3)	22.7 (21.7–23.8)	15.2 (14.2–16.2)	6.9 (6.3–7.6)	6.8 (6.2–7.5)
	35–44	0.3 (0.2–0.5)	10.2 (9.3–11.1)	30.4 (29.0–31.8)	27.8 (26.4–29.3)	15.9 (14.7–17.0)	7.3 (6.5–8.1)	6.9 (6.1–7.6)
	45–64	0.3 (0.2–0.3)	9.1 (8.5–9.7)	29.9 (28.9–30.9)	26.6 (25.7–27.6)	16.7 (15.9–17.5)	8.0 (7.4–8.5)	6.8 (6.3–7.4)
	≥65	0.4 (0.3–0.5)	9.3 (8.7–10.0)	29.5 (28.4–30.5)	26.7 (25.7–27.7)	15.1 (14.3–15.9)	6.8 (6.1–7.4)	4.6 (4.1–5.1)
	All	0.3 (0.3, 0.4)	10.8 (10.3, 11.2)	30.5 (29.9, 31.1)	25.9 (25.3, 26.4)	15.8 (15.4, 16.3)	7.3 (7.0, 7.7)	6.4 (6.1, 6.7)
All	20–34	0.9 (0.7–1.1)	19.2 (18.5–20.0)	35.6 (34.6–36.5)	20.6 (19.8–21.3)	11.9 (11.2–12.6)	5.1 (4.7–5.5)	4.7 (4.3–5.1)
	35–44	0.5 (0.4–0.7)	15.5 (14.7–16.2)	35.3 (34.2–36.3)	24.5 (23.5–25.4)	12.4 (11.7–13.1)	5.1 (4.6–5.6)	4.8 (4.3–5.3)
	45–64	0.4 (0.3–0.5)	13.2 (12.7–13.7)	34.1 (33.3–34.8)	25.6 (24.9–26.3)	13.4 (12.9–13.9)	5.9 (5.5–6.3)	4.6 (4.3–5.0)
	≥65	0.5 (0.4, 0.6)	11.0 (10.5, 11.5)	30.7 (29.9, 31.5)	25.7 (24.9, 26.5)	13.6 (13.0, 14.2)	5.6 (5.2, 6.1)	3.9 (3.5, 4.2)
	All	0.6 (0.5, 0.6)	15.0 (14.7, 15.3)	34.2 (33.7, 34.6)	24.0 (23.6, 24.4)	12.8 (12.5, 13.1)	5.5 (5.3, 5.7)	4.6 (4.4, 4.8)

[a] Data from the Canadian Community Health Survey (2003).

Table 3a
Cancer cases and proportions attributable to low fruit consumption in Canada (2015).

Age at exposure	Age at Dx	Lung			Colorectum			Breast			Bladder			Pancreas			Stomach			Esophagus[a]		
		Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC
Men																						
20–34	30–44	75	12.9	10	385	6.4	25	–	–	–	120	4.3	5	60	8.9	5	65	3.6	2	6	33.8	2
35–44	45–54	645	13.4	87	1265	6.8	86	–	–	–	440	4.5	20	195	9.3	18	195	3.6	7	36	34.5	13
45–64	55–74	7390	13.3	983	6820	6.7	458	–	–	–	3825	4.5	172	1315	9.2	121	1100	3.5	39	251	34.3	86
≥65	≥75	4835	11.9	574	4195	5.9	249	–	–	–	3150	3.9	124	750	8.2	61	865	2.5	21	120	31.0	37
Total		12,945	12.8	1654	12,665	6.5	817	–	–	–	7535	4.3	321	2320	8.9	206	2225	3.1	70	413	33.3	138
Women																						
20–34	30–44	115	9.5	11	415	5.8	24	2245	5.9	132	60	3.8	2	40	9.7	4	40	2.6	1	0	30.4	0
35–44	45–54	855	10.2	87	1050	6.1	64	4920	6.2	305	165	4.1	7	150	10.4	16	120	2.9	3	14	32.0	4
45–64	55–74	7125	9.6	682	4530	5.8	261	12,685	5.9	747	1080	3.8	41	1025	9.7	100	530	2.4	13	124	30.4	38
≥65	≥75	4195	8.7	366	3950	5.2	205	4705	5.3	249	1030	3.4	36	870	8.8	77	560	1.6	9	129	27.7	36
Total		12,290	9.3	1146	9945	5.6	554	24,555	5.8	1432	2335	3.7	86	2085	9.4	196	1250	2.1	26	267	29.2	78
Total																						
20–34	30–44	190	10.9	21	800	6.1	49	2245	5.9	132	180	4.1	7	100	9.2	9	105	3.2	3	6	33.8	2
35–44	45–54	1500	11.6	174	2315	6.5	150	4920	6.2	305	605	4.4	27	345	9.7	34	315	3.4	11	50	33.8	17
45–64	55–74	14,515	11.5	1666	11,350	6.3	719	12,685	5.9	747	4905	4.3	213	2340	9.4	221	1630	3.2	51	374	33.0	124
≥65	≥75	9030	10.4	940	8145	5.6	453	4705	5.3	249	4180	3.8	159	1620	8.5	138	1425	2.1	30	250	29.3	73
Total		25,235	11.1	2800	22,610	6.1	1371	24,555	5.8	1432	9870	4.1	407	4405	9.1	402	3475	2.8	96	680	31.7	216

Abbreviations: AC = Attributable cases due to exposure, Dx = Diagnosis, Obs. = Total number of observed cases per age-sex group, PAR = Population attributable Risk.

[a] Squamous cell esophageal cancer.

Table 3b
Cancer cases and proportions attributable to low non-starchy vegetable consumption in Canada (2015).

Age at exposure	Age at Dx	Lung			Colorectum			Bladder			Pancreas			Ovary			Liver			Esophagus[a]			Head and neck		
		Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC
Men																									
20–34	30–44	75	6.9	5	385	2.8	11	120	5.2	6	60	9.2	6	–	–	–	35	8.4	3	14	15.2	2	150	11.5	17
35–44	45–54	645	6.6	43	1265	2.7	34	440	5.0	22	195	8.8	17	–	–	–	160	8.0	13	94	14.7	14	545	11.0	60
45–64	55–74	7390	6.1	453	6820	2.5	168	3825	4.6	176	1315	8.2	108	–	–	–	1085	7.5	81	644	13.7	89	2460	10.4	255
≥65	≥75	4835	5.4	260	4195	2.1	89	3150	4.0	126	750	7.2	54	–	–	–	410	6.5	27	310	12.0	37	835	9.0	75
Total		12,945	5.9	761	12,665	2.4	302	7535	4.4	330	2320	8.0	185	–	–	–	1690	7.3	124	1062	13.3	142	3990	10.2	408
Women																									
20–34	30–44	115	5.2	6	415	2.1	9	60	3.9	2	40	7.0	3	205	3.0	6	10	6.2	1	0	11.9	0	80	8.7	7
35–44	45–54	855	4.9	42	1050	1.9	20	165	3.7	6	150	6.6	10	450	2.8	13	45	6.0	3	11	11.1	1	235	8.2	19
45–64	55–74	7125	4.6	329	4530	1.8	83	1080	3.4	37	1025	6.2	63	1285	2.7	34	250	5.6	14	101	10.5	11	845	7.8	66
≥65	≥75	4195	4.7	195	3950	1.9	73	1030	3.5	36	870	6.3	55	610	2.7	16	210	5.7	12	106	10.6	11	420	7.8	33
Total		12,290	4.7	572	9945	1.9	186	2335	3.5	82	2085	6.3	131	2550	2.7	69	515	5.7	29	218	10.6	23	1580	7.9	125
Total																									
20–34	30–44	190	5.9	11	800	2.4	19	180	4.8	9	100	8.3	8	205	3.0	6	45	7.9	4	14	15.2	2	230	10.6	24
35–44	45–54	1500	5.6	85	2315	2.3	54	605	4.6	28	345	7.8	27	450	2.8	13	205	7.6	15	105	14.3	15	780	10.2	79
45–64	55–74	14,515	5.4	782	11,350	2.2	251	4905	4.3	213	2340	7.3	171	1285	2.7	34	1335	7.1	95	746	13.3	99	3305	9.7	321
≥65	≥75	9030	5.0	455	8145	2.0	163	4180	3.9	162	1620	6.7	108	610	2.7	16	620	6.2	39	415	11.7	48	1255	8.6	108
Total		25,235	5.3	1333	22,610	2.2	487	9870	4.2	411	4405	7.2	315	2550	2.7	69	2205	6.9	153	1280	12.9	165	5570	9.6	533

Abbreviations: AC = Attributable cases due to exposure, Dx = Diagnosis, Obs. = Total number of observed cases per age-sex group, PAR = Population attributable Risk.
[a] Adenocarcinoma esophageal cancer.

Table 4
Summary of cases and proportions of cancer in Canada in 2015 attributable to low fruit and vegetable consumption.

Exposure	Cancer site	Total			Men			Women		
		Observed cases[b]	Attributable cases[c]	% attributable[d]	Observed cases	Attributable cases	% attributable	Observed cases	Attributable cases	% attributable
Low fruit consumption[a]	Lung	25,235	2800	11.1	12,945	1654	12.8	12,290	1146	9.3
	Colorectum	22,610	1371	6.1	12,665	817	6.5	9945	554	5.6
	Breast	24,555	1432	5.8	–	–	–	24,555	1432	5.8
	Bladder	9870	407	4.1	7535	321	4.3	2335	86	3.7
	Pancreas	4405	402	9.1	2320	206	8.9	2085	196	9.4
	Stomach	3475	96	2.8	2225	70	3.1	1250	26	2.1
	Esophagus[h]	680	216	31.7	413	138	33.3	267	78	29.2
	All probable cancers[e]	22,610	1371	6.1	12,665	817	6.5	9945	554	5.6
	All associated cancers[f]	90,830	6723	7.4	38,103	3205	8.4	52,727	3518	6.7
	All cancers[g]	187,070	1371/6723	0.7/3.6	94,910	3205	3.4	92,160	3518	3.8
Low non-starchy vegetable consumption[a]	Lung	25,235	1333	5.3	12,945	761	5.9	12,290	572	4.7
	Colorectum	22,610	487	2.2	12,665	302	2.4	9945	186	1.9
	Bladder	9870	411	4.2	7535	330	4.4	2335	82	3.5
	Pancreas	4405	315	7.2	2320	185	8.0	2085	131	6.3
	Ovary	2550	69	2.7	–	–	–	2550	69	2.7
	Liver	2205	153	6.9	1690	124	7.3	515	29	5.7
	Esophagus[i]	1280	165	12.9	1062	142	13.3	218	23	10.6
	Head and neck	5570	533	9.6	3990	408	10.2	1580	125	7.9
	All probable cancers[e]	22,610	487	2.2	12,665	302	2.4	9945	186	1.9
	All associated cancers[f]	73,774	3472	4.7	42,207	2250	5.3	31,567	1221	3.9
	All cancers[g]	187,070	487/3472	0.3/1.9	94,910	2250	2.4	92,160	1221	1.3

[a] Data on prevalence of low non-starchy vegetable consumption from the Canadian Community Health Survey (2000/01).
[b] Number of observed cancer cases in Canada in 2015 at individual cancer sites from the Canadian Cancer Registry.
[c] Number of cancer cases at individual cancer sites that can be attributed to low non-starchy vegetable consumption.
[d] Proportion of cancers at individual cancer sites attributable to low non-starchy vegetable consumption.
[e] Results presented for cancer sites classified by the WCRF as having a probable association with food containing dietary fibre (colorectal cancer).
[f] All associated cancers includes all cancers known to be associated with low non-starchy vegetable consumption (as listed in the current table).
[g] All cancers includes all incident cancer cases in Canada for ages 30 and above in 2015. The attributable cases and PAR are presented as "Probable/All Associated."
[h] Squamous cell esophageal cancer.
[i] Adenocarcinoma esophageal cancer.

3. Results

3.1. Current attributable burden of cancer

3.1.1. Fruit consumption

All results in-text have been rounded to three significant figures. Table 2 shows that the estimated prevalence of low fruit consumption in the Canadian population was 80.5% (81.8% in men and 79.2% in women) in 2003, where 41.9% of Canadians consumed less than two servings of fruit/day. The prevalence of fruit consumption by Canadian provinces is presented in Supplementary Table 2a.

The PAR estimates for esophageal (squamous cell carcinoma), lung, pancreatic, colorectal, breast, bladder, and stomach cancers were 31.7%, 11.1%, 9.1%, 6.1%, 5.8%, 4.1%, and 2.8%, respectively (Table 3a). The highest numbers of attributable cases were observed for lung (2800 cases), breast (1430 cases) and colorectal (1400 cases) cancers (Table 3a).The proportion of cancer attributable to low fruit consumption in 2015 was 7.4% for all associated cancers and 3.6% for all incident cancers, corresponding to about 6700 incident cases (Table 4). PAR estimates associated with low fruit consumption with 95% confidence intervals are presented in Supplementary Table 3a. PAR estimates for low fruit consumption in Canadian provinces are presented in Supplementary Table 4a.

3.1.2. Vegetable consumption

As shown in Table 2, the current prevalence of low vegetable consumption in the Canadian population is 86.6% (89.8% in men and 83.3% in women). The prevalence of vegetable consumption by Canadian provinces is presented in Supplementary Table 2b.

The burden of cancer in 2015 attributable to low vegetable consumption was 12.9% for esophageal adenocarcinoma, 9.6% for head and neck (oral cavity, pharynx and larynx) cancers, 7.2% for pancreatic cancer, 6.9% for liver cancer, 5.3% for lung cancer, 4.2% for bladder cancer, 2.7% for ovarian cancer, and 2.2% for colorectal cancer (Table 3b). In terms of the highest number of attributable cases, an estimated 1333 cases of lung cancer, 533 cases of head and neck cancers and 487 cases of colorectal cancer were attributable to low vegetable consumption (Table 4). The proportion of incident cancer in 2015 attributable to low vegetable consumption was 4.7% for all associated cancers and 1.9% of all incident cancers, corresponding to approximately 3470 incident cases (Tables 3b and 4). PAR estimates associated with low vegetable consumption with 95% confidence intervals are presented in Supplementary Table 3b. PAR estimates for low vegetable consumption by Canadian provinces are presented in Supplementary Table 4b.

3.2. Future avoidable burden of cancer

If fruit consumption trends in Canada remain unchanged, an

Table 5a
Projected cancer cases and proportions attributable to low fruit consumption and the proportion of cancer cases that could be prevented in 2042 with various changes in fruit consumption levels in Canada.

Sex	Statistic	CTF[a]	Colorectum	Lung	Breast	Bladder	Pancreas	Stomach	Esophagus	All
Men	Projected cases	Base	28,094	14,853	–	10,697	3967	4139	420	62,170
	PAR (%)		7.2	14.3	–	4.9	9.9	4.5	36.3	8.7
	Attributable cases		2036	2125	–	519	394	188	153	5414
Women	Projected cases		21,064	19,156	40,564	3359	3501	2573	195	90,413
	PAR (%)		6.4	10.7	6.5	4.3	10.9	3.1	33	7.4
	Attributable cases		1356	2045	2651	144	381	80	64	6721
All	Projected cases		49,158	34,008	40,564	14,057	7467	6712	615	152,583
	PAR (%)		6.9	12.3	6.5	4.7	10.4	4.0	35.3	8.0
	Attributable cases		3392	4171	2651	663	774	267	217	12,135
Men	Projected cases	1	27,335	14,044	–	10,505	3819	3952	358	60,013
	PIF (%)		2.7	5.4	–	1.8	3.7	4.5	14.9	3.5
	Prevented cases		758	809	–	192	148	188	63	2157
	Cumulative cases		11,993	15,329	–	3149	2465	3140	1351	37,427
Women	Projected cases		20,504	18,302	39,468	3300	3342	2493	166	87,575
	PIF (%)		2.7	4.5	2.7	1.8	4.5	3.1	14.7	3.1
	Prevented cases		560	854	1096	59	159	80	29	2837
	Cumulative cases		8717	15,299	18,080	973	2735	1302	647	47,753
All	Projected cases		47,839	32,346	39,468	13,805	7161	6445	524	147,588
	PIF (%)		2.7	4.9	2.7	1.8	4.1	4.0	14.8	3.3
	Prevented cases		1319	1663	1096	251	307	267	91	4994
	Cumulative cases		20,710	30,628	18,080	4122	5201	4442	1998	85,181
Men	Projected cases	2	26,708	13,389	–	10,345	3697	3952	311	58,402
	PIF (%)		4.9	9.9	–	3.3	6.8	4.5	26	6.1
	Prevented cases		1386	1464	–	352	269	188	109	3768
	Cumulative cases		22,139	28,092	–	5834	4537	3140	2396	66,138
Women	Projected cases		20,079	17,661	38,637	3255	3223	2493	146	85,494
	PIF (%)		4.7	7.8	4.8	3.1	7.9	3.1	24.9	5.4
	Prevented cases		985	1494	1927	105	278	80	48	4918
	Cumulative cases		15,561	27,218	32,300	1742	4862	1302	1120	84,106
All	Projected cases		46,786	31,051	38,637	13,600	6920	6445	457	143,897
	PIF (%)		4.8	8.7	4.8	3.2	7.3	4.0	25.7	5.7
	Prevented cases		2372	2958	1927	457	547	267	158	8686
	Cumulative cases		37,700	55,310	32,300	7576	9400	4442	3516	150,244
Men	Projected cases	3	27,076	13,790	–	10,438	3770	4046	344	59,463
	PIF (%)		3.6	7.2	–	2.4	5.0	2.3	18.2	4.4
	Prevented cases		1018	1063	–	259	197	94	76	2707
	Cumulative cases		7370	8393	–	1915	1465	646	649	20,438
Women	Projected cases		20,386	18,133	39,239	3287	3311	2533	163	87,052
	PIF (%)		3.2	5.3	3.3	2.2	5.4	1.6	16.5	3.7
	Prevented cases		678	1023	1326	72	190	40	32	3361
	Cumulative cases		4872	7925	9805	535	1446	271	280	25,135
All	Projected cases		47,462	31,923	39,239	13,725	7080	6579	507	146,515
	PIF (%)		3.4	6.1	3.3	2.4	5.2	2.0	17.6	4.0
	Prevented cases		1696	2085	1326	332	387	134	108	6068
	Cumulative cases		12,242	16,319	9805	2450	2911	917	929	45,572

Abbreviations: CTF = counterfactual scenario, PIF = Potential impact fraction.
*Adenocarcinoma esophageal cancer.
[a] Base = no change in prevalence trend. Scenario 1 = increase in fruit consumption by 1.0 serving/day. Scenario 2 = increase in fruit consumption by 2.0 servings/day. Scenario 3 = a 50% relative reduction in the prevalence of fruit insufficiency by 2032.

estimated 3400 colorectal cancers cases and 12,100 cancer cases at all associated sites will be attributable to low fruit consumption in 2042 provided the current trend in fruit consumption (Table 5a). An increase of 1.0 serving/day of fruit across the Canadian population is estimated to prevent 1300 colorectal cancer cases in 2042 and 20,700 cases cumulatively by 2042 for men and women combined (Table 5a). Increasing fruit consumption by 2.0 servings/day is estimated to prevent 2400 colorectal cancer cases in 2042 and 37,700 cases cumulatively by 2042 (Table 5a). According to the third counterfactual scenario, a 50% reduction in the prevalence of low fruit consumption by 2032 is estimated to prevent 1700 colorectal cancer cases in 2042 and 12,200 cases cumulatively by 2042 (Table 5a; Fig. 1).

We estimated that about 1450 colorectal cancer cases and 7310 cancer cases at all associated sites in Canada in 2042 will be attributable to low vegetable consumption if no changes in vegetable consumption habits occur (Table 5b). Equivalent increases in vegetable intake of 1.0 and 2.0 servings/day are estimated to prevent 600 cases of colorectal cancer in 2042 (10,200 cases cumulatively by 2042; Table 5b) and 1070 colorectal cancers in 2042 (18,300 cases cumulatively; Table 5b), respectively. A 50% reduction in the number of people who are consuming a low amount of vegetables by 2032 is estimated to prevent 730 colorectal cancers in 2042 and 5500 cases cumulatively by 2042 (Table 5b; Fig. 2).

4. Discussion

Approximately 50% of the Canadian population consumes less than two servings of vegetables per day, while Health Canada recommends 4–5 servings per day (Table 2) (Health Canada, 2011). In 2015, 7.4% (6720 cases) and 4.7% (3470 cases) of cancer cases at sites known or suggested to be causally associated with low fruit and vegetable consumption were attributable to low consumption of fruit and vegetables, respectively. Considering all incident cancers in 2015, these PAR estimates correspond to 3.6% and 1.9% of all cancer attributable to low

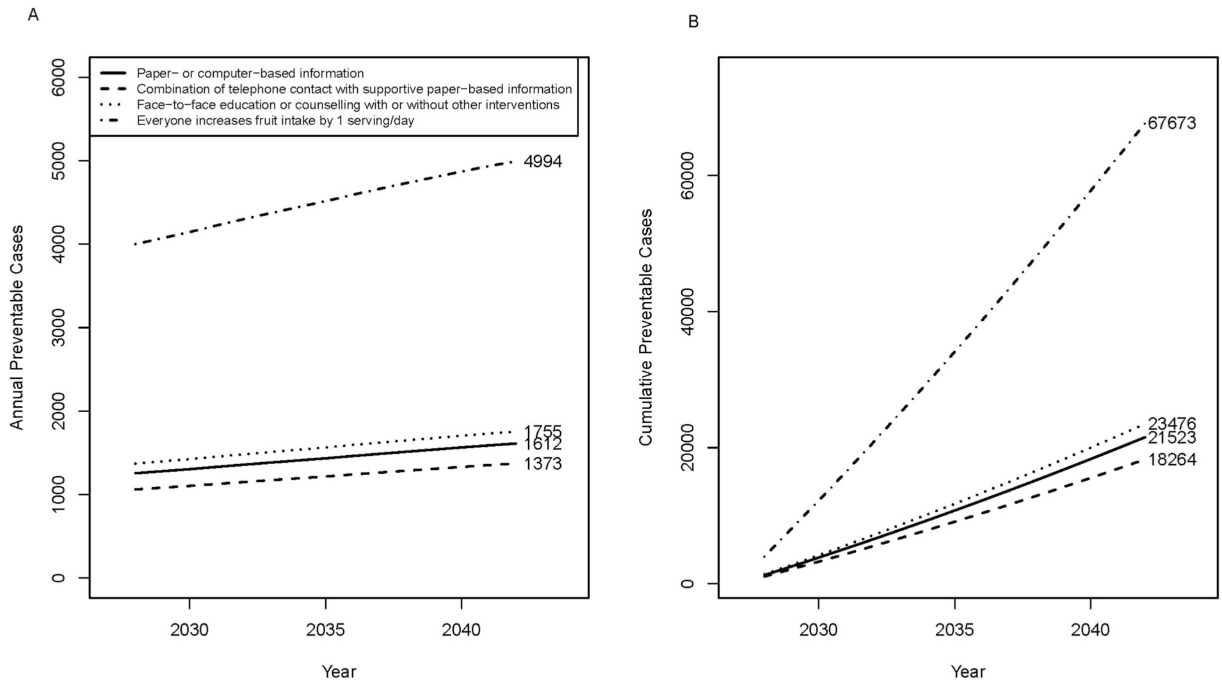

Fig. 1. A) Projected annual preventable cases attributable to low fruit consumption based on three counterfactual scenarios; B) Projected cumulative preventable cancer cases attributable to low fruit consumption by applying three counterfactual scenarios.

fruit and vegetable consumption, respectively. If we consider only colorectal cancer, which is the only site classified by the WCRF as having a probable association with food containing dietary fibre, 0.7% and 0.3% of all cancers diagnosed in Canada in 2015 were attributable to a lack of fruit and vegetable consumption, respectively. We showed in our hypothetical scenarios that a large number of cases could be avoided cumulatively by 2042, if Canadians began consuming more fruits and vegetables. If the trends for these dietary behaviours remain unchanged, we projected that in 2042, about 19,400 cancer cases from all associated sites would be attributable to low fruit and vegetable consumption. Up to 150,000 cancer cases could be prevented by 2042 by increasing fruit consumption in Canada and up to 101,000 cases could be prevented by increasing vegetable consumption.

In 2016, we estimated that the cancer incidence attributable to low fruit and vegetable consumption in Alberta, Canada was 10.2% and 1.8% of cancers at associated sites and all incident cancers in 2012 were attributable to low consumption, respectively (Grundy et al., 2016). In the Alberta-based analysis, fruit and vegetable consumption were combined and low consumption was considered fewer than five servings per day. Studies conducted in Australia (Nagle et al., 2015) and the UK (Parkin and Boyd, 2011) have also estimated the burden of cancer attributable to low fruit and vegetable consumption. It was estimated that 1.4% and 0.3% of all cancers in Australia in 2010 were attributable to low fruit consumption and low vegetable consumption, respectively (Nagle et al., 2015). These estimates are lower than those presented here. The Australian study used 3 and 3.5 servings/day as the reference category for fruit and vegetable consumption, respectively, and they excluded colorectal cancer in the analysis, which could account for the lower PAR estimates. The UK study estimated that 4.7% of all cancers in the UK in 2010 were attributable to low fruit and vegetable consumption combined (Parkin and Boyd, 2011), which is in-line with our results.

Several methodologic features distinguish our study from previous investigations. We included additional cancer sites beyond both the Australian and UK studies, such as breast, bladder and pancreatic cancers for low fruit consumption, and bladder, pancreatic, ovarian and liver cancer for low vegetable consumption. The decisions for inclusions of these cancer sites were based on the results of updated reports and meta-analyses (Aune et al., 2012; Hu et al., 2015; Luo et al., 2015; World Cancer Research Fund, 2016b; Wu et al., 2016). Furthermore, by conducting separate analyses for fruit and vegetable consumption, we are able to better distinguish the protective effects that each have on their respective associated cancer sites and the number of attributable cases for each.

Our analyses add to the current literature by providing, for the first time, estimates of the future avoidable burden of cancer up to 2042 under different hypothetical intervention scenarios. Randomized controlled trials of various intervention types have provided evidence on the effectiveness of increasing fruit and vegetable consumption at the population level; a median increase of 0.56 servings/day combined fruit and vegetable consumption was reported through computer or paper-based interventions (Pomerleau et al., 2005), a six-month general practitioner counselling intervention resulted in an increase of 1.31 servings/day of both fruits and vegetables (Sacerdote et al., 2006) and mobile app intervention conducted over eight weeks, resulted in an increase of 2.0 servings/day of vegetables (Mummah et al., 2017). These studies demonstrate that increases in fruit and vegetable consumption can be achieved with interventions, which could greatly decrease the future burden of cancer.

There are some limitations that need to be acknowledged. First, although we used prevalence exposure estimates from nationally representative surveys (CCHS), the data were restricted to the frequency of dietary consumption only; no portion-size data were captured. We assumed that a response of "one time per day" equated to "one serving per day" to match the RRs used. However, this assumption introduces measurement errors. Since we had no information on portion size, we may have overestimated or underestimated fruit and vegetable consumption. Moreover, self-reported food frequency data are known to have limited validity in accurately measuring dietary consumption (Shim et al., 2014). We did include fruit juice in our prevalence estimates of fruit consumption. However, we did not have information on what types of fruit juices were consumed, which could have resulted in an overestimation of fruit consumption prevalence given that some fruit juices are made with very little real fruit.

We assumed a log-linear dose relation between the RRs of low fruit and vegetable consumption and the associated cancers. This assumption

Table 5b
Projected cancer cases and proportions attributable to low vegetable consumption and the proportion of cancer cases that could be prevented in 2042 with various changes in vegetable consumption levels in Canada.

Sex	Statistic	CTF[a]	Colorectum	Lung	Bladder	Pancreas	Ovary	Liver	Esophagus[b]	Head & neck[c]	All
Men	Projected cases	Base	28,094	14,853	10,697	3967	–	3342	2592	4594	68,139
	PAR (%)		3.4	8.5	6.4	11.3	–	10.2	18.7	14.1	7.1
	Attributable cases		958	1258	681	447	–	343	484	646	4816
Women	Projected cases		21,064	19,156	3359	3501	3366	909	523	2099	53,977
	PAR (%)		2.3	5.9	4.4	7.9	3.4	7.1	13.3	9.9	4.6
	Attributable cases		492	1125	148	276	113	65	69	207	2496
All	Projected cases		49,158	34,008	14,057	7467	3366	4251	3115	6693	122,116
	PAR (%)		2.9	7.0	5.9	9.7	3.4	9.6	17.8	12.7	6.0
	Attributable cases		1450	2383	828	723	113	407	553	853	7312
Men	Projected cases	1	27,717	14,351	10,428	3787	–	3205	2393	4332	66,213
	PIF (%)		1.3	3.4	2.5	4.5	–	4.1	7.7	5.7	2.8
	Prevented cases		376	502	270	180	–	137	199	262	1926
	Cumulative cases		6207	9922	4620	3127	–	2425	3300	4847	34,449
Women	Projected cases		20,828	18,611	3288	3367	3312	877	489	1998	52,770
	PIF (%)		1.1	2.8	2.1	3.8	1.6	3.5	6.5	4.8	2.2
	Prevented cases		236	545	71	134	55	31	34	101	1208
	Cumulative cases		3978	10,574	1263	2494	1047	544	552	1921	22,373
All	Projected cases		48,545	32,962	13,716	7153	3312	4082	2882	6330	118,983
	PIF (%)		1.2	3.1	2.4	4.2	1.6	4.0	7.5	5.4	2.6
	Prevented cases		613	1046	341	314	55	169	233	363	3133
	Cumulative cases		10,185	20,497	5883	5621	1047	2969	3852	6769	56,822
Men	Projected cases	2	27,417	13,956	10,214	3646	–	3098	2242	4130	64,703
	PIF (%)		2.4	6.0	4.5	8.1	–	7.3	13.5	10.1	5.0
	Prevented cases		677	896	483	320	–	245	350	464	3435
	Cumulative cases		11,418	18,179	8468	5692	–	4421	5934	8803	62,916
Women	Projected cases		20,676	18,265	3243	3282	3277	857	468	1934	52,001
	PIF (%)		1.8	4.7	3.5	6.3	2.7	5.7	10.6	7.9	3.7
	Prevented cases		388	891	117	219	89	51	55	165	1976
	Cumulative cases		6852	18,194	2173	4274	1809	930	934	3287	38,454
All	Projected cases		48,093	32,221	13,457	6928	3277	3955	2710	6064	116,704
	PIF (%)		2.2	5.3	4.3	7.2	2.7	7.0	13	9.4	4.4
	Prevented cases		1065	1787	600	539	89	296	405	629	5411
	Cumulative cases		18,271	36,373	10,641	9966	1809	5351	6868	12,090	101,369
Men	Projected cases	3	27,615	14,224	10,357	3743	–	3171	2350	4271	65,731
	PIF (%)		1.7	4.2	3.2	5.6	–	5.1	9.3	7.0	3.5
	Prevented cases		479	629	340	224	–	171	242	323	2408
	Cumulative cases		3589	5146	2602	1721	–	1342	1828	2531	18,759
Women	Projected cases		20,818	18,593	3286	3363	3310	876	488	1995	52,729
	PIF (%)		1.2	2.9	2.2	3.9	1.7	3.6	6.6	4.9	2.3
	Prevented cases		246	563	74	138	57	32	35	104	1248
	Cumulative cases		1894	4675	585	1121	465	254	263	846	10,104
All	Projected cases		48,433	32,817	13,643	7106	3310	4047	2839	6266	118,460
	PIF (%)		1.5	3.5	2.9	4.8	1.7	4.8	8.9	6.4	3.0
	Prevented cases		725	1192	414	362	57	204	277	427	3656
	Cumulative cases		5483	9821	3187	2843	465	1596	2090	3378	28,863

Abbreviations: CTF = counterfactual scenario, PAR = population attributable risk; PIF = Potential impact fraction.
[a] Base = continuing prevalence trends with no change [a]Scenario 1 = everyone increases vegetable consumption by 1.0 serving/day. Scenario 2 = everyone increases vegetable consumption by 2.0 servings/day. Scenario 3 = a relative 50% reduction in the prevalence of vegetable insufficiency by 2032.
[b] Squamous cell esophageal cancer.
[c] Oral cavity, pharynx and larynx.

is appropriate for some cancer sites but not others, in which a plateau effect exists (Aune et al., 2017). This limitation highlights the need for future research on dietary consumption and specific cancer sites. Third, fruit and vegetable consumption were analyzed separately when there is likely some overlap in the effects of exposure. Fourth, our analyses did not account for potential confounding effects of other dietary or lifestyle factors. We relied on effect estimates that were adjusted for relevant confounders and had to use the marginal exposure distributions. Smoking status is a likely confounder for the association between low fruit consumption and lung cancer risk (Miller et al., 2004). Body mass index and physical activity are also associated with dietary habits and thus may be confounders. Nonetheless, the RRs used in this analysis were adjusted for dietary and lifestyle behaviours, which increases our confidence in the accuracy of our estimates. In addition, we are developing methods to address this issue by incorporating multiple risk factors in our PAR analyses (Poirier et al., 2019). Finally, given the available data, we assumed a 10-year latency period between exposure and cancer diagnosis. This latency period is relatively short given the often long periods of dietary exposure associated with cancer risk. In addition, because of the cross-sectional and self-reported nature of the CCHS, we assumed that the dietary habits reported were representative of an individual's regular diet, which may not be true due to diets changing annually or even seasonally.

With the emerging evidence on fruit and vegetable consumption and cancer prevention, we chose to be inclusive in terms of cancer sites associated with fruit and vegetable consumption. However, we recognize that the WCRF has only identified colorectal cancer as having a probable association with a lack of fruit and vegetable consumption (World Cancer Research Fund/American Institute for Cancer Research, 2018) and therefore our results may be an overestimate of the burden of cancer due to a lack of fruit and vegetable consumption. Colorectal cancer specific estimates are presented throughout the manuscript as

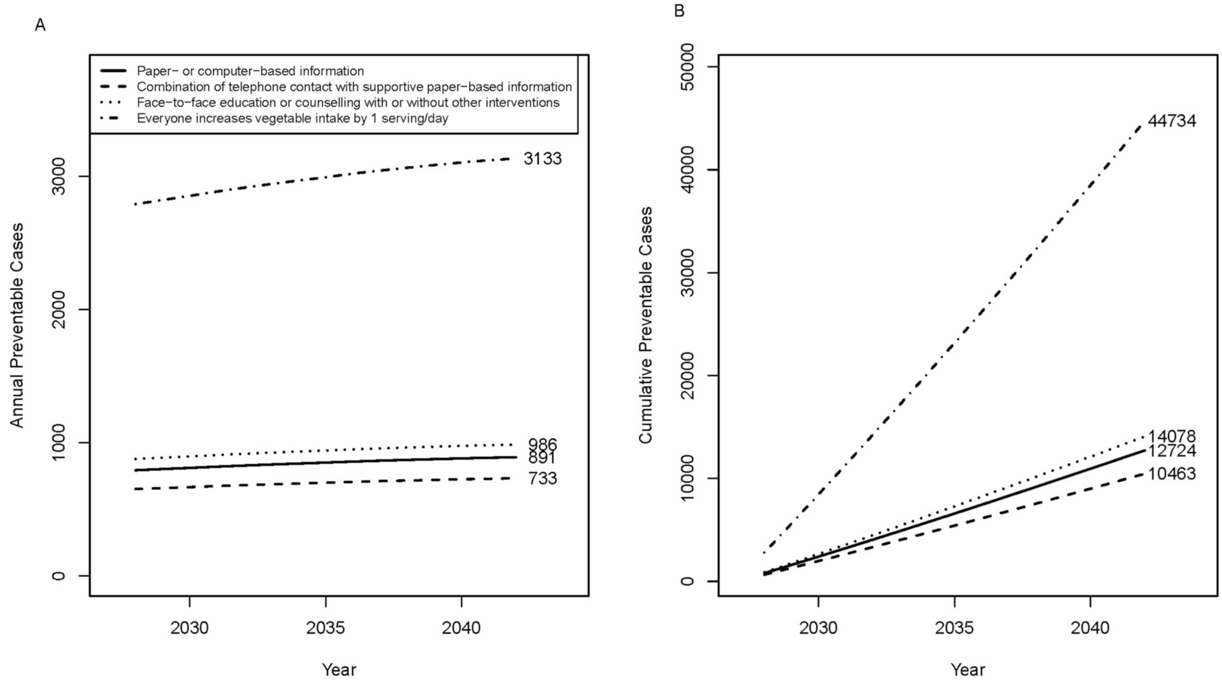

Fig. 2. A) Projected annual preventable cases attributable to low vegetable consumption based on three counterfactual scenarios; B) Projected cumulative preventable cancer cases attributable to low vegetable consumption by applying three counterfactual scenarios.

well to align with the WCRF classifications. In addition, specific fruits and vegetables may have an impact on specific cancer sites, however, the evidence and data on this topic are lacking and therefore could not be assessed in our study.

Our projection of future cancer burden and the prevented cancer cases from intervention targets is based on a simple model and should be interpreted as estimates only. Expert opinion was used in selecting models to help reduce the inevitable error associated with projections. In addition, projected prevalence estimates for fruit and vegetable consumption were not age-specific in our analysis of the future burden of cancer. Age groups were collapsed for Canada and provinces. Although this could be interpreted as a limitation, by using age-specific prevalence projections we would be introducing more assumptions and variability. The aim of our prevalence projections was not to predict or forecast the future fruit and vegetable consumption pattern in Canada, but rather to establish a reasonable trend, based on which we could provide reasonable estimates of the scale of the cancer burden as well as the potential effects of prevention scenarios that may be useful to inform policy setting and public health promotion.

4.1. Conclusion

Over 1800 colorectal cancers and another 8200 cancer cases at possibly associated sites in Canada were attributable to low consumption of fruits and vegetables in 2015. If current dietary trends continue, this number will continue to rise. Policies and intervention programs aiming at increasing the consumption of fruits and vegetables have the potential to reduce the cancer burden in Canada.

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Conflict of interest

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.03.013.

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