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Estimates of the current and future burden of cancer attributable to active and passive tobacco smoking in Canada

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ABSTRACT

Although previous studies have examined the burden of cancer attributable to tobacco smoking, updated estimates are needed given the dramatic changes in smoking behaviours over the last 20 years. In this study, we estimate the proportion of cancer cases in 2015 attributable to past tobacco smoking and passive exposure in Canada and the proportion of cancers in the future that could be prevented through the implementation of interventions targeted at reducing tobacco use. Data from the Canadian Community Health Survey (2003) were used to estimate the prevalence of active tobacco smoking and passive exposure. Population attributable risk estimates were employed to estimate the proportion of cancers attributable to tobacco in 2015. The prevalence of active tobacco smoking and passive exposure was projected to 2032 and cancer incidence was projected from 2016 to 2042 to estimate the future burden of cancer attributable to tobacco. In 2003, 30% and 24% of Canadians were former and current smoker, respectively and 24% had been exposed to tobacco smoke in the past. We estimated that 17.5% (32,655 cases; 95% CI: 31,253–34,034) of cancers were attributable to active tobacco smoking and 0.8% (1408 cases; 95% CI: 1048–1781) to passive tobacco exposure in never smokers. Between 41,191 and 50,696 cases of cancer could be prevented by 2042 under various prevention scenarios. By decreasing passive tobacco exposure by 10–50%, between 730 and 3650 cancer cases could be prevented by 2042. Strategies focused on reducing the prevalence of tobacco smoking are crucial for cancer control in Canada.

1. Introduction

In 1986, the International Agency for Research on Cancer (IARC) determined that there was sufficient human evidence to classify tobacco smoking and second-hand smoke as carcinogenic to humans (Group 1) (International Agency for Reseach on Cancer Working Group on the Evaluation of Carcinogenic Risks to Humans, 1986). The IARC working group concluded that tobacco smoking is associated with cancers of the lung, oral cavity, larynx, esophagus, bladder and pancreas. Cancers of the stomach, paranasal sinus, nasopharynx, liver, kidney, ureter, uterine cervix, ovary, colorectum and myeloid leukemia have since been added to the list in subsequent IARC monographs (International

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Table 1
Relative risks of cancers for active tobacco smoking and passive exposure.

Cancer site	Level of exposure	Relative risk (95% confidence interval)	
		Men	Women
Active tobacco smoking			
Lung[a]	Current smoker	8.96 (6.73–12.10)	8.96 (6.73–12.1)
	Former smoker	3.85 (2.77–5.34)	3.85 (2.77–5.34)
Colorectal[b]	Current smoker	1.20 (1.07–1.34)	1.20 (1.07–1.34)
	Former smoker	1.20 (1.15–1.25)	1.20 (1.15–1.25)
Breast[c]	Current smoker	–	1.11 (1.06–1.12)
	Former smoker	–	1.09 (1.06–1.12)
Bladder[a]	Current smoker	2.77 (2.17–3.54)	2.77 (2.17–3.54)
	Former smoker	1.72 (1.46–2.04)	1.72 (1.46–2.04)
Kidney[a]	Current smoker	1.52 (1.33–1.74)	1.52 (1.33–1.74)
	Former smoker	1.25 (1.14–1.37)	1.25 (1.14–1.37)
Pancreas[a]	Current smoker	1.70 (1.51–1.91)	1.70 (1.51–1.91)
	Former smoker	1.18 (1.04–1.33)	1.18 (1.04–1.33)
Oral cavity[a]	Current smoker	3.57 (2.63–4.84)	3.57 (2.63–4.84)
	Former smoker	1.18 (0.73–1.91)	1.18 (0.73–1.91)
Stomach[a]	Current smoker	1.64 (1.37–1.95)	1.64 (1.37–1.95)
	Former smoker	1.31 (1.17–1.95)	1.31 (1.17–1.95)
Ovary[d]	Current smoker	–	1.06 (1.00–1.13)
	Former smoker	–	1.06 (1.00–1.12)
Liver[a]	Current smoker	1.56 (1.29–1.87)	1.56 (1.29–1.87)
	Former smoker	1.49 (1.06–2.10)	1.49 (1.06–2.10)
Esophagus[a]	Current smoker	2.50 (2.00–3.13)	2.50 (2.00–3.13)
	Former smoker	2.03 (1.77–2.33)	2.03 (1.77–2.33)
Cervix[a]	Current smoker	–	2.24 (1.14–4.39)
	Former smoker	–	1.26 (1.11–1.42)
Larynx[a]	Current smoker	6.98 (3.14–15.5)	6.98 (3.14–15.5)
	Former smoker	4.65 (3.35–6.45)	4.65 (3.35–6.45)
Ureter[e]	Current smoker	3.96 (3.07–5.09)	3.96 (3.07–5.09)
	Former smoker	2.25 (1.74–2.91)	2.25 (1.74–2.91)
Myeloid leukemia[f]	Current smoker	1.52 (1.10–2.14)	1.52 (1.10–2.14)
	Former smoker	1.45 (1.08–1.94)	1.45 (1.08–1.94)
Passive tobacco exposure			
Lung[g]	Ever exposure	1.34 (1.24–1.45)	1.34 (1.24–1.45)
Colorectal[h]	Ever exposure	1.14 (1.05–1.2)	1.14 (1.05–1.2)
Breast[c]	Ever exposure	–	1.20 (1.07–1.33)
Cervix[j]	Ever exposure	–	1.73 (1.35–2.21)

[a] Estimates from Gandini et al. (2008).
[b] Estimates from Ordonez-Mena et al. (2016).
[c] Estimates from Macacu et al. (2015).
[d] Estimates from Beral et al. (2012).
[e] Estimates from Bjerregaard et al. (2006).
[f] Estimates from Colamesta et al. (2016).
[g] Estimates from Kim et al. (2014).
[h] Estimates from Yang et al. (2016).
[j] Estimates from Zeng et al. (2012).

Agency for Reseach on Cancer (IARC), 2012; International Agency for Research on Cancer (IARC), 2004). A recent large meta-analysis showed that active tobacco smoking is also associated with breast cancer (Macacu et al., 2015). In addition, IARC concluded that there is sufficient evidence that secondhand smoke exposure (i.e. passive smoking) causes lung cancer (International Agency for Reseach on Cancer (IARC), 2012). Since the most recent IARC monograph on tobacco use in 2012, large meta-analyses have shown that secondhand smoke exposure (i.e. passive tobacco exposure) is also associated with an increased risk of colorectal, breast and cervical cancers (Macacu et al., 2015; Yang et al., 2016; Zeng et al., 2012).

There are many complex biological mechanisms hypothesized that link tobacco smoke to cancer. The most widely accepted mechanism involves the binding of inhaled carcinogens to DNA and forming DNA adducts, which in turn can cause miscoding and permanent mutations. These mutations can cause the loss of normal cell proliferation and lead to cancer when mutations occur in oncogenes or tumor suppressor genes (International Agency for Reseach on Cancer (IARC), 2012).

In 2012, an estimated 45,464 deaths from all causes in Canada were attributable to smoking tobacco and the total costs of tobacco use were $16.2 billion, including both direct and indirect health care costs (Dobrescu et al., 2017). Given these statistics, reducing the prevalence of smoking through prevention strategies should be a top priority for public health agencies. Previous analyses conducted in the United Kingdom (Parkin, 2011), Australia (Pandeya et al., 2015) and globally (Reitsma et al., 2017) have estimated the burden of cancer attributable to smoking tobacco. In addition, previous estimates for Canada and the provinces of Ontario and Alberta estimated that 15–16% of cancer is attributable to tobacco smoking (Cancer Care Ontario, 2014; Krueger et al., 2016; Poirier et al., 2016). However, current detailed estimates for Canada and individual provinces are not available. Previous studies did not estimate the proportion of cancer that could be prevented in the future with reductions in smoking prevalence.

Table 2
Prevalence of active tobacco smoking and passive tobacco exposure in Canada[a], 2003.

Age (years)	Prevalence (95% confidence interval)		
	Active tobacco smoking		Passive tobacco exposure
	Former smoker	Current smoker	Ever exposure
Men	33.3 (32.6–33.9)	26.6 (25.9–27.2)	28.4 (27.3–29.5)
20–34	15.3 (14.3–16.3)	33.5 (32.1–34.8)	37.9 (35.8–39.9)
35–44	25.3 (24.0–26.6)	31.1 (29.7–32.5)	26.7 (24.7–28.7)
45–64	42.3 (41.2–43.5)	24.3 (23.3–25.3)	23.4 (21.6–25.2)
≥65	59.1 (57.7–60.5)	11.4 (10.6–12.2)	13.8 (11.9–15.8)
Women	25.8 (25.3–26.3)	21.7 (21.1–22.2)	21.3 (20.6–22.1)
20–34	16.4 (15.4–17.3)	26.3 (25.2–27.5)	30.3 (28.5–32.0)
35–44	25.1 (23.7–26.4)	25.3 (24.0–26.6)	19.7 (17.9–21.5)
45–64	31.6 (30.6–32.6)	21.6 (20.7–22.4)	19.9 (18.6–21.3)
≥65	29.9 (28.8–30.9)	10.4 (9.7–11.1)	12.4 (11.4–13.4)
Total	29.5 (29.0–29.9)	24.1 (23.6–24.5)	24.3 (23.7–25.0)
20–34	15.8 (15.1–16.5)	29.9 (29.0–30.8)	33.9 (32.5–35.2)
35–44	25.2 (24.2–26.1)	28.2 (27.3–29.2)	23.0 (21.7–24.3)
45–64	36.9 (36.1–37.7)	22.9 (22.3–23.6)	21.4 (20.3–22.4)
≥65	42.7 (41.8–43.6)	10.8 (10.3–11.4)	12.8 (11.9–13.7)

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

Given the strong, consistent relationships between active and passive tobacco smoking and the associated cancer sites, we aimed to estimate the proportion of incident cancer cases in 2015 that can be attributed to past tobacco exposure in Canada (attributable burden). We also estimated the proportion of cancers in the future (to 2042) that could potentially be prevented through the implementation of one of several intervention scenarios targeted at reducing the prevalence of active tobacco smoking and passive exposure (avoidable burden).

2. Methods

The detailed methodological framework for the current study was previously published (Brenner et al., 2018). A brief overview of the methods is included in this supplement. To estimate the attributable and avoidable burden of cancer in Canada, three measures of data were required: 1) risk estimates (i.e. relative risks, RRs) for the association between smoking and each cancer, 2) the prevalence of active tobacco smoking and passive exposure in Canada and provinces, and 3) age- and sex-specific cancer incidence data (as described in the Methods summary in this issue).

2.1. Current population attributable burden

2.1.1. Latency period

It is well documented that cancer risk attributable to tobacco smoking is the result of past exposure and therefore. Large cohort studies have shown that the latency period for tobacco smoking and cancer can range from 3 to 33 years. Therefore, a latency period within this range was identified for active tobacco smoking and passive exposure.

Table 3
Cancer cases and proportions attributable to active tobacco smoking in Canada (2015) ***No Confidence Intervals.

Age at exposure	Age at Dx	Lung			Colorectal			Breast			Bladder			Kidney			Pancreas			Oral		
		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	95	74.8	71	380	8.9	34				120	40.8	49	220	17.2	38	60	20.2	12	145	45.8	66
35–44	45–54	755	76.6	578	1280	10.3	132				440	42.7	188	610	18.4	112	195	21.2	41	480	46.5	223
45–64	55–74	8035	75.5	6066	6510	11.9	774				3825	42	1608	2105	18.8	396	1250	19.3	242	1835	43.0	789
≥65	≥75	5230	72.5	3790	4025	12.4	498				3150	38.7	1220	755	17.4	132	725	16.0	116	585	34.8	203
Total		14,115	74.4	10,506	12,195	11.8	1438				7535	40.7	3065	3690	18.4	678	2230	18.4	411	3045	42.1	1282
Women																						
20–34	30–44	110	71.4	79	410	7.8	32	2230	4.1	92	60	36.4	22	130	14.8	19	40	17.2	7	70	40.7	29
35–44	45–54	870	73.4	639	1060	9.3	98	5005	4.8	241	165	38.9	64	320	16.4	52	160	18.3	29	215	41.9	90
45–64	55–74	6805	71.6	4869	4345	9.5	413	12,220	4.9	602	1080	37.1	401	1090	15.9	173	1055	16.5	174	730	38.8	283
≥65	≥75	4115	64.0	2632	3865	7.6	293	4620	3.8	176	1030	28.8	296	520	11.8	61	965	11.4	110	365	27.5	100
Total		11,900	69.1	8218	9680	8.6	836	24,075	4.6	1111	2335	33.5	783	2060	14.9	306	2220	14.4	321	1380	36.4	502
Total																						
20–34	30–44	205	73.0	150	790	8.3	66	2230	4.1	92	180	39.3	71	350	16.3	57	100	19.0	19	215	44.2	95
35–44	45–54	1625	74.9	1217	2340	9.8	230	5005	4.8	241	605	41.7	252	930	17.7	165	355	19.9	71	695	45.1	313
45–64	55–74	14,840	73.7	10,936	10,855	10.9	1188	12,220	4.9	602	4905	40.9	2008	3195	17.8	569	2305	18.1	416	2565	41.8	1072
≥65	≥75	9345	68.7	6422	7890	10.0	791	4620	3.8	176	4180	36.3	1516	1275	15.1	193	1690	13.4	226	950	32.0	304
Total		26,015	72.0	18,724	21,875	10.4	2274	24,075	4.6	1111	9870	39.0	3847	5750	17.1	984	4450	16.4	732	4425	40.3	1784

Age at exposure	Age at Dx	Stomach			Ovary			Liver			Esophagus			Myeloid leukemia			Cervix			Larynx			Ureter		
		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	65	20.3	13				35	20.5	7	20	38.4	8	60	19.4	12				5	70.7	4	5	52.2	3
35–44	45–54	195	21.9	43				160	23.4	37	130	42.7	56	65	21.8	14				65	74.2	48	10	55.2	6
45–64	55–74	1100	22.2	244				1085	25.7	279	895	44.6	399	340	24.2	82				595	75.0	446	50	55.2	28
≥65	≥75	865	20.5	177				410	26.2	107	430	43.9	189	270	24.5	66				240	74.2	178	65	52.2	34
Total		2225	21.5	477				1690	25.5	431	1475	44.1	651	735	23.7	174				905	74.7	676	130	53.6	70
Women																									
20–34	30–44	40	17.5	7	205	2.5	5	10	18.2	2	0	36.0	0	40	17.4	7	465	26.7	124	10	67.3	7	0	49.5	0
35–44	45–54	120	19.5	23	460	2.9	14	45	21.2	10	25	39.4	10	70	19.8	14	310	27.4	85	20	71.1	14	0	51.4	0
45–64	55–74	530	18.8	100	1235	3.1	38	245	21.4	52	225	39.0	88	245	20.1	49	360	26.2	94	100	70.7	71	60	49.6	30
≥65	≥75	560	13.7	76	600	2.4	15	205	17.4	36	235	31.8	75	180	16.2	29	115	17.4	20	55	63.6	35	45	40.2	18
Total		1250	16.5	207	2500	2.8	71	505	19.7	99	485	35.5	172	535	18.6	99	1250	25.9	323	185	68.4	127	105	45.6	48
Total																									
20–34	30–44	105	19.2	20	205	2.5	5	45	20.0	9	20	38.4	8	100	18.6	19	465	26.7	124	15	68.4	10	5	52.2	3
35–44	45–54	315	21.0	66	460	2.9	14	205	22.9	47	155	42.2	65	135	20.7	28	310	27.4	85	85	73.5	62	10	55.2	6
45–64	55–74	1630	21.1	344	1235	3.1	38	1330	24.9	332	1120	43.4	486	585	22.5	132	360	26.2	94	695	74.4	517	110	52.1	57
≥65	≥75	1425	17.8	254	600	2.4	15	615	23.3	143	665	39.6	264	450	21.2	95	115	17.4	20	295	72.2	213	110	47.3	52
Total		3475	19.7	684	2500	2.8	71	2195	24.2	531	1960	42.0	823	1270	21.6	274	1250	25.9	323	1090	73.6	803	235	50	118

Abbreviations: AC = attributable cases due to exposure, Dx = diagnosis, Obs. = total number of observed cases per age-sex group, PAR = population attributable risk.

Table 4
Summary of cases and proportions of cancer in Canada in 2015 attributable to active tobacco smoking[a].

Exposure	Cancer site	Total			Men			Women		
		Observed cases[b]	Attributable cases[c]	% Attributable[d]	Observed cases	Attributable cases	% Attributable	Observed cases	Excess attributable cases	% Attributable
Active tobacco smoking	Lung	25,235	18,120	71.8	12,945	9632	74.4	12,290	8488	69.1
	Colorectal	22,610	2354	10.4	12,665	1495	11.8	9945	859	8.6
	Breast	24,555	1133	4.6				24,555	1133	4.6
	Bladder	9870	3847	39.0	7535	3065	40.7	2335	783	33.5
	Kidney	5930	1015	17.1	3815	701	18.4	2115	314	14.8
	Pancreas	4405	731	16.6	2320	428	18.4	2085	303	14.6
	Oral cavity	4425	1784	40.3	3045	1282	42.1	1380	502	36.4
	Stomach	3475	684	19.7	2225	477	21.5	1250	207	16.5
	Ovary	2550	73	2.8				2550	73	2.8
	Liver	2205	533	24.2	1690	431	25.5	515	101	19.7
	Esophagus	1960	823	42.0	1475	651	44.1	485	172	35.5
	Myeloid leukemia	1270	274	21.6	735	174	23.7	535	99	18.6
	Cervix	1250	323	25.9				1250	323	25.9
	Larynx	1145	843	73.6	945	706	74.7	200	137	68.6
	Ureter	235	118	50.0	130	70	53.6	105	48	45.6
	All associated cancers[e]	111,120	32,655	29.4	49,525	19,111	38.6	61,595	13,543	22
	All cancers[f]	187,070	32,655	17.5	94,910	19,111	20.1	92,160	13,543	14.7

[a] Data on prevalence of active tobacco smoking from the Canadian Community Health Survey (2003).
[b] Number of observed cancer cases in Canada in 2015 at individual cancer site from the Canadian Cancer Registry.
[c] Number of cancer cases at individual cancer sites that can be attributed to active tobacco smoking.
[d] Proportion of cancers at individual cancer sites attributable to active tobacco smoking.
[e] All associated cancers includes all cancers known to be associated with active tobacco smoking (as listed in the current table).
[f] All cancers include all incident cancer cases in Canada for all ages in 2015.

Table 5
Cancer cases and proportions attributable to passive tobacco exposure in Canada (2015) ***No Confidence Intervals.

Age at exposure	Age at Dx	Lung			Colorectal			Breast			Cervix		
		Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC	Obs.	PAR	AC
Men													
20–34	30–44	19	9.9	2	340	4.6	16						
35–44	45–54	165	8.5	14	1116	3.6	41						
45–64	55–74	1892	7.3	138	6015	3.1	188						
≥65	≥75	1238	4.8	59	3700	2.0	74						
Total		3314	6.4	213	11,171	2.9	319						
Women													
20–34	30–44	36	8.9	3	379	3.7	14	2142	1.8	39	345	17.7	61
35–44	45–54	264	6.4	17	960	2.7	26	4694	1.4	64	230	12.5	29
45–64	55–74	2202	6.3	139	4140	2.7	112	12,101	1.4	166	267	12.7	34
≥65	≥75	1296	4.4	58	3610	1.8	65	4489	0.9	42	85	8.6	7
Total		3798	5.7	217	9090	2.4	217	23,425	1.3	311	926	14.1	131
Total													
20–34	30–44	55	9.2	5	719	4.2	30	2142	1.8	39	345	17.7	61
35–44	45–54	429	7.2	31	2075	3.2	67	4694	1.4	64	230	12.5	29
45–64	55–74	4093	6.8	276	10,156	3.0	300	12,101	1.4	166	267	12.7	34
≥65	≥75	2534	4.6	117	7310	1.9	139	4489	0.9	42	85	8.6	7
Total		7112	6.0	429	20,260	2.6	536	23,425	1.3	311	926	14.1	131

Abbreviations: AC = attributable cases due to exposure, Dx = diagnosis, Obs. = total number of observed cases per age-sex group, PAR = population attributable risk.

As described previously (Brenner et al., 2018), the latency period we used for the burden of cancer in 2015 was based on available prevalence data for active tobacco smoking and passive exposure. We used the 2003 Canadian Community Health Survey (CCHS) exposure data, resulting in a 12 year latency period relative to incident cases identified in 2015, for both active tobacco smoking and passive. A fixed latency period of 10 years was assumed for the future burden of cancer analysis to facilitate the modelling approach. To apply the latency period, the age groups used for prevalence estimates were 20–34, 35–44, 45–64 and ≥65 and the age groups used for cancer incidence were 35–44, 45–54, 55–74 and ≥75. Previous analyses have used similar methods to account for a latency period between exposure and cancer diagnosis (Cancer Care Ontario, 2014; Poirier et al., 2016).

2.1.2. *Risk estimates*

We collected risk estimates for each smoking-associated cancer site from large meta-analyses (Table 1) (Beral et al., 2012; Bjerregaard et al., 2006; Colamesta et al., 2016; Gandini et al., 2008; Macacu et al., 2015; Ordonez-Mena et al., 2016). For active tobacco smoking, the relative risk (RR) estimates were stratified by sex and smoking status (current smoker or ever smoker). For passive tobacco exposure, the risk estimates were based on ever exposure and stratified by sex (Table 1)

Table 6
Summary of cases and proportions of cancer in Canada in 2015 attributable to passive tobacco exposure[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
Passive tobacco exposure	Lung	7112	429	6.0	3314	213	6.4	3798	217	5.7
	Colorectal	20,260	536	2.6	11,171	319	2.9	9090	217	2.4
	Breast	23,425	311	1.3				23,425	311	1.3
	Cervix	926	131	14.1				926	131	14.1
	All associated cancers[e]	51,724	1408	2.7	14,484	532	3.7	37,239	876	2.4
	All cancers[f]	187,070	1408	0.8	94,910	532	0.6	92,160	876	1.0

[a] Data on prevalence of passive tobacco exposure from the Canadian Community Health Survey (2003).
[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 passive tobacco exposure.
[d] Proportion of cancers at individual cancer sites attributable to passive tobacco exposure.
[e] All associated cancers includes all cancers known to be associated with passive tobacco exposure (as listed in the current table).
[f] All cancers include all incident cancer cases in Canada for all ages in 2015.

(Kim et al., 2014; Macacu et al., 2015; Yang et al., 2016; Zeng et al., 2012).

2.1.3. Prevalence of exposure

Data on the prevalence of active tobacco smoking and passive exposure were obtained from the 2003 cycle of the CCHS (Statistics Canada, 2003). Detailed methods for the CCHS have been published previously (Béland, 2002). Briefly, the CCHS is a biennial population-based cross-sectional survey used to collect self-reported information on the health status, health determinants and health care use of Canadians. The CCHS sampling frame is representative of 96–98% of the Canadian population. The 2003 cycle includes weighted data on 135,573 respondents aged 12 and older. In the survey, current smokers are defined as individuals who smoke cigarettes daily or occasionally at the time of the interview. Former smokers are those who have smoked > 100 cigarettes in their lifetime, but were not smokers at the time of the interview. Those categorized as never smokers had smoked fewer than 100 cigarettes in their lifetime and were not smokers at the time of the survey. Passive smokers are defined as those who were regularly exposed to tobacco smoke in their home, a vehicle or a public place. The proportion of missing data on smoking status was negligible (0.6%) and therefore excluded from the analysis.

2.1.4. Statistical analysis

To estimate the proportion of cancer attributable to active tobacco smoking, the following population attributable risk (PAR) equation, which has been used in previous PAR studies (Cancer Care Ontario, 2014; Pandeya et al., 2015; Parkin, 2011) was applied:

$$PAR = \frac{(p_{e1} \times ERR_1) + (P_{e2} \times ERR_2)}{1 + (p_{e1} \times ERR_1) + (P_{e2} \times ERR_2)}$$

where P_{e1} is the prevalence of current active tobacco smokers, P_{e2} is the prevalence of former active tobacco smokers, ERR_1 is the excess RR (ERR; RR − 1) of cancer in current smokers compared with never smokers and ERR_2 is the ERR of cancer in former smokers compared with never smokers.

To estimate the PAR for passive tobacco exposure in never smokers, the following equation was used:

$$PAR = \frac{P_e(RR - 1)}{1 + P_e(RR - 1)}$$

where P_e is the prevalence of passive tobacco exposure and RR is the risk of cancer in those exposed to tobacco smoke compared to those never exposed.

The PAR for each cancer site was then multiplied by the number of incident cancer cases in 2015 to estimate the number of cancer cases attributable to active tobacco smoking and passive exposure. For passive tobacco exposure, we approximated the proportion of incident cancer cases in 2015 among never smokers to be 1-PAR of active smoking. Monte Carlo simulation methods were used to estimate 95% confidence intervals (CIs) around PAR estimates.

2.2. Future avoidable burden

2.2.1. Projected exposure prevalence

To estimate the future burden of cancer attributable to active tobacco smoking and passive exposure up to 2042, we projected the crude prevalence of active tobacco smoking and passive exposure to 2032 (to account for the 10 year latency period) among all Canadian men and women aged 20 and over. Data on active tobacco smoking were used from the 1994, 1996, and 1998 National Population Health Survey (NPHS) and the 2000, 2003, 2005, 2007 and 2011 cycles of the CCHS to generate a model to project future prevalence. Because NPHS only asked whether the participants had ever smoked cigarettes and did not contain the question regarding whether one has smoked a total of 100 or more cigarettes in lifetime like CCHS, we redefined never smokers as those who had not smoked a whole cigarette, in order to pool the data from the two surveys and acquire more information on the historical trends.

We observed a steadily decreasing trend in current smoking prevalence in both sexes among all Canadian provinces. We noticed an increase in the prevalence of former smokers in all Canadian provinces until 2000 to 2003, after which the prevalence was stable. We modeled the current smoking prevalence using a log-linear model (log(prevalence) ~ year) and extrapolated the future prevalence. We fitted a logistic growth curve to the former smoking prevalence using the grofit package in R (ref). The prevalence of never smokers was derived by taking the remainder of 100% from the prevalence of current smokers and the prevalence of former smokers.

The data on ever exposure to passive smoking among the never smokers are only available from the 2000, 2003, 2005, 2007 and 2011 cycles of the CCHS. We modeled the passive smoking prevalence using a log-linear model (log(prevalence) ~ year) and extrapolated the future prevalence. Because the prevalence was assessed among never smokers, we subtracted the cancer cases due to active smoking in the future, which were estimated in this study (Table 7), from the projected cancer incidence. This calculation gave the cancer incidence not attributable to active smoking.

2.2.2. Projected cancer incidence

A brief summary of the methods used to project cancer incidence to 2042 are included in this issue (Brenner et al., 2019). Detailed methods

Table 7
Projected cancer cases and proportions attributable to active tobacco smoking and the proportion of cancer cases that could be prevented in 2042 with various changes in active tobacco smoking levels in Canada.

Sex	Statistic	CTF[a]	Myeloid leukemia	Bladder	Breast	Cervix	Colorectum	Kidney	Larynx	Liver	Lung	Esophagus	Oral	Ovary	Pancreas	Stomach	Ureter	All associated
Men	Projected cases	Base	1311	10,697			28,094	7230	1230	3342	14,853	3013	3364		3967	4139	302	81,541
	PAR (%)		23.3	39.6			11.5	17.4	73.6	24.8	73.4	42.9	38.4		17.4	20.6	52.8	31.8
	EAC		306	4235			3224	1258	905	830	10,908	1293	1293		689	855	160	25,954
Women	Projected cases		946	3359	40,564	1857	21,064	3797	186	909	19,156	718	1913	3366	3501	2573	208	104,118
	PAR (%)		19.1	32.5	4.6	19.5	9.2	13.6	67.8	20.4	66.9	36.5	30.1	2.9	13	16.3	45.2	20.1
	EAC		181	1093	1852	361	1938	515	126	185	12,806	262	576	99	455	418	94	20,961
Both	Projected cases		2257	14,057	40,564	1857	49,158	11,028	1415	4251	34,008	3730	5278	3366	7467	6712	510	185,659
	PAR (%)		21.5	37.9	4.6	19.5	10.5	16.1	72.8	23.9	69.7	41.7	35.4	2.9	15.3	19	49.7	25.3
	EAC		486	5328	1852	361	5162	1773	1031	1015	23,714	1555	1868	99	1144	1273	253	46,915
Men	Projected cases	1	1308	10,446			28,094	7170	1202	3336	14,107	2983	3209		3903	4099	293	80,150
	PIF (%)		0.2	2.3			0	0.8	2.3	0.2	5	1	4.6		1.6	1	3	1.7
	Prevented cases		3	251			0	60	28	7	746	30	156		63	40	9	1391
	Cumulative cases		35	3292			0	804	358	89	10,635	401	2172		845	491	116	19,237
Women	Projected cases		944	3271	40,536	1803	21,064	3765	180	907	17,955	710	1813	3366	3442	2547	201	102,504
	PIF (%)		0.2	2.6	0.1	2.9	0	0.9	2.8	0.2	6.3	1.1	5.3	0	1.7	1	3.5	1.5
	Prevented cases		2	88	29	54	0	33	5	2	1201	8	100	0	59	26	7	1614
	Cumulative cases		26	1156	385	724	0	442	70	25	16,431	108	1370	0	809	314	95	21,954
Both	Projected cases		2252	13,718	40,536	1803	49,158	10,935	1382	4242	32,062	3692	5022	3366	7346	6646	494	182,654
	PIF (%)		0.2	2.4	0.1	2.9	0	0.8	2.3	0.2	5.7	1	4.9	0	1.6	1	3.2	1.6
	Prevented cases		5	339	29	54	0	92	33	8	1946	38	256	0	122	66	16	3005
	Cumulative cases		61	4448	385	724	0	1246	428	114	27,066	508	3542	0	1653	805	211	41,191
Men	Projected cases	2	1303	9977			28,094	7059	1149	3324	12,712	2927	2918		3786	4024	276	77,547
	PIF (%)		0.6	6.7			0	2.4	6.5	0.6	14.4	2.8	13.3		4.6	2.8	8.6	4.9
	Prevented cases		7	721			0	171	80	19	2141	86	447		181	115	26	3994
	Cumulative cases		59	5641			0	1366	614	151	17,730	683	3636		1437	858	201	32,377
Women	Projected cases		944	3243	40,527	1785	21,064	3754	179	906	17,573	707	1781	3366	3424	2538	198	101,990
	PIF (%)		0.3	3.5	0.1	3.9	0	1.1	3.7	0.3	8.3	1.5	6.9	0	2.2	1.3	4.6	2
	Prevented cases		3	116	38	72	0	43	7	2	1583	10	132	0	77	35	10	2128
	Cumulative cases		22	950	313	589	0	361	57	20	13,339	87	1113	0	655	264	78	17,848
Both	Projected cases		2247	13,220	40,527	1785	49,158	10,813	1328	4230	30,285	3634	4698	3366	7209	6563	475	179,537
	PIF (%)		0.4	6	0.1	3.9	0	1.9	6.2	0.5	10.9	2.6	11	0	3.5	2.2	6.9	3.3
	Prevented cases		10	837	38	72	0	215	87	21	3724	96	579	0	258	150	35	6122
	Cumulative cases		81	6591	313	589	0	1727	671	171	31,069	771	4748	0	2092	1122	279	50,225
Men	Projected cases	3	1302	9818			28,094	7021	1131	3320	12,240	2908	2819		3746	3999	271	76,667
	PIF (%)		0.7	8.2			0	2.9	8	0.7	17.6	3.5	16.2		5.6	3.4	10.5	6
	Prevented cases		9	880			0	209	98	23	2613	105	545		221	141	32	4875
	Cumulative cases		138	13,143			0	3212	1429	357	42,651	1601	8703		3375	1953	463	77,026
Women	Projected cases		943	3211	40,516	1766	21,064	3742	177	905	17,138	704	1745	3366	3402	2529	196	101,405
	PIF (%)		0.4	4.4	0.1	4.9	0	1.5	4.7	0.3	10.5	1.9	8.8	0	2.8	1.7	5.8	2.6
	Prevented cases		3	148	48	91	0	55	9	3	2018	13	169	0	98	44	12	2712
	Cumulative cases		58	2549	852	1602	0	979	156	54	36,409	238	3036	0	1794	685	208	48,621
Both	Projected cases		2244	13,029	40,516	1766	49,158	10,763	1308	4225	29,378	3612	4564	3366	7148	6528	466	178,072
	PIF (%)		0.6	7.3	0.1	4.9	0	2.4	7.5	0.6	13.6	3.2	13.5	0	4.3	2.8	8.6	4.1
	Prevented cases		12	1028	48	91	0	264	107	26	4631	118	714	0	319	185	44	7587
	Cumulative cases		197	15,692	852	1602	0	4191	1585	411	79,061	1840	11,739	0	5169	2638	671	125,646

(*continued on next page*)

Table 7 (*continued*)

Sex	Statistic	CTF[a]	Myeloid leukemia	Bladder	Breast	Cervix	Colorectum	Kidney	Larynx	Liver	Lung	Esophagus	Oral	Ovary	Pancreas	Stomach	Ureter	All associated
Men	Projected cases	4	1307	10,332			28,094	7143	1189	3333	13,766	2969	3138		3875	4081	289	79,515
	PIF (%)		0.3	3.4			0	1.2	3.3	0.3	7.3	1.4	6.7		2.3	1.4	4.4	2.5
	Prevented cases		4	366			0	87	41	9	1086	44	227		92	58	13	2026
	Cumulative cases		52	4945			0	1207	537	134	15,924	602	3252		1268	738	175	28,833
Women	Projected cases		944	3279	40,538	1808	21,064	3768	181	907	18,064	710	1822	3366	3448	2549	201	102,650
	PIF (%)		0.2	2.4	0.1	2.7	0	0.8	2.5	0.2	5.7	1	4.8	0	1.5	0.9	3.2	1.4
	Prevented cases		2	80	26	49	0	30	5	2	1092	7	91	0	53	24	7	1468
	Cumulative cases		26	1151	383	720	0	441	70	24	16,364	107	1364	0	805	312	94	21,862
Both	Projected cases		2251	13,611	40,538	1808	49,158	10,911	1370	4240	31,830	3679	4960	3366	7322	6630	490	182,165
	PIF (%)		0.2	3.2	0.1	2.7	0	1.1	3.2	0.3	6.4	1.4	6	0	1.9	1.2	3.9	1.9
	Prevented cases		6	446	26	49	0	117	45	11	2178	51	318	0	145	82	20	3494
	Cumulative cases		78	6097	383	720	0	1647	607	159	32,288	709	4616	0	2073	1050	269	50,696

Abbreviations: CTF = counterfactual scenario, PIF = potential impact fraction.

[a] Base = continuing prevalence trends with no change. Scenario 1 = price increase to reduce smoking by 3.7% in 2018. Scenario 2 = reduce smoking prevalence to 5% by 2035, and decrease at same tempo afterwards. Scenario 3 = 50% reduction in smoking by 2032. Scenario 4 = WHO 2020 goal of 30% relative reduction in current smoking by 2020.

have been published previously (Poirier et al., 2019a).

2.2.3. Counterfactual scenarios

To estimate the proportion of cancer associated with tobacco exposure that could be avoided in the future, several hypothetical intervention or "counterfactual" scenarios were considered. For active smoking, we considered four counterfactual scenarios: 1) price increase on cigarettes to reduce smoking prevalence by 3.7% in 2018 (Hoffman and Tan, 2015; Hopkins et al., 2001); 2) reduce smoking prevalence to 5% by 2035 and continue to decrease at the same rate; 3) 50% reduction in tobacco smoking by 2032 and 4) the World Health Organization goal of a 30% relative reduction in current smokers by 2020 (World Health Organization, 2013). For passive tobacco exposure, we considered three counterfactual scenarios of a 10, 25 and 50% reduction in prevalence by 2032. Under our counterfactual framework, the current smokers can quit smoking and become former smokers, while the former smokers will retain their status.

2.2.4. Potential impact fraction analysis

Using the projected prevalence, cancer incidence and counterfactual scenarios, we estimated the proportion of cancer that could be prevented by 2042 if the counterfactual scenarios were realized. The proportions shift method (Barendregt and Veerman, 2010) was employed to estimate the potential impact fractions (PIF) for each counterfactual scenario:

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

where P_c is the projected prevalence in category c of tobacco exposure, RR_c is the RR for that category, and P_c^* is the prevalence for category c after counterfactual intervention. This method is used to determine the proportion of the population in each smoking category (i.e. current smoker and former) following an intervention.

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

3. Results

3.1. Prevalence of tobacco exposure

Based on results from the 2003 CCHS survey, an estimated 24.1% of Canadians were current smokers and 29.5% were former smokers (Table 2). The unadjusted prevalence of current smokers was higher for men (26.6%) than women (21.7%). This difference in rates by sex was also true for former smokers, where the prevalence was 33.3% and 25.8% for men and women, respectively. The prevalence of former smoking increased by age group ranging from 15.8% in those aged 20–34 years to 42.7% in those aged 65 years or older. In contrast, the prevalence of current smoking was 29.9% in those aged 20–34 years and decreased to 10.8% in those aged 65 years and older.

The estimated prevalence of passive smoking exposure was 24.3% for never smokers in Canada as estimated in the 2003 CCHS survey. Men (28.4%) were more likely than women (21.3%) to be exposed to tobacco smoke and the prevalence of exposure decreased with increasing age (Table 2). The prevalence of active tobacco smoking and passive exposure in Canadian provinces are presented in Supplementary Tables 1 and 2, respectively.

3.2. Current attributable burden of cancer

3.2.1. Active tobacco smoking

The age- and sex-stratified PAR estimates and numbers of observed and attributable cancer cases for active tobacco smoking are presented in Table 3. Measures of uncertainty (95% CIs) are presented in

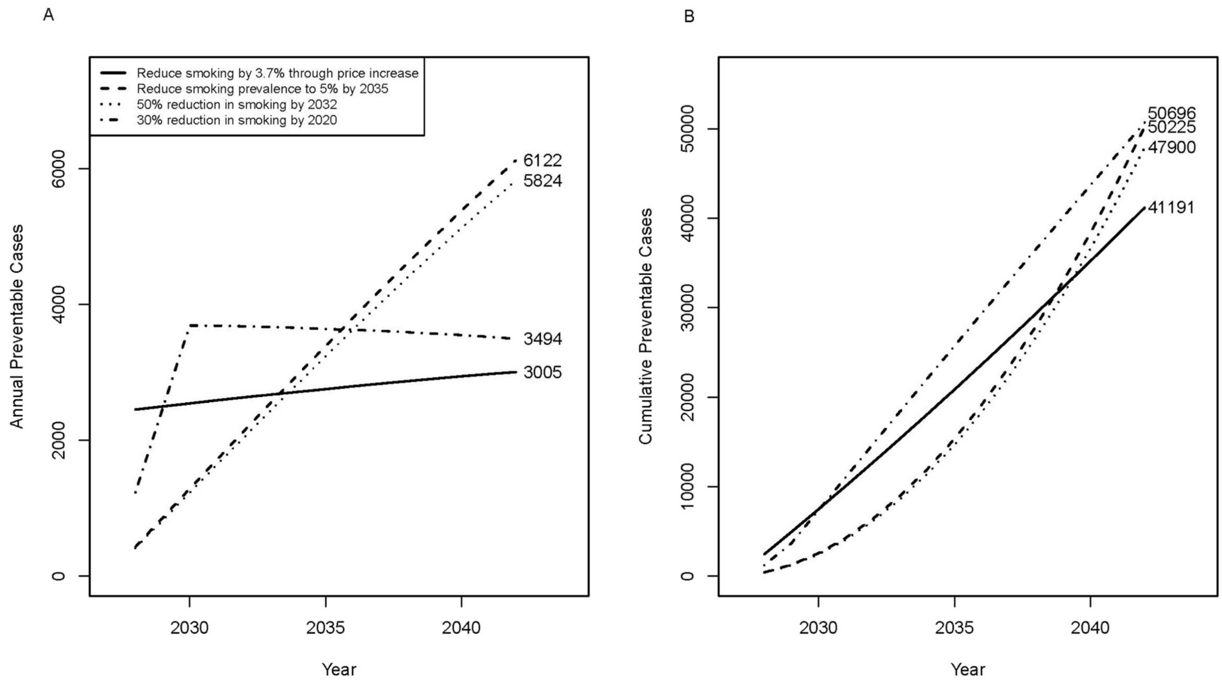

Fig. 1. A) Projected annual preventable cancer cases attributable to active tobacco smoking by applying four counterfactual scenarios; B) projected cumulative preventable cancer cases attributable to active tobacco smoking by applying four counterfactual scenarios.

Supplementary Table 3. PAR results for Canadian provinces are presented in Supplementary Table 4. In 2015, an estimated 32,655 incident cases of cancer were attributable to active tobacco smoking.

This number corresponds to 29.4% incident cancers at sites associated with active tobacco smoking and 17.5% of all incident cancer cases in 2015 (Table 4). The proportion of incident cancer cases in 2015 attributable to active tobacco smoking was 20.1% in men and 14.7% in women. Lung cancer accounted for over half (18,120 cases) the number of cases attributable to active tobacco smoking, followed by bladder cancer (3847 cases) and colorectal cancer (2354 cases). Aside from breast, cervical and ovarian cancer, the proportion of cancer attributable to active tobacco smoking was greater for men than women for each cancer site.

3.2.2. Passive tobacco exposure

The PAR estimates and proportion of cancer cases attributable to passive tobacco smoke exposure in 2015 by age and sex are presented in Table 5. Measures of uncertainty (95% CIs) and provincial PAR estimates are presented in Supplementary Tables 5 and 6, respectively. In 2015, 1408 incident cancer cases were attributable to passive tobacco smoke exposure in never smokers, corresponding to 2.7% of incident lung, colorectal, breast and cervical cancers and 0.8% of all incident cancers (Table 6). In men and women, 3.7% and 2.4% of associated incident cancer cases were attributable to passive tobacco exposure, respectively. In women, 14.1% of cervical cancer was attributable to passive tobacco exposure and in men the highest proportion of attributable cases was observed for lung cancer (6.4%).

3.3. Future avoidable burden of cancer

3.3.1. Active tobacco smoking

Based on our projections, the prevalence of current smoking is expected to continue to decrease in men and women, while the prevalence of former smoking is expected to remain relatively stable (Supplementary Fig. 1). In 2042, we estimate that there will be a total of 185,659 incident cases at sites associated with tobacco smoking (Table 7). The number of cases for these sites attributable to active tobacco smoking will be 46,915 in 2042 if no changes in smoking trends occur. However, if price increases on tobacco cigarettes were instated to reduce smoking prevalence by 3.7% in 2018, 3005 cancer cases could be prevented in 2042, with a cumulative total of 41,191 cases prevented from 2018 and 2042. If smoking prevalence was reduced to 5% by 2035 and continued to decrease at the same rate thereafter, 6122 incident cancer cases could be prevented in 2042, with a cumulative total of 50,225 preventable cases by 2042. Assuming a 50% reduction in tobacco smoking prevalence by 2032, 5824 incident cancer cases could be prevented in 2042, with a cumulative total of 47,900 avoidable cases by 2042. Finally, if the World Health Organization goal of a 30% relative reduction in current smokers by 2020 was achieved, 3494 incident cancer cases in 2042 could be prevented, with a cumulative total of 50,696 cases by 2042 (Table 7; Fig. 1).

3.3.2. Passive tobacco exposure

The prevalence of never smokers passively exposed to tobacco smoke is projected to continue to decrease to 2042 (Supplementary Fig. 2). We projected that in 2042 there will be 94,498 incident cases of breast, cervical, colorectal and lung cancers in never smokers, of which, 797 would be attributable to passive tobacco smoke exposure. If the prevalence of passive tobacco smoke exposure was decreased by 10%, 25% and 50% by 2032, 730, 1825 and 3650 cases of cancer could be prevented by 2042, respectively (Table 8; Fig. 2). Results for provincial cancer incidence projections and counterfactual scenarios for active and passive tobacco smoke exposure are presented in Supplementary Tables 7–10.

4. Discussion

Our results suggest that of cancers diagnosed in 2015 associated with active tobacco smoking and passive exposure, 29.4% (32,655 cases) were attributable to active tobacco smoking and 2.7% (1408 cases) were attributable to passive tobacco exposure in never smokers. These estimates correspond to 17.5% and 0.8% of all cancers diagnosed in 2015, respectively. Of the 33,672 cancer cases attributable to tobacco exposure, more than half (18,549) were lung cancer cases. Other than cancer sites specific to women (ovary, breast, cervix), the PAR estimates were higher for men than women for all associated cancer

Table 8
Projected cancer cases and proportions attributable to passive tobacco exposure and the proportion of cancer cases that could be prevented in 2042 with various changes passive tobacco exposure levels in Canada.

Sex	Statistics	CTF[a]	Breast	Cervix	Colorectal	Lung	All associated
Men	Projected cases	Base			24,870	3944	28,814
	PAR (%)				0.9	2.1	1.1
	EAC				220	84	303
Women	Projected cases		38,713	1496	19,127	6350	65,684
	PAR (%)		0.4	4.1	0.8	1.9	0.8
	EAC		156	61	154	123	494
Both	Projected cases		38,713	1496	43,996	10,294	94,498
	PAR (%)		0.4	4.1	0.8	2	0.8
	EAC		156	61	374	206	797
Men	Projected cases	1			24,848	3936	28,784
	PIF (%)				0.1	0.2	0.1
	Prevented cases				22	8	30
	Cumulative cases				200	82	282
Women	Projected cases		38,697	1490	19,111	6337	65,635
	PIF (%)		0	0.4	0.1	0.2	0.1
	Prevented cases		16	6	15	12	49
	Cumulative cases		143	55	136	114	448
Both	Projected cases		38,697	1490	43,959	10,273	94,419
	PIF (%)		0	0.4	0.1	0.2	0.1
	Prevented cases		16	6	37	21	80
	Cumulative cases		143	55	336	195	730
Men	Projected cases	2			24,815	3924	28,738
	PIF (%)				0.2	0.5	0.3
	Prevented cases				55	21	76
	Cumulative cases				500	204	704
Women	Projected cases		38,674	1480	19,088	6319	65,561
	PIF (%)		0.1	1	0.2	0.5	0.2
	Prevented cases		39	15	38	31	123
	Cumulative cases		359	137	341	285	1121
Both	Projected cases		38,674	1480	43,903	10,242	94,299
	PIF (%)		0.1	1	0.2	0.5	0.2
	Prevented cases		39	15	93	52	199
	Cumulative cases		359	137	841	489	1825
Men	Projected cases	3			24,760	3903	28,662
	PIF (%)				0.4	1.1	0.5
	Prevented cases				110	42	152
	Cumulative cases				1001	408	1408
Women	Projected cases		38,634	1465	19,050	6288	65,437
	PIF (%)		0.2	2	0.4	1	0.4
	Prevented cases		78	30	77	61	247
	Cumulative cases		717	274	681	569	2242
Both	Projected cases		38,634	1465	43,809	10,191	94,100
	PIF (%)		0.2	2	0.4	1	0.4
	Prevented cases		78	30	187	103	399
	Cumulative cases		717	274	1682	977	3650

Abbreviations: CTF = counterfactual scenario, PAR = population attributable risk, PIF = potential impact fraction.

[a] Base = continuing prevalence trends with no change. Scenario 1 = 10% reduction in secondhand smoking by 2032. Scenario 2 = 25% reduction in secondhand smoking by 2032. Scenario 3 = 50% reduction in secondhand smoking by 2032.

sites, due to the historically higher prevalence of tobacco smoking in men. Our projections suggest that by 2042, 47,712 cases of cancer will be attributable to active and passive tobacco smoke exposure. Depending on the proposed prevention scenario for active tobacco smoking, we estimated that between 41,191 and 50,696 cases of cancer could be prevented by 2042, corresponding to PIF estimates between 1.6% and 4.1% for all cancers combined. By decreasing passive tobacco exposure by 10–50%, between 730 and 3650 cancer cases could be prevented by 2042.

Two Canadian studies previously estimated the proportion of cancer attributable to active tobacco smoking using CCHS data from 2000/01 for the provinces of Ontario and Alberta (Cancer Care Ontario, 2014; Poirier et al., 2016). In Ontario, 15% of incident cancer cases in 2009 were estimated to be attributable to active tobacco smoking (Cancer Care Ontario, 2014). In Alberta, members of our study group estimated that 15.7% of cancers diagnosed in 2012 were attributable to active tobacco smoking. These results are both comparable to our estimate of 17.5% (Poirier et al., 2016). The slightly higher estimate for Canada as a whole is partially due to the addition of breast cancer as a site associated with tobacco smoking, since the prevalence estimates for Alberta, Ontario and Canada as a whole were very similar. When breast cancer is removed from the analysis, the PAR for Canada is decreased to 16.6%.

In the United Kingdom (UK), Parkin and colleagues estimated that 19.4% of all incident cancers in 2010 were attributable to current, former or passive tobacco smoking exposure (Parkin, 2011). The inclusion of passive tobacco exposure could account for the marginally higher estimate in the UK. In addition, the RR estimates used in the UK study were higher for most cancer sites. For example, the RR for lung cancer used in the UK study was based on the outcome of cancer mortality, not incidence and for men was more than twice the RR used in the current study (21.3 vs. 9.0). The PAR estimate for lung cancer in non-smokers attributable to tobacco smoke exposure was 14.8%, which is markedly higher than the 6% in our analysis. However, the UK study estimated much higher prevalence (up to 71% in men) of exposure from a spouse or at the workplace from other studies previously conducted

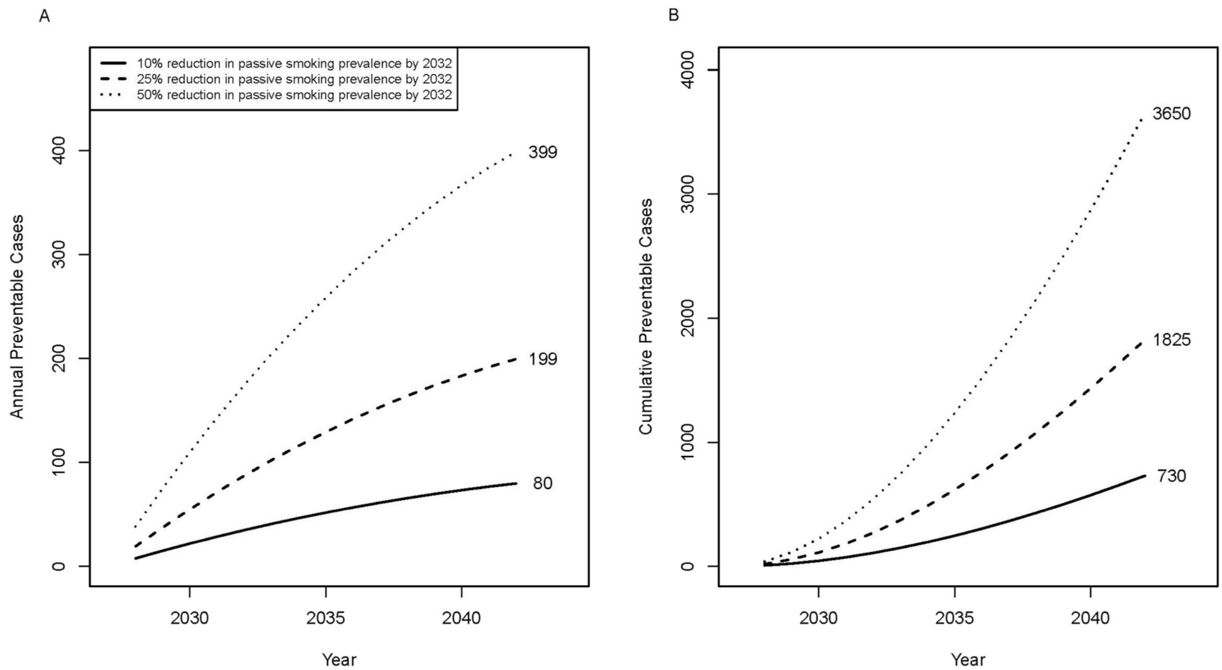

Fig. 2. A) Projected annual preventable cancer cases attributable to passive tobacco smoke exposure by applying four counterfactual scenarios; B) projected cumulative preventable cancer cases attributable to passive tobacco smoke exposure by applying four counterfactual scenarios.

due to a lack of their own prevalence data.

In Australia, it was estimated that 13% of cancers diagnosed in 2010 were attributable to active tobacco smoking and exposure to a partner's tobacco smoke (Pandeya et al., 2015). In contrast to the current study, the Australian study included all ages in their analyses, which could account for the lower overall PAR estimate. In addition, as explained by Pendaya and colleagues, the lower PAR estimate in Australia is likely because of a higher denominator in Australia when estimating the proportion of all incident cancers attributable to tobacco, as the denominator includes all cancer sites and Australia has the highest incidence of prostate cancer and melanoma in the world (Pandeya et al., 2015).

One pooled analysis of seven Australian cohorts estimated that if the prevalence of current smoking was reduced to 0, 18.3% of lung cancer could be prevented over 10 years and 53.7% could be prevented over 40 years (Laaksonen et al., 2018). In our analysis, we did not consider a shift in prevalence to 0 for tobacco smoking, however, by achieving the WHO goal of reducing current smoking prevalence by 30% by 2020 (World Health Organization, 2013), Canada could reach a 23% reduction in the proportion of cancer attributable to active tobacco smoking by 2042.

To our knowledge, this study is one of the first to examine the future avoidable burden of cancer attributable to tobacco. However, long-term projections of exposure prevalence and cancer incidence involve a great deal of uncertainty. We used high quality population-based, nationally representative data for the projections and sound modelling approaches to strengthen the validity of our results. Our intervention targets are practical and attainable, thus making our estimation of potential impact fractions relevant to Canadian policy. To help manage some of the uncertainty inherent in projections, expert opinion was sometimes used in model selection for projections. Statistically driven projections can be unrealistic and therefore using expert opinion strengthened the plausibility of our projections.

Although no data on other tobacco products (smokeless, chewing, cigars, pipes, etc.) were available for the current analysis, a previous analysis in the Canadian province of Alberta showed a low prevalence of other forms of tobacco use and therefore we are confident that the addition of other tobacco products in our analysis would not have a meaningful impact on our results (Poirier et al., 2016). In addition, we did not have data on the duration of exposure, cumulative tobacco exposure (such as pack-years), or time since cessation, which are known to have a substantial impact on the risk of cancer. Specifically, for former smokers, cancer risk is known to decrease as years since cessation increase (Reid et al., 2006) and due to lack of data we were unable to account for this in our estimates. Furthermore, because of prevalence data availability, we assumed a 12-year latency period between exposure and cancer diagnosis, which is relatively short in comparison to long biological latency between smoking and lung cancer diagnosis. The data on tobacco use status and habits were from self-reported questionnaires, possibly introducing biases, which could lead to an underestimation of the prevalence of tobacco smoking and consequentially an underestimation of the burden of cancer attributable to smoking. However, a validation study suggests that both CHMS and CCHS have excellent sensitivity (92%) and specificity (98%) in measuring smoking status (Wong et al., 2012). In contrast, self-reported passive smoking has been shown to have limited validity (Fang et al., 2016). Our prevalence estimates of passive smoking were obtained from one survey question on whether the participants had been exposed to second-hand smoke on most days in the past month. We did not have the information regarding the duration or intensity of this exposure, which is a limitation of this study. Although the RR estimates used to estimate PARs were adjusted RRs, we did not take into account the prevalence of various other factors that may be associated with tobacco smoking status in Canada such as alcohol consumption. Accounting for multiple risk factors in PAR analyses involves complicated statistical modelling, which was beyond the scope of this study and was addressed in a separate publication (Poirier et al., 2019b).

Our study suggests that no colorectal and ovarian cancer cases could be prevented under our intervention targets (Table 7). This scenario is due to the fact that the RRs for current and former smokers are the same for these two cancer sites, and under our methodological framework, the proposed interventions would shift current smokers into former smokers, but not from former smokers to never smokers. This shift would not therefore lead to a reduction in risk. Similarly, very small intervention effects were expected for acute myeloid leukemia, liver, and breast cancer, because of the small differences in the RRs for current and former smokers. A more sophisticated model that takes into account a non-categorical risk reduction over time may improve the estimates (Soerjomataram et al., 2010). However, this was beyond the scope of the current study and requires data that are not available for the Canadian population and for most cancer sites included in this analysis.

4.1. Conclusion

Estimates of the current and future impact of tobacco in Canada are essential for planning, implementing prevention policies, and informing future research. Tobacco remains the leading preventable driver of cancer incidence in Canada. Over 70% of incident lung cancer, which is the leading cause of cancer death in Canada (Canadian Cancer Society's Advisory Committee on Cancer Statistics Canada, 2017), was attributable to active tobacco smoking. By reducing the prevalence of tobacco smoking using evidence-informed approaches, up to 50,696 cancer cases could be avoided by 2042. In addition to cancer prevention, reducing the prevalence of tobacco use in Canada would have a significant impact on mortality and the economic burden associated with various other diseases caused by tobacco smoking.

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Appendix A. Supplementary data

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