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Estimates of the current and future burden of cancer attributable to red and processed meat consumption in Canada

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ABSTRACT

Red meat and processed meat have been consistently associated with an increased risk of colorectal, stomach, pancreatic cancer and esophageal cancer (processed meat only). The purpose of this analysis was to estimate the current attributable and future avoidable burden of cancer related to red and processed meat consumption in Canada. We estimated the population attributable risk of cancer separately for red meat consumption (beef, lamb, and pork, excluding processed meat) and processed meat consumption (sausage and bacon) incorporating current cancer incidence data, relative risks, and exposure prevalence. We also estimated the future avoidable burden of cancer from 2015 to 2042 for Canada and by province using the potential impact fraction associated with various potential intervention scenarios intended to reduce consumption, ranging from a decrease of 0.2 servings/week to 2.0 servings/week among the adult Canadian population aged 20 and over. The estimated mean red meat consumption in the Canadian population in 2007 to 2011 was approximately 3.2 times per week. In addition, Canadians consume an average of 1.2 times of processed meat per week. In 2015, an estimated 5.9% of associated cancers and 0.9% of all cancers were attributable to red meat consumption. An estimated 4.5% of associated cancers and 0.7% of all cancers were attributable to processed meat consumption. A mean decrease of 0.5 servings/week of red meat or processed meat could prevent about 8700 or 16,600 cancer cases, respectively, between 2015 and 2042. In conclusion, a small but meaningful cancer burden is associated with red and processed meat consumption. Interventions aimed at reducing consumption at the population level have the potential in the prevention of many cancers in Canada.

1. Introduction

In 2015, the International Agency for Research on Cancer (IARC) classified processed meat as carcinogenic to humans (Group 1) based on sufficient evidence, and red meat as probably carcinogenic to humans (Group 2A) based on "strong mechanistic evidence supporting a

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carcinogenic effect" (International Agency for Research on Cancer, 2015). Likewise, the World Cancer Research Fund (WCRF) found convincing or probable evidence for the association of red and processed meat and colorectal cancer, and suggestive evidence for several other cancers. The WCRF recommends limiting red meat consumption to < 500 g per week, with very little if any processed meat, for cancer prevention (World Cancer Research Fund, 2011).

Red and processed meat consumption has been consistently associated with a convincing or probable increased risk of colorectal and non-cardia stomach cancers (processed meat only) (Gonzalez and Riboli, 2010; Lippi et al., 2016; Wiseman, 2008; World Cancer Research Fund, 2016a; World Cancer Research Fund/American Institute for Cancer Research, 2011; Zhao et al., 2017a; Zhao et al., 2017b). Additional cancer sites associated with the consumption of red and processed meat have been suggested in recent WCRF reports and meta-analyses, including male pancreatic cancer (World Cancer Research Fund, 2012), stomach cancer (red meat) (Song et al., 2014), and squamous cell carcinoma of esophagus (World Cancer Research Fund, 2016b). The proposed biologic mechanisms to explain the etiologic association between red and processed meat consumption and colorectal cancer risk are that mutagenic heterocyclic amines and polycyclic aromatic hydrocarbons are formed during the cooking of meat at high temperatures and that high levels of heme iron found in red meat stimulates the endogenous formation of carcinogenic N-nitroso compound (Key et al., 2004; Kim et al., 2013; Vineis and Stewart, 2016). In addition, nitrates and nitrites in smoked, salted, and processed meat can be converted into carcinogenic nitrosamines. (Joosen et al., 2009; Key et al., 2004).

The population attributable risk (PAR) on red and processed meat consumption has been previously estimated in a few countries. Parkin estimated that 21.1% of colorectal cancers or 2.7% of all cancer cases could be attributed to red and processed meat in the United Kingdom in 2010 (Parkin, 2011). A similar study in Australia in 2010 estimated that 18% of colorectal cancer or 2.3% of all cancers were attributable to red and processed meat consumption (Nagle et al., 2015). We previously estimated that 12% of colorectal cancers or 1.5% of all cancers were attributable to red and processed meat consumption in Alberta in 2012 (Grundy et al., 2016). However, no nationwide PAR estimates for red and processed meat exist in Canada, which are valuable to inform health policy interventions in Canada. From a prevention and policy perspective, understanding the impact that changes in red and processed meat consumption could have on the future avoidable burden of cancer is of interest since the exposure is modifiable. As part of the ComPARe study, the objectives of this analysis were to: 1) estimate the proportion and number of cases of cancer in 2015 that were attributable to excess red and processed meat consumption and 2) estimate the proportion and the number of excess cases of cancer that could be avoided by 2042 if changes in behaviour with respect to red and processed meat consumption were made now.

2. Methods

This manuscript is part of a special issue of the ComPARe project examining the exposure-specific current attributable and future avoidable burden of cancer in Canada due to modifiable lifestyle and environmental risk factors. More detailed information of the methods used throughout the ComPARe study can be found in previously published work (Brenner et al., 2018) and are included in brief in this special issue (Brenner et al., 2019). We incorporated three data sources in order to estimate the current and future proportion of cancer attributable to red and processed meat: risk estimates for the association between red and processed meat consumption and cancer, the prevalence of red and processed meat consumption in Canada and provinces, and age- and sex-specific cancer incidence data.

Table 1
Relative risks of cancers for red and processed meat consumption.

Cancer site	Level of exposure	Relative risk (95% confidence interval)	
		Men	Women
Read meat			
Colorectum[a]	100 g/day	1.17 (1.05–1.31)	1.17 (1.05–1.31)
Stomach[b]	100 g/day	1.17 (1.05–1.32)	1.17 (1.05–1.32)
Pancreas[c]	100 g/day	1.43 (1.10–1.86)	–
Processed meat			
Colorectum[a]	50 g/day	1.18 (1.10–1.28)	1.18 (1.10–1.28)
Stomach[d,f]	50 g/day	1.18 (1.01–1.38)	1.18 (1.01–1.38)
Pancreas[c]	50 g/day	1.21 (1.01–1.45)	–
Esophagus[e,g]	50 g/day	1.34 (1.00–1.81)	1.34 (1.00–1.81)

[a] Estimates from WCRF/AICR CUP: Colorectal Cancer 2011 Report. (World Cancer Research Fund/American Institute for Cancer Research, 2011).
[b] Estimates from Song and colleagues. (Song et al., 2014).
[c] Estimates from WCRF/AICR CUP: Pancreatic Cancer 2012 Report. (World Cancer Research Fund, 2012).
[d] Estimates from WCRF/AICR CUP: Stomach Cancer 2016 Report (World Cancer Research Fund, 2016a).
[e] Estimates from WCRF/AICR CUP: Esophageal Cancer 2016 Report. (World Cancer Research Fund, 2016b).
[f] Non-cardia stomach.
[g] Squamous esophageal carcinoma.

2.1. Current attributable burden of cancer

2.1.1. Latency period

We acknowledge that there is a latency period between the exposure to carcinogens from red and processed meat and tumor diagnosis. The latency period varies by individuals, is typically quite long and is often unobserved. We used the exposure data from the Canadian Health Measures Survey (CHMS) in 2007 to 2011, assuming that the overall consumption pattern of red and processed meat remained unchanged during the plausible latency period. Using the most recent available cancer incidence data (2015), our resulting assumed latency period ranged from 11 to 15 years.

2.1.2. Risk estimate sources

Risk estimates were obtained from the most current literature syntheses, including the IARC monographs, WCRF reports (Marmot et al., 2007; Stroup et al., 2000), or published meta-analyses of sufficient quality (Table 1). The quality of meta-analyses was assessed based on the Meta-analyses of Observational Studies in Epidemiology (MOOSE) guidelines (Stroup et al., 2000).

2.1.3. Prevalence of exposure data

Red and processed meat exposure data were obtained from the CHMS, a population-representative national survey conducted every two years by Statistics Canada in which self-reported data were collected on lifestyle behaviours, medical history, and demographic and socioeconomic characteristics (Statistics Canada, 2015; Tremblay and Connor Gorber, 2007). In the CHMS, participants reported how often they usually ate red meat such as beef, pork or lamb, and processed meat such as bacon and sausages. The frequency was assessed as times per week. The average times per week of red and processed meat consumption was estimated for each age-sex-region group. We assumed that the reported "times per week" approximates "portions per week", in which one portion is defined by the Canadian Food Guideline as 75 g of red meat or 75 g of processed meat (Health Canada, 2011). The CHMS does not measure the cooking methods of red meat. To our knowledge, there are no population-representative national surveys conducted on cooking methods of meat in Canada.

2.1.4. Statistical analysis

We converted the relative risks (RRs) from grams per day into times per week, assuming that 1 time per week is equivalent to 75 g per week (i.e., 10.7 g per day) of red or processed meat. Because we only acquired mean consumptions for each age-sex-region group instead of proportions of different levels of consumption, we used an alternative PAR estimation method based on average exposure (International Agency for Research on Cancer, 2007):

$$Risk = e^{\ln RR \times M},\ PAR = \frac{Risk - 1}{Risk}$$

where RR is the risk associated with 1 time/week of consumption, and M is the average time/week consumption in each age-sex-region group. To estimate the total number of cancer cases attributable to red and processed meat for each site, PARs were applied using cancer incidence data from 2015. The total proportion of cancer attributable to red and processed meat was estimated by dividing the total number of excess attributable cases for an associated cancer across all age groups by the total number of observed cancer cases at that site for both men and women, individually and combined. Acknowledging that our PAR estimation method is based on the assumption of 100% exposure prevalence (i.e., 0% population not consuming red or processed meat) and may bias the PAR estimates, we carried out sensitivity analyses by adjusting the average time/week consumption in the scenario of 5%, 10%, 15%, and 20% of population that do not eat red or processed meat.

2.2. Future avoidable burden of cancer

2.2.1. Prevalence of exposure projections

Historical data on the red and processed meat consumption that would allow future trends to be projected were not available. Therefore, we assumed that the future consumption levels remained unchanged from the 2007 to 2011 period of the CHMS survey. We also assumed a fixed latency period of 10 years, given current understanding of the carcinogenic process for colorectal cancer, and projected the prevalence in each region to year 2032.

2.2.2. Cancer incidence projections

Cancer incidence from 2016 to 2042 was projected for all cancer sites associated with red and processed meat consumption. Details on the methods used for the projections have been previously published. (Poirier et al., 2019) The methods summary included in this issue also briefly summarizes the projection methods.(Brenner et al., 2019).

2.2.3. Counterfactual scenarios

To estimate the future avoidable burden of cancer, we modeled different intervention scenarios for the exposure distribution of red and processed meat consumption in the Canadian population. These distributions represent an alternative reality in which counterfactual population interventions alter the proportion of 'exposed' individuals in the population. The counterfactual distribution is the exposure distribution in the presence of an intervention or a change in prevalence of the exposure (Murray et al., 2003). We applied a range of counterfactual distributions, including the plausible reductions of 0.5, 1.0 and 2.0 servings/week of red meat (i.e, 37.5, 75, 150 g/week), and 0.2, 0.5 and 1.0 servings/week of processed meat (i.e., 15, 37.5, 75 g/week). We assumed that the other components of the diet remain unchanged in these scenarios. For example, the reduction in red meat consumption is not compensated by eating more processed meat, nor is it compensated by eating more fruits and vegetables or other cancer protective foods.

2.2.4. Estimation of potential impact fractions

We used a combination of the average exposure method (International Agency for Research on Cancer, 2007) and RR shift method (Barendregt and Veerman, 2010) to estimate the potential impact fraction (PIF) for various counterfactual scenarios, when the intervention changes the RR:

$$Risk = e^{\ln RR \times M},\ Risk^* = e^{\ln RR * M^*}$$

$$PIF = \frac{Risk - Risk^*}{Risk}$$

where RR is the risk associated with 1 time/week, and M is the projected average servings/week consumption, and M* is the average servings/week after 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
Mean consumption of red and processed meat (times/week) in Canada[a].

Age (years)	Mean consumption (95% confidence interval)	
	Red meat (times/week)	Processed meat (times/week)
Men		
18–39	3.98 (3.71–4.26)	1.67 (1.44–1.91)
40–59	3.37 (3.17–3.57)	1.23 (1.10–1.36)
60–80	3.16 (2.93–3.39)	1.35 (1.09–1.61)
Women		
18–39	2.88 (2.64–3.11)	1.13 (0.99–1.26)
40–59	2.66 (2.47–2.84)	0.90 (0.79–1.01)
60–80	2.83 (2.32–3.33)	0.86 (0.55–1.18)
Total		
18–39	3.43 (3.24–3.62)	1.40 (1.26–1.54)
40–59	3.01 (2.87–3.16)	1.06 (0.96–1.17
60–80	2.99 (2.70–3.28)	1.10 (0.89–1.30)

[a] Data from Cycle 1 (spring 2007 to spring 2009) and Cycle 2 (August 2009 to November 2011) of the Canadian Health Measures Survey.

3. Results

3.1. Current attributable burden of cancer

3.1.1. Red meat

The estimated average red meat consumption in the Canadian population is approximately 3.2 times per week (Table 2). Provincial prevalence estimates for red and processed meat consumption are presented in Supplementary Table 1. The average weekly frequency of red meat consumption was 3.6 times for men, which decreased by age from 4.0 times among 18–39 years old to 3.2 times among 60–80 years old (Table 2). Canadian women ate red meat for an average of 2.8 times per week, which did not differ by age (Table 2). Red meat consumption is probably associated with colorectal cancer and is suggestive with pancreatic cancer in men, and stomach cancer. The current burden of cancer attributable to red meat consumption is 5.9% for all associated cancers (Tables 3 and 4). In Canada in 2015, the estimated current burden of cancer attributable to red meat consumption is 5.3% for colorectal cancer, 12.8% for male pancreatic cancer and 5.4% for stomach cancer. The consumption of red meat contributes 1193 cases of colorectal cancer, 297 cases of male pancreatic cancer, and a total of 1677 cases for all associated cancers (Table 4). This amounts to 0.6% and 0.9% of all incident cancers aged 30 and over in 2015 for probable cancers (colorectum) and all associated cancers (colorectum, pancreas, stomach), respectively.

3.1.2. Processed meat

The estimated current average consumption of processed meat consumption in the Canadian population is 1.2 times per week for the total population. For men, the weekly frequency of processed meat consumption is 1.4 times and is highest among 18–39 years old (1.7 times) and lowest among 40–59 years old (1.2 times) (Table 2). For

Table 3
Population attributable risk of red and processed meat consumption in Canada.

Age at exposure	Age at diagnosis	Colorectum				Stomach[a]				Pancreas				Esophagus[b]	
		Red meat		Processed meat		Red meat		Processed meat		Red meat		Processed meat		Processed meat	
		PAR	AC	PAR	AC	PAR	AC	PAR	AC	PAR	AC	PAR	AC	PAR	AC
Men															
18–39	30–49	6.5	52	5.8	46	6.5	9	5.8	4	14.2	16	6.6	8	10	1
40–59	50–69	5.5	314	4.3	243	5.5	50	4.3	21	12.1	129	4.9	52	7.4	16
60–80	≥70	5.2	320	4.7	289	5.2	61	4.7	30	11.4	131	5.4	61	8.1	15
Total	Total	5.8	739	4.9	627	5.8	130	4.9	59	12.8	297	5.7	132	8.6	35
Women															
18–39	30–49	4.7	35	3.9	29	4.7	4	3.9	2					6.8	0
40–59	50–69	4.4	173	3.1	124	4.4	21	3.1	11					5.5	6
60–80	≥ 70	4.6	244	3	158	4.6	32	3	16					5.3	9
Total	Total	4.6	454	3.4	340	4.6	57	3.4	32					6	16
Total															
18–39	30–49	5.6	87	4.9	76	5.8	13	4.9	7	14.2	16	6.6	8	9.4	2
40–59	50–69	5	486	3.8	367	5.1	71	3.8	32	12.1	129	4.9	52	6.8	21
60–80	≥70	4.9	564	3.9	447	5	93	3.9	45	11.4	131	5.4	61	6.8	24
Total	Total	5.3	1193	4.3	967	5.4	187	4.3	91	12.8	297	5.7	132	7.6	51

Abbreviations: AC = Attributable cases; PAR = Population attributable Risk.
[a] Non-cardia stomach cancer for processed meat.
[b] Squamous esophageal cancer.

women, the frequency is 1.0 times per week, which is slightly different by age groups (18–39 years old: 1.1 times; 40–59 and 60–80 years old: 0.9 times) (Table 2). Processed meat consumption is convincingly or probably associated with colorectal cancer and non-cardia gastric cancer (NCGC). The association is also suggestive in pancreatic cancer in men, and squamous esophageal cancer. The estimated current burden of cancer attributable to processed meat consumption is 4.5% for all associated cancers (Tables 3 and 4). The current attributable burden due to processed meat consumption is 4.3% for colorectal cancer, 4.3% for non-cardia stomach cancer, 5.7% for pancreatic cancer in men, and 7.6% for esophageal squamous cell carcinoma (Table 4). In 2015, consumption of processed meat attributed to 1058 probable cancers (colorectum and NCGC), 183 suggestive cancers (pancreas, esophagus), and a total of 1241 all associated cancers (Table 4), which amounts to 0.6% and 0.7% of all incident cancers aged 30 and over in 2015 for probable cancers and all associated cancers, respectively. PAR estimates for the Canadian provinces are presented in Supplementary Table 2. Canadian PAR estimates with 95% confidence intervals are presented separately for processed meat (Supplementary Table 3) and red meat (Supplementary Table 4).

3.2. Future avoidable cancer burden

3.2.1. Red meat consumption

We projected that if the consumption pattern of red meat remains unchanged until 2032, the PAR of each associated cancer site will remain the same in 2042 as compared to that of 2015, although the attributable cases will rise because of the increased projected incident cases (Table 5a). Projected provincial estimates for both red and processed meat are presented in Supplementary Table 5.

A reduction of 0.5 servings/week of red meat consumption (i.e., half a portion per week less) across the Canadian population is estimated to prevent 543 of all associated cancer cases in 2042 and 8655 associated cases cumulatively between 2015 and 2042 for men and women combined (Table 5a). By sex, a reduction of 0.5 servings/week could prevent 345 male cancers and 198 female cancers in 2042 and 5547 male cancers and 3108 female cancers cumulatively by 2042. Reducing red meat consumption across the Canadian population by 1.0 serving/week is estimated to double the intervention effects of 0.5 servings/week reduction, preventing 687, 394, and 1081 associated cancer cases among men, women, and combined in 2042 respectively, and 11,038, 6191, and 17,229 cases cumulatively among men, women, and combined by 2042 respectively (Table 5a). Finally, a reduction of 2.0 servings/week of red meat across the Canadian population is estimated to double the intervention effects of 1.0 servings/week reduction, preventing 1359, 782, and 2141 associated cancer cases among men, women, and combined in 2042 respectively, and 21,856, 12,285, and 34,141 cases cumulatively among men, women, and combined by 2042 (Table 5a). The projected proportions of cancer cases in Canadian provinces that could be prevented by 2038 with three different counterfactual scenarios applied to red meat consumption are presented in Supplementary Table 5a.

3.2.2. Processed meat consumption

Similar to red meat, we projected that if the consumption pattern of processed meat remains unchanged until 2032, the PAR of each associated cancer site will remain the same in 2042 as compared to that of 2015 (Table 5b).

An average reduction of 0.2 servings/week of processed meat consumption (i.e., 15 g per week less) across the Canadian population is estimated to prevent 417 associated cancer cases in 2042 and 6673 associated cases cumulatively by 2042 for men and women combined (Table 5b). For males, this reduction could prevent 252 cases in 2042 and 4065 cases cumulatively by 2042. For females, this reduction could prevent 165 cases in 2042 and 2608 cases cumulatively by 2042. Reducing processed meat consumption across the Canadian population by 0.5 serving/week is estimated to prevent 626, 410, and 1036 cancer cases in 2042 and 10,109, 6489, and 16,598 cases cumulatively among men, women, and combined by 2042, respectively (Table 5b). Finally, a reduction of 1.0 serving/week of processed meat across the Canadian population is estimated to prevent 1241, 797, and 2038 associated cancer cases in 2042 and 20,046, 12,677, and 32,723 cases cumulatively among men, women, and combined by 2042, respectively (Table 5b). The projected proportions of cancer cases in Canadian provinces that could be prevented by 2038 with three different counterfactual scenarios applied to red meat consumption are presented in Supplementary Table 5b.

4. Discussion

In Canada, there is currently a sizeable cancer burden attributable to the consumption of red and processed meat. Based on data from cycle

Table 4
Summary of cases and proportions of cancer in Canada in 2015 attributable to red and processed meat consumption[a].

Exposure	Cancer site	Total			Men			Women		
		Observed Cases[b]	Attributable Cases[c]	% Attributable[d]	Observed cases	Attributable cases	% attributable	Observed cases	Attributable cases	% attributable
Red meat consumption	Colorectum	22,610	1193	5.3	12,665	739	5.8	9945	454	4.6
	Stomach	3475	187	5.4	2225	130	5.8	1250	57	4.6
	Pancreas	2320	297	12.8	2320	297	12.8			
	All probable Cancers[e]	22,610	1193	5.3	12,665	739	5.8	9945	454	4.6
	All associated cancers[f]	28,405	1677	5.9	17,210	1166	6.8	11,195	511	4.6
	All cancers[g]	187,070	1193/1677	0.6/0.9	94,910	739/1166	0.8/1.2	92,160	454/511	0.5/0.6
Processed meat consumption	Colorectum	22,610	967	4.3	12,665	627	4.9	9945	340	3.4
	Stomach[h]	2126	91	4.3	1202	59	4.9	925	32	3.4
	Pancreas	2320	132	5.7	2320	132	5.7			
	Esophagus[i]	680	51	7.6	413	35	8.6	267	16	6
	All probable Cancers[e]	24,736	1058	4.3	13,867	686	4.9	10,870	372	3.4
	All associated cancers[f]	27,736	1241	4.5	16,600	853	5.1	11,137	388	3.5
	All cancers[g]	187,070	1058/1241	0.6/0.7	94,910	686/853	0.7/0.9	92,160	372/388	0.4/0.4

[a] Data on prevalence of red and processed meat consumption from Cycle 1 (spring 2007 to spring 2009) and Cycle 2 (August 2009 to November 2011) of the Canadian Health Measures Survey.
[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 red or processed meat consumption.
[d] Proportion of cancers at individual cancer sites attributable to red or processed meat consumption.
[e] All probable cancers includes cancers known to be associated with red or processed meat consumption (with convincing and probable evidence).
[f] All associated cancers includes all cancers that are at least suggestive in the association with red or processed meat consumption.
[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] Non-cardia stomach cancer.
[i] Squamous esophageal cancer.

Table 5a
Proportion of cancer cases in Canada that could be prevented in 2042 with various changes in red meat consumption.

Counterfactual scenario[a]	Sex	Statistic	Colorectum	Stomach	Pancreas	All Associated
Base	Male	Projected cases	28,094	4139	3967	36,200
		PAR (%)	5.8	5.8	12.8	6.6
		Attributable cases	1639	242	508	2389
	Female	Projected cases	21,064	2573		23,637
		PAR (%)	4.6	4.6		4.6
		Attributable cases	962	118		1080
	All Associated	Projected cases	49,158	6712	3967	59,837
		PAR (%)	5.3	5.3	12.8	5.8
		Attributable cases	2602	359	508	3469
1	Male	Projected cases	27,859	4105	3891	35,854
		PIF (%)	0.8	0.8	1.9	1
		Prevented cases	235	35	75	345
		Cumulative cases	3756	523	1268	5547
	Female	Projected cases	20,888	2552		23,439
		PIF (%)	0.8	0.8		0.8
		Prevented cases	176	22		198
		Cumulative cases	2793	315		3308
	All Associated	Projected cases	48,746	6656	3891	59,293
		PIF (%)	0.8	0.8	1.9	0.9
		Prevented cases	412	56	75	543
		Cumulative cases	6549	838	1268	8855
2	Male	Projected cases	27,625	4070	3817	35,513
		PIF (%)	1.7	1.7	3.8	1.9
		Prevented cases	469	69	149	687
		Cumulative cases	7483	1042	2513	11,038
	Female	Projected cases	20,713	2530		23,243
		PIF (%)	1.7	1.7		1.7
		Prevented cases	351	43		394
		Cumulative cases	5563	628		6191
	All Associated	Projected cases	48,338	6600	3817	58,756
		PIF (%)	1.7	1.7	3.8	1.8
		Prevented cases	820	112	149	1081
		Cumulative cases	13,046	1670	2513	17,229
3	Male	Projected cases	27,164	4002	3674	34,841
		PIF (%)	3.3	3.3	7.4	3.8
		Prevented cases	929	137	293	1359
		Cumulative cases	14,849	2069	4938	21,856
	Female	Projected cases	20,367	2488		22,855
		PIF (%)	3.3	3.3		3.3
		Prevented cases	697	85		782
		Cumulative cases	11,040	1245		12,285
	All Associated	Projected cases	47,532	6490	3674	57,696
		PIF (%)	3.3	3.3	7.4	3.7
		Prevented cases	1626	222	293	2141
		Cumulative cases	25,889	3314	4938	34,141

[a] Scenario 1 = everyone decreases red meat intake by 0.5 serving/week. Scenario 2 = everyone decreases red meat intake by 1.0 servings/week. Scenario 3 = everyone decreases red meat intake by 2.0 servings/week. Abbreviations: PIF = Potential impact fraction. PR = Prairie Provinces (Alberta, Saskatchewan, Manitoba). ATL = Atlantic provinces (New Brunswick, Prince Edward Island, Nova Scotia, Newfoundland and Labrador).

1 and 2 of the CHMS (2007–2009), Canadians eat red meat between 3 and 3.4 times per week and processed meat between 1.1 and 1.4 times per week. In 2015, 5.9% of associated cancers were attributable to red meat consumption (0.9% of all cancer) and 4.5% of associated cancers were attributable to processed meat consumption (0.7% of all cancers). These PAR estimates correspond to 1677 cancer cases attributable to red meat consumption and 1241 cases attributable to processed meat consumption. If no changes to consumption are made, we estimate that 3469 and 2560 cancer cases will be attributable to red and processed meat in 2042, respectively. Up to 34,000 cases of cancer could be avoided by 2042 if red meat consumption was reduced. With reductions in processed meat consumption, about 33,000 cancer cases could be avoided by 2042.

Our findings differ somewhat from similar previous studies in which PARs for red and processed meat were estimated. Nagle et al. estimated that 18%, or 2614 cases, of colorectal cancer occurring in Australia in 2010 were attributable to red and/or processed meat consumption (Nagle et al., 2015). They also estimated that if Australians reduced their consumption of red and/or processed meat to ≤65 g/day, as recommended by the Australian Dietary Guideline, there would be 5.4% fewer colorectal cancers in 2010.(Nagle et al., 2015) Parkin estimated that 21.1% of colorectal cancer in the UK in 2010 was attributable to red and processed meat consumption (Parkin and Boyd, 2011). We have also estimated that 12% of the colorectal cancers were attributable to red and processed meat consumption previously in Alberta in 2012 (Grundy et al., 2016). Our finding that 5.3% of colorectal cancers in Canada are attributable to red meat consumption and 4.3% attributable to processed meat consumption is lower than other studies. These lower estimates may reflect real differences in the consumption levels of red and processed meat between other countries and Canada. For example, Australia reports one of the highest per capita consumptions of red and processed meat (125.7 g/day for males; 84.1 g/day for females) compared to other Western regions (North America: 85.9 g/day; 57.7 g/day, North and Central Europe: 47.3 g/day; 35.0 g/day) (Nagle et al., 2015). Our prevalence exposure data would be 53.9 g/day for males and 40.5 g/day for female after conversion from times/week. On the other hand, the difference could also be due to the limited quality of our exposure data, from which we could only estimate mean consumption of each age-sex-region stratum. Furthermore, we approximated the unit "times per week" as "portions per week", and converted portions into

Table 5b
Proportion of cancer cases in Canada and Canadian provinces that could be prevented in 2042 with various changes in processed meat consumption.

Counterfactual Scenario[a]	Sex	Statistic	Colorectum	Stomach	Pancreas	Esophagus	All Associated
Base	Male	Projected cases	28,094	2235	3967	420	34,716
		PAR (%)	4.9	4.9	5.7	8.6	5.1
		Attributable cases	1390	111	225	36	1762
	Female	Projected cases	21,064	1904		195	23,163
		PAR (%)	3.4	3.4		6	3.4
		Attributable cases	721	65		12	797
	All Associated	Projected cases	49,158	4139	3967	615	57,879
		PAR (%)	4.3	4.2	5.7	7.8	4.4
		Attributable cases	2111	176	225	48	2560
1	Male	Projected cases	27,895	2219	3934	415	34,464
		PIF (%)	0.7	0.7	0.8	1.2	0.7
		Prevented cases	199	16	32	5	252
		Cumulative cases	3170	238	543	113	4065
	Female	Projected cases	20,915	1891		192	22,998
		PIF (%)	0.7	0.7		1.2	0.7
		Prevented cases	149	13		2	165
		Cumulative cases	2357	197		55	2609
	All Associated	Projected cases	48,811	4110	3934	607	57,462
		PIF (%)	0.7	0.7	0.8	1.2	0.7
		Prevented cases	347	29	32	8	417
		Cumulative cases	5526	435	543	168	6674
2	Male	Cumulative cases	27,600	2196	3886	407	34,090
		Projected cases	1.8	1.8	2	3.1	1.8
		PIF (%)	494	39	80	13	626
		Prevented cases	7885	593	1350	280	10,109
	Female	Projected cases	20,694	1871		189	22,753
		PIF (%)	1.8	1.8		3.1	1.8
		Prevented cases	370	33		6	410
		Cumulative cases	5862	489		137	6488
	All Associated	Projected cases	48,294	4067	3886	596	56,843
		PIF (%)	1.8	1.8	2	3.1	1.8
		Prevented cases	864	73	80	19	1036
		Cumulative cases	13,748	1083	1350	417	16,597
3	Male	Projected cases	27,115	2157	3808	395	33,475
		PIF (%)	3.5	3.5	4	6.1	3.6
		Prevented cases	979	78	159	26	1241
		Cumulative cases	15,641	1177	2675	553	20,046
	Female	Projected cases	20,344	1839		183	22,366
		PIF (%)	3.4	3.4		6	3.4
		Prevented cases	721	65		12	797
		Cumulative cases	11,455	956		266	12,677
	All Associated	Projected cases	47,459	3996	3808	578	55,841
		PIF (%)	3.5	3.5	4	6	3.6
		Prevented cases	1699	143	159	37	2038
		Cumulative cases	27,096	2133	2675	819	32,723

[a] Scenario 1 = everyone decreases processed meat intake by 0.2 serving/day. Scenario 2 = everyone decreases processed meat intake by 0.5 servings/day. Scenario 3 = everyone decreases processed meat intake by 1.0 serving/day. Abbreviations: PIF = Potential impact fraction. PR = Prairie Provinces (Alberta, Saskatchewan, Manitoba). ATL = Atlantic Provinces (New Brunswick, Prince Edward Island, Nova Scotia, Newfoundland and Labrador).

grams according to the Canadian Food Guide (Health Canada, 2011), resulting in the assumption that one time per week was 10.7 g per day for red and processed meat, respectively. However, we do not know the direction or magnitude of bias these limitations would cause. This lack of available precise dietary exposure data for red and processed meats highlights the need for improved dietary assessment in future national surveys in Canada.

There are several strengths of this analysis. First, we were able to include multiple cancer sites associated with red and processed meat. We provided estimates for four associated sites for red meat, and five associated sites for processed meat, each with the up-to-date RRs from either the WCRF reports, the IARC monographs, or meta-analyses. The inclusion of multiple cancer sites, aside from colorectal cancer, was possible because of the updates in recent WCRF/AICR CUPs and current meta-analyses that demonstrate a strong RR between the various cancer sites and red and processed meat consumption. We excluded female pancreatic cancers from our analysis because RRs from WCRF reports were not statistically significantly increased. Second, by conducting separate analyses for both red and processed meat, we were able to better distinguish the proportion that each was contributing to the current attributable burden of cancer and estimate the number of future avoidable cases that interventions would have due to both exposures. Third, we obtained our exposure data from CHMS surveys, which were designed to represent the Canadian population. In Canada, we have an excellent cancer registration system, which allows us to acquire high coverage, high quality incidence data. We further obtained provincial exposure and incidence data, which improved the resolution of our results and provided useful information for local health agencies.

The limitations of our study must also be recognized. First, the exposure prevalence data of red and processed meat consumption came from the CHMS was based on a single weekly frequency question without any corresponding portion size, which would vary across respondents. Consequently, the meat consumption exposure estimates may have substantial measurement errors. Moreover, these estimates were from self-reported data and were prone to biases that might result in an underestimation of the real meat consumption frequency. Third, by using mean consumption of each age-sex-region specific stratum instead of individual-level data, Our PAR estimation method assumed 100% prevalence exposure, which may bias the PAR estimates because of the non-consumers of red or processed meat. We conducted a

sensitivity analysis assuming that the mean consumption was obtained from a population with 0–20% non-consumers. The PAR and attributable cases only differed slightly from 0% to 20% non-consumers, with the largest difference observed among men in red meat consumption (attributable cases with 0% non-consumers: 1166 (6.77%); with 20% non-consumers: 1177 (6.84%); Supplementary Table 6). Nevertheless, using mean consumption of each age-sex-region specific stratum restricted us to use no consumptions (0 g) as the reference level. We were not able to conduct sensitivity analyses using an alternative reference consumption, particularly for red meat. Lastly, red and processed meat consumptions were analyzed in isolation from other dietary and lifestyle behaviours which may be confounders. For example, body mass index may be the main confounder in the association between red meat consumption and cancer risk.(Grosso et al., 2017) Other confounders of dietary consumption and cancer risk include smoking and physical activity which are also associated with dietary habits (Key et al., 2004). Confounding can be accounted for through statistical adjustments and most of the RRs have been adjusted for other dietary and lifestyle behaviours. For example, most studies included in the meta-analyses by WCRF to estimate the RR of meat consumption for colorectal cancer adjusted the results by age, sex, smoking, alcohol, BMI, and physical activity (World Cancer Research Fund, 2011). Nevertheless, residual confounding may still exist that leads to some bias in the PAR estimates.

4.1. Conclusions and implications for practice, policy or future research

This analysis provides evidence for policy and decision makers regarding the current and future burden of cancer in Canada that could be avoided by changes in red and processed meat consumption. Although a reduction of > 1 serving per week of red meat and processed meat may seem improbable for the entire Canadian population now, smaller reductions would accumulate a sizeable number of preventable cancers in the future. These more ambitious intervention targets may be attainable in the future after smaller reductions are met. Previous research has evaluated the feasibility and the effectiveness of the intervention programs aiming at promoting healthy diet including reducing red and processed meat consumption (Celis-Morales et al., 2017; Hawkes et al., 2012; Mummah et al., 2017). To date, this research has found either a very small effect of the intervention or has not assessed the long-term effects of these interventions. Hence, developing effective interventions that result in long-term and sustained reductions in red and processed meat consumption is a priority for cancer prevention research and population-based programs.

This analysis adds to the evidence base for the implementation of dietary behaviour interventions with the purpose of reducing the future burden of cancer in Canada. The counterfactual scenarios demonstrate that a large number of associated cancer cases are avoidable by 2042 through interventions targeted at reducing red and processed meat consumption. The results of this study provide potential targets for efforts aimed towards improving dietary behaviours with the goal of reducing future cancer incidence.

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Conflict of interest

None disclosed.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.03.011.

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