The economic benefits of risk factor reduction in Canada: Tobacco smoking, excess weight and physical inactivity

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ABSTRACT

OBJECTIVE: Tobacco smoking, excess weight and physical inactivity contribute substantially to the preventable disease burden in Canada. The purpose of this paper is to apply a recently developed approach in addressing the issue of double counting in estimating the combined current economic burden of these risk factors (RFs) and to estimate the economic benefits of long-term RF reduction in Canada.

METHODS: We used an approach based on population attributable fractions (PAF) to estimate the economic burden associated with the various RFs. Sex-specific relative risk and age-/sex-specific prevalence data were used in the modelling when available. Excess weight was modelled as a trichotomous exposure (normal weight, overweight, obese) while tobacco smoking was modelled as a tetrachotomous exposure (non-smoker, light, medium or heavy smoker). All costs are given in constant 2012 Canadian dollars.

RESULTS: The annual economic burden of the RFs of tobacco smoking, excess weight and physical inactivity in Canada are estimated at $50.3 billion in 2012. Sensitivity analysis suggests a range for the economic burden of $41.6 to $58.7 billion. Of the $50.3 billion, $21.3 ($20.0 to $22.6) billion is attributable to tobacco smoking, $19.0 ($13.8 to $24.0) billion to excess weight and $10.0 ($7.8 to $12.0) billion to physical inactivity. A 1% relative annual reduction in each of the three RFs would result in an $8.5 billion annual reduction in economic burden by 2031.

CONCLUSION: A modest annual 1% relative reduction in the RFs of tobacco smoking, excess weight and physical inactivity can have a substantial health and economic impact over time at the population level.

KEY WORDS: Economic burden; population attributable fraction; risk factors; tobacco smoking; excess weight; physical inactivity

La traduction du résumé se trouve à la fin de l'article.

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Despite years of successful reduction in the prevalence of tobacco smoking,[1,2] it remains the number one risk factor (RF) with respect to the preventable disease burden in Canada and the United States.[3,4] Recent trend information from the US suggests a convergence of relative and absolute risk of death from smoking in men and women, resulting from the convergence of smoking patterns between the sexes since the 1960s.[5] Furthermore, the rate of death from chronic obstructive pulmonary disease (COPD) appears to be increasing in both male and female smokers, possibly due to design changes in cigarettes that promote deeper inhalation of smoke.[5]

Excess weight is second on the list of RFs with respect to the preventable disease burden in Canada and the US,[3] and yet this RF continues to increase in prevalence.[6] Both excess weight and physical inactivity have independently been implicated as RFs for a variety of chronic diseases. Consequently, these RFs have joined tobacco smoking as key prevention targets.

Estimations of the economic burden generated by such RFs have been undertaken in many jurisdictions in the world,[7] including Canada[8-12] and several Canadian provinces.[13,14] In addition to understanding the costs related to a single RF, estimating the aggregate economic burden generated by two or more RFs in a population is often of interest.[15] This information can inform prevention strategies aimed at more than one RF. There are, however, analytical challenges involved with the estimation of the aggregate burden of multiple RFs in a population. Certain costs (e.g., those generated by incident disease or death) are, by definition, accrued only once. Thus, it is important to account for the confounding effect of multiple RFs in the same individual, and specifically to adjust for any increase in the calculated economic burden due to double counting cases and costs.[16]

The purpose of this study is twofold: 1) to apply a recently developed approach to address this issue of double counting in estimating the combined economic burden of tobacco smoking, excess weight and physical inactivity in Canada, and 2) to estimate the economic benefits of long-term RF reduction in Canada.[16] This current model has been updated to include economic data for the year 2012, prevalence and relative risk information for tobacco smoking by intensity and a flexible module, which can be used to estimate the economic benefits of long-term RF reduction.

METHODS

The details of our base model have been previously published.[16] In short, we used an approach based on population attributable

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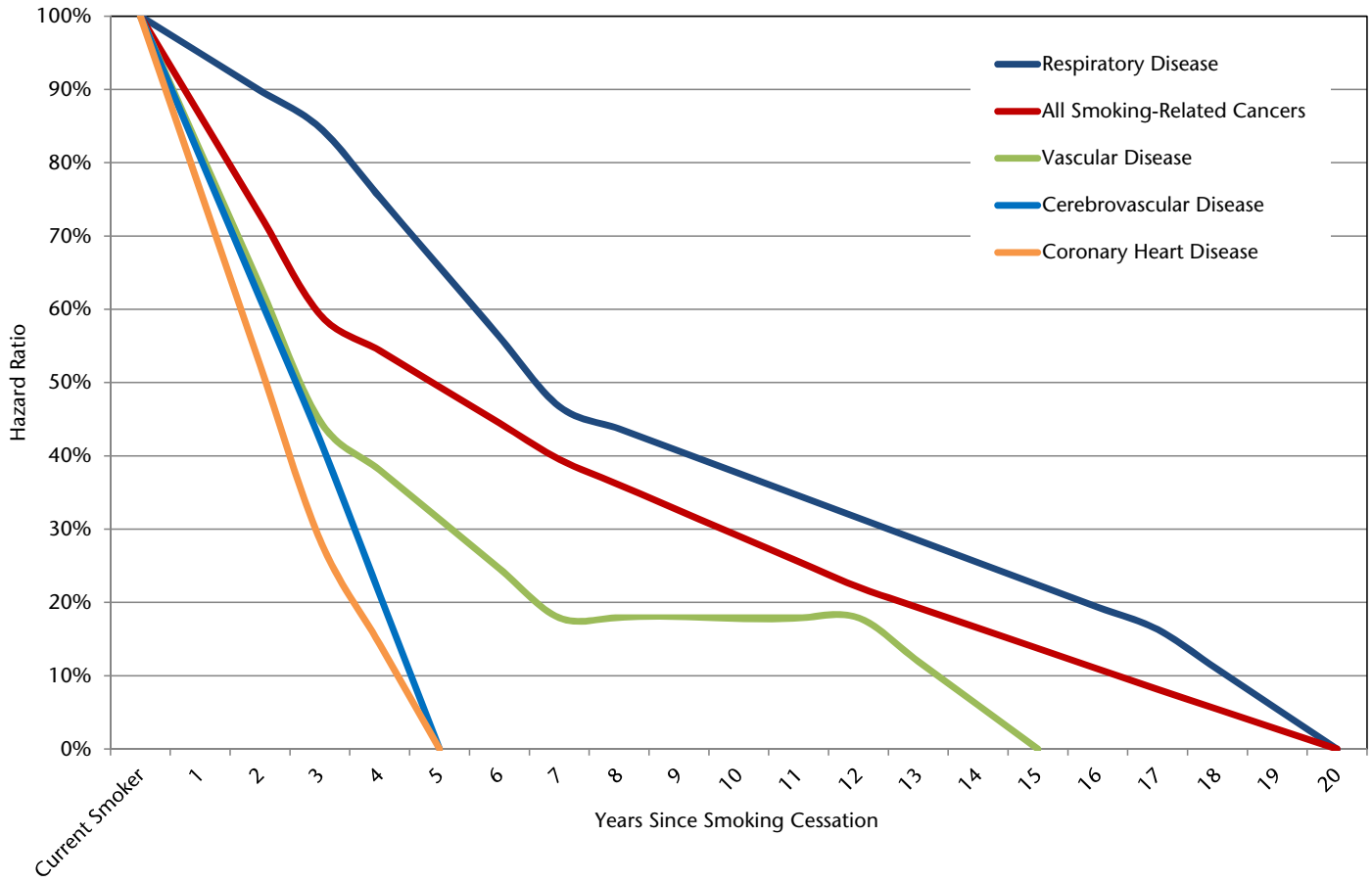
Figure 1. Reduction in risk of mortality after smoking cessation, relative to current smokers, females by cause and by year since smoking cessation



Source: Kenfield et al., *Journal of the American Medical Association,* 2008.

fraction (PAF) to estimate the economic burden associated with the various RFs. PAF is a statistic that combines two facets of a RF and its impact on disease: relative risk (RR) of the RF in reference to a particular disease, and the prevalence of exposure to the RF in the population of interest.

Relative risk

The sources for the RRs associated with excess weight and physical inactivity remain the same as in the previously published model.[9,17] The 2013 study on 1.3 million UK women was used as the source for RR data associated with tobacco smoking.[2] RRs were adjusted for geographic region, age, body mass index (BMI), socio-economic status, current alcohol intake, weekly strenuous physical activity, height, oral contraceptive use, menopausal status and menopausal hormone therapy use. RRs are also presented by three levels of smoking intensity based on the number of cigarettes smoked per day at the time of study recruitment, namely <10, 10-19 or ≥20.

The relative risk data for excess weight is specific to males and females while the source of RR data for physical inactivity did not make this distinction. An additional review of research for sex variations associated with physical inactivity and the risk of stroke,[18] colon[19] and rectal cancers,[20] supported the assumption that there is no significant difference in RR between males and females for this RF. The source of RR data for tobacco smoking is based on females only. Recent information suggests a convergence in RR between females and males, especially when adjusted for smoking intensity.[5] Even without adjusting for smoking intensity, Jha and colleagues found no significant differences between the sexes in adjusted hazard ratios for various causes of death in current smokers, including cancers, vascular diseases, respiratory diseases and all causes.[1] We therefore assumed that the RRs by smoking intensity would be the same for males and females by disease category.

The point estimates of the RRs are used for calculations in the base model with the upper and lower bounds of the 95% confidence intervals assessed in a sensitivity analysis.

Risk factor exposure

The other half of a PAF calculation depends on high-quality RF prevalence data.[21] The analysis of Canada's population exposure to tobacco smoking, physical inactivity and overweight/obesity began with information drawn from the 2010 Canadian Community Health Survey (CCHS). First, overweight and obese individuals were those with a BMI of between 25 kg/m^2 and 30 kg/m^2 for overweight and 30 kg/m^2 or greater for obesity, calculated based on self-reported height and weight. For youth aged 12 to 17, the Cole system of BMI was used to determine overweight and obesity rates.[22] Second, tobacco smokers were grouped into light (<10 cigarettes per day), moderate (10-19 per day) and heavy (≥20 per day) smokers based on additional details on the average

Table 1. Relative risk, prevalence of risk factors, and population attributable fraction in Canada, 2010

		Tobacco smoking												Excess weight								Physical inactivity			
		Light				Moderate				Heavy				Overweight				Obesity							
Prevalence of Risk Factor in Canada in 2010		**Male 8.3%**		**Female 7.0%**		**Male 5.9%**		**Female 5.0%**		**Male 6.5%**		**Female 3.0%**		**Male 34.7%**		**Female 22.5%**		**Male 16.0%**		**Female 12.8%**		**Male 41.1%**		**Female 47.5%**	
		All ages				All ages				All ages				All ages				All ages				All ages			
Cancers	ICD-9 Code	RR	PAF	RR	PAF	RR	PAF	RR	PAF	RR	PAF	RR	PAF	RR	PAF	RR	PAF	RR	PAF	RR	PAF	RR	PAF	RR	PAF
Trachea, bronchus, lung	162	10.83	21.4%	10.83	21.0%	22.03	26.6%	22.03	26.2%	36.00	33.3%	36.00	26.5%												
Lip, oral cavity, pharynx, larynx	140-149,160,161	2.85	9.6%	2.85	8.9%	4.91	13.6%	4.91	12.6%	7.20	20.9%	7.20	12.3%												
Urinary bladder	188	2.68	9.7%	2.68	8.9%	3.66	10.8%	3.66	9.9%	3.24	10.2%	3.24	5.4%												
Esophagus	150	2.17	7.1%	2.17	6.5%	2.99	8.5%	2.99	7.7%	4.62	15.5%	4.62	8.5%	1.13	4.3%										
Pancreas	157	1.89	5.9%	1.89	5.3%	2.37	6.5%	2.37	5.7%	2.66	8.4%	2.66	4.3%					2.29	17.1%	1.60	7.1%				
Stomach	151	1.75	5.2%	1.75	4.6%	2.04	5.2%	2.04	4.5%	2.20	6.5%	2.20	3.2%												
Liver	155	1.42	3.1%	1.42	2.7%	1.56	3.0%	1.56	2.6%	1.54	3.2%	1.54	1.5%												
Kidney, other urinary	189	1.42	3.0%	1.42	2.6%	2.28	6.3%	2.28	5.5%	2.56	8.2%	2.56	4.2%	1.40	10.9%	1.82	13.4%	1.82	10.4%	2.64	14.9%				
Colorectal cancer	153, 154	1.20	1.6%	1.20	1.4%	1.22	1.2%	1.22	1.1%	1.39	2.4%	1.39	1.1%	1.51	13.2%	1.45	8.5%	1.95	11.6%	1.66	7.2%	1.41	14.4%	1.41	16.3%
Breast cancer	174, 175							1.15	0.7%			1.25	0.8%											1.31	12.8%
Postmenopausal breast cancer	174, 175															1.08	1.7%			1.13	1.6%				
Endometrial cancer	179, 181, 182															1.53	9.3%			3.22	19.3%				
Ovarian cancer	183															1.18	3.8%			1.28	3.3%				
Cardiovascular Diseases																									
Aortic aneurysm	441	3.87	12.7%	3.87	12.1%	7.18	17.8%	7.18	17.0%	8.09	21.1%	8.09	12.9%												
Coronary heart disease	410-414, 429	3.19	11.2%	3.19	10.4%	4.55	12.7%	4.55	11.8%	5.92	17.8%	5.92	10.2%	1.29	4.7%	1.80	8.6%	1.72	8.6%	3.10	18.7%	1.45	15.6%	1.45	17.6%
Stroke/cerebrovascular disease	430-438	2.29	7.8%	2.29	7.1%	3.20	9.3%	3.20	8.4%	3.81	12.5%	3.81	6.7%	1.23	6.9%	1.15	3.1%	1.51	7.0%	1.49	5.6%	1.60	19.8%	1.60	22.2%
Venous thromboembolism	415,451-453	1.34	2.6%	1.34	2.2%	1.39	2.1%	1.39	1.8%	1.77	4.5%	1.77	2.2%												
Pulmonary embolism	415.1													1.91	19.0%	1.91	14.2%	3.51	22.7%	3.51	20.2%				
Congestive heart failure	428																	1.79	11.2%	1.78	9.0%				
Hypertension	401-405													1.28	4.5%	1.65	7.3%	1.84	9.9%	2.42	13.9%	1.30	11.0%	1.30	12.5%
Respiratory Diseases																									
Chronic lung disease	490-492, 493.2	22.71	27.1%	22.71	27.0%	32.87	27.6%	32.87	27.4%	60.49	33.6%	60.49	28.8%												
Pneumonia, influenza	480-486	2.06	6.5%	2.06	5.9%	3.06	8.8%	3.06	7.9%	4.42	14.8%	4.42	8.1%												
Asthma	493													1.20	6.1%	1.25	5.0%	1.43	6.1%	1.78	8.5%				
Diabetes																									
Type 2 diabetes	250.x0, 250.x2					1.86	4.6%	1.86	3.9%	2.17	6.7%	2.17	3.3%	2.40	16.1%	3.92	21.0%	6.74	35.4%	12.41	43.9%	1.50	17.0%	1.50	19.2%
Other																									
Cirrhosis of alcoholic liver	571.0, .1, .2,.3,.5,.6,.9	2.73	9.8%	2.73	9.1%	3.34	9.6%	3.34	8.7%	3.97	12.8%	3.97	6.9%												
Gallbladder disease	574, 575															1.44	5.2%	1.43	5.7%	2.32	13.4%				
Osteoarthritis	715													2.76	27.9%	1.80	13.5%	4.20	25.0%	1.96	9.7%	1.59	19.5%	1.59	21.9%
Chronic back pain	720-724													1.59	14.3%	1.59	10.3%	2.81	18.8%	2.81	16.4%				

ICD = International Classification of Disease; RR = Relative Risk; PAF = Population Attributable Fraction.

number of cigarettes smoked per day.[23] All current smokers who identified themselves as occasional smokers were included in the "light" smoking category. Third, physically inactive individuals were those categorized in the CCHS as "inactive."

We made one adjustment to these base CCHS data, namely estimating the rates of overweight, obesity and physical inactivity for children aged less than 12 years based on the sex-specific rates for 12-14 year olds in the CCHS. We assumed no smoking occurs in children younger than 12 years of age.

Multiple exposure levels

The most basic version of a PAF calculation, derived from the prevalence of a single RF and the RR of a related disease, uses the formula $(E(RR-1)) / (E(RR-1)+ 1))$, where E is the proportion of the population exposed to the factor of interest and RR is the relative risk of disease developing in the group exposed to the factor.

More sophisticated approaches are required to calculate PAF when a polytomous RF is involved.[24] This is the case for both the excess weight and the tobacco smoking RFs in the current model. Overweight and obesity should be conceived as a trichotomous exposure to excess body weight; i.e., 1) no excess weight, 2) intermediate excess or overweight (prevalence E_{OW}), and 3) more extreme excess or obesity (prevalence E_{OB}). The PAF calculation is as follows:

$$(E_{OW}(RR_{OW}-1) + E_{OB}(RR_{OB}-1)) / (E_{OW}(RR_{OW}-1) + E_{OB}(RR_{OB}-1) + 1))$$

Tobacco smoking, on the other hand, should be conceived as a tetrachotomous exposure; i.e., 1) non-smoker, 2) light smoker (prevalence E_{TSL}), 3) moderate smoker (prevalence E_{TSM}), and 4) heavy smoker (prevalence E_{TSH}). The PAF calculation is as follows:

$$(E_{TSL}(RR_{TSL}-1) + E_{TSM}(RR_{TSM}-1) + E_{TSH}(RR_{TSH}-1)) / (E_{TSL}(RR_{TSL}-1) + E_{TSM}(RR_{TSM}-1) + E_{TSH}(RR_{TSH}-1) + 1))$$

Calculating and adjusting costs

We estimated the economic burden using a prevalence-based cost-of-illness approach, and reported this in 2012 Canadian dollars. We began calculating direct costs using the approach adopted by Anis et al.[11] In short, direct costs, including hospital care, physician services, other health care professionals (but excluding dental services), drugs, health research and "other" health

Table 2. Estimated prevalence of RFs, total economic burden for multifactorial system, and disaggregated costs by RF Canada, 2012, by sex, adjusted for multiple RFs in one individual

	% Population with RF	# Individuals with RF	Direct cost per individual with RF ($'s)	Indirect cost per individual with RF ($'s)	Total cost per individual with RF ($'s)	Total direct cost of RF (million$)	Total indirect cost of RF (million$)	Total cost of RF (million$)
Males								
Smokers								
Light	8.3%	1,435,035	$767	$1,598	$2,365	$1,100	$2,294	$3,394
Moderate	5.9%	1,024,846	$1,279	$2,669	$3,948	$1,311	$2,735	$4,046
Heavy	6.5%	1,129,249	$1,598	$3,283	$4,881	$1,805	$3,707	$5,512
Subtotal - Male Smokers	20.7%	3,589,130	$1,175	$2,434	$3,609	$4,216	$8,736	$12,952
Excess Weight								
Overweight	34.7%	6,046,660	$156	$468	$624	$945	$2,827	$3,772
Obese	16.0%	2,773,601	$565	$1,384	$1,949	$1,567	$3,838	$5,406
Subtotal - Male Excess Weight	50.7%	8,820,261	$285	$756	$1,041	$2,513	$6,665	$9,178
Inactive	41.1%	7,149,313	$195	$422	$618	$1,397	$3,020	$4,417
Subtotal						$8,125	$18,422	$26,547
Females								
Smokers								
Light	7.0%	1,227,115	$681	$1,366	$2,047	$836	$1,676	$2,512
Moderate	5.0%	867,893	$1,144	$2,315	$3,459	$992	$2,009	$3,002
Heavy	3.0%	530,887	$1,753	$3,562	$5,315	$930	$1,891	$2,822
Subtotal - Female Smokers	15.0%	2,625,894	$1,051	$2,124	$3,174	$2,759	$5,577	$8,336
Excess Weight								
Overweight	22.5%	3,987,187	$256	$685	$940	$1,020	$2,730	$3,750
Obesity	12.8%	2,258,665	$842	$1,863	$2,705	$1,901	$4,209	$6,109
Subtotal - Female Excess Weight	35.3%	6,245,852	$468	$1,111	$1,579	$2,921	$6,939	$9,859
Inactive	47.5%	8,409,362	$191	$472	$663	$1,603	$3,968	$5,571
Subtotal						$7,282	$16,484	$23,766
Both Sexes								
Smokers								
Light	7.6%	2,662,149	$727	$1,491	$2,218	$1,936	$3,970	$5,906
Moderate	5.4%	1,892,739	$1,217	$2,507	$3,724	$2,303	$4,744	$7,048
Heavy	4.8%	1,660,137	$1,648	$3,372	$5,020	$2,735	$5,599	$8,334
Subtotal - Smokers	17.9%	6,215,024	$1,122	$2,303	$3,425	$6,974	$14,313	$21,288
Excess Weight								
Overweight	28.6%	10,033,847	$196	$554	$750	$1,965	$5,557	$7,522
Obesity	14.4%	5,032,267	$689	$1,599	$2,288	$3,468	$8,047	$11,515
Subtotal - Excess Weight	42.9%	15,066,113	$361	$903	$1,264	$5,433	$13,604	$19,037
Inactive	44.3%	15,558,675	$193	$449	$642	$3,000	$6,988	$9,988
Total						$15,408	$34,906	$50,313

RF = Risk factor.

care expenditures were extracted from the National Health Expenditure Database for Canada.[25] All costs (except hospital care) were allocated to each of the co-morbidity categories based on weights published in the *Economic Burden of Illness in Canada (EBIC*) for 1998.[26] Hospital costs were allocated to each co-morbidity based on the proportion of total patient bed-days (based on data from the Canadian Institute for Health Information (CIHI) Hospital Morbidity Database 2000/2001[27]) used in treating patients in Canada with that co-morbidity. Estimated total direct costs were distributed between males and females based on the proportion of hospital bed-days in 2000/2001 utilized by males and females for each of the co-morbidities. Finally, the Canadian sex-specific costs by co-morbidity were multiplied by the calculated sex- and co-morbidity-specific PAF. We calculated indirect costs (premature mortality, short- and long-term disability) following the method used in *EBIC, 1998* (a modified human-capital approach).

Economic benefits of risk factor reduction

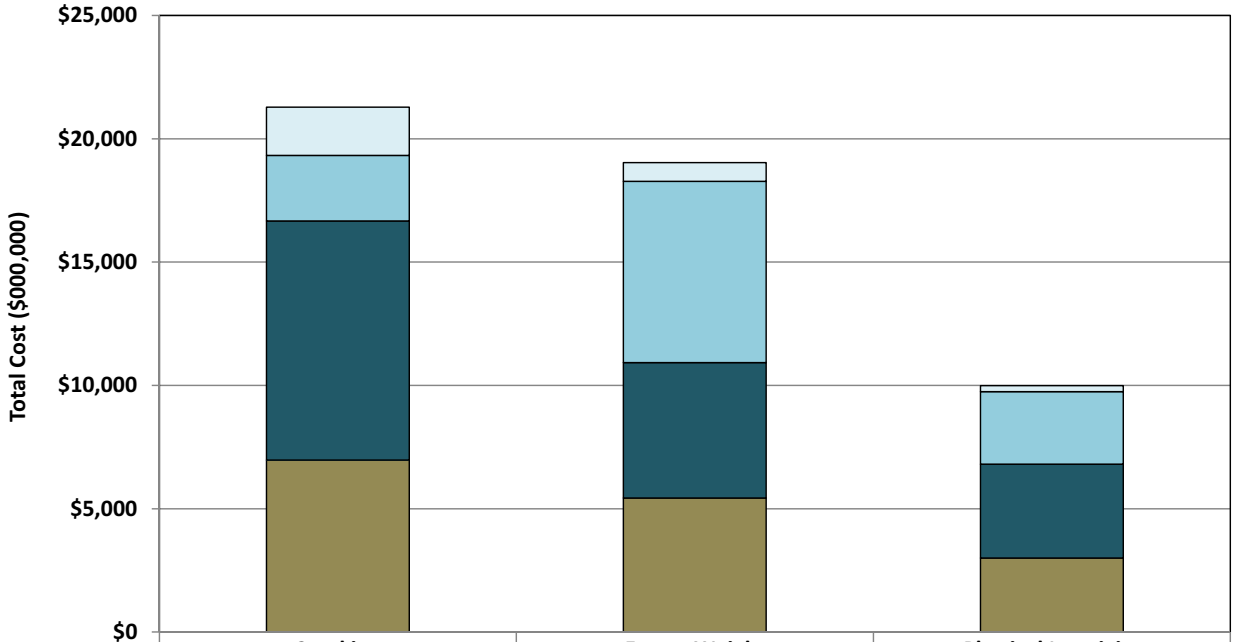
A number of key assumptions were made in modelling the economic benefits associated with future RF reduction in the Canadian population. First, population projections for the 20-year timeframe from 2012 to 2031 by sex and five-year age group were based on projections by Statistics Canada.[28] Second, RF prevalence by sex and five-year age group was calculated for 2010 using the CCHS 2010 Public Use Microdata File.[23] Third, the base model uses a constant 1% relative annual reduction in the RFs of tobacco smoking, physical inactivity and excess weight. Current trends of decreasing smoking prevalence and increasing weight and inactivity are not factored into the model. Fourth, constant 2012 dollars are used throughout the modelling process (i.e., no adjustments are made for projected inflation) in order to clearly identify changes in the economic burden associated with changing RF prevalence, rather than confusing these results with inflationary increases. Fifth, obese individuals move into the overweight category while overweight individuals move into the healthy weight category. Sixth, the benefits associated with physical activity and moving to a healthier weight accrue within a year.[29] Last, the benefits of smoking cessation accrue over time, as per Figure 1.[30]

RESULTS

Table 1 shows the fully adjusted prevalence of RF exposure, the statistically significant RR data by sex and the calculated PAF of disease incidence related to each RF. The PAF for all co-morbidities, with the obvious exception of gynecological and breast cancers, vary by sex. This type of detailed analysis has important implications in determining direct and indirect costs.

Table 2 includes a summary of the adjusted estimates of the prevalence of the chronic disease RFs, the absolute numbers of Canadians with each RF and the fully adjusted economic results. The total annual economic burden in Canada attributable to

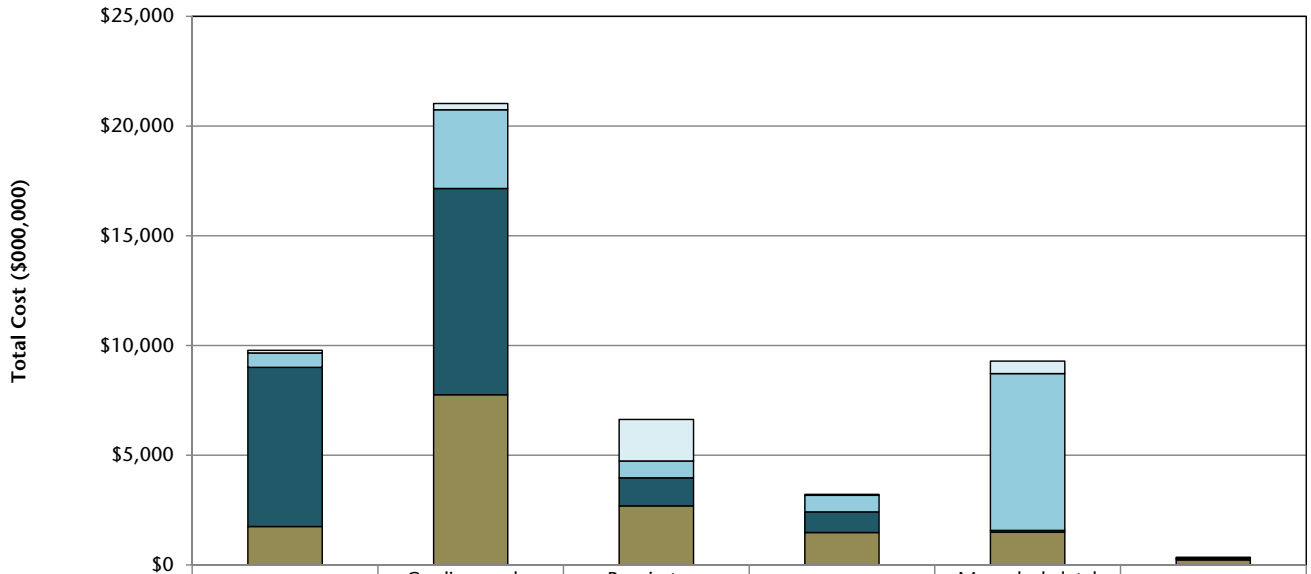
Figure 2. Estimated direct and indirect economic burden of smoking, excess weight and physical inactivity, Canada, 2012 ($000,000), adjusted for multiple risk factors in one individual



	Smoking	Excess Weight	Physical Inactivity
Indirect - S-T Disability	$1,963	$762	$243
Indirect - L-T Disability	$2,655	$7,349	$2,942
Indirect - Mortality	$9,695	$5,493	$3,803
Direct Cost	$6,974	$5,433	$3,000

S-T = Short-term; L-T = Long-term.

Figure 3. Estimated direct and indirect economic burden of smoking, excess weight and physical inactivity by disease category, Canada, 2012 ($000,000), adjusted for multiple risk factors in one individual



	Cancers	Cardiovascular Diseases	Respiratory Diseases	Diabetes	Musculoskeletal Diseases	Other
Indirect - S-T Disability	$119	$288	$1,896	$48	$573	$45
Indirect - L-T Disability	$657	$3,587	$766	$759	$7,145	$31
Indirect - Mortality	$7,257	$9,391	$1,281	$942	$71	$50
Direct Cost	$1,751	$7,761	$2,692	$1,474	$1,502	$228

S-T = Short-term; L-T = Long-term.

Table 3. Projected risk factor prevalence, Canada, 2012 compared with 2031 (no change) & 2031 (1% reduction)

	2012		2031 (No Change)		2031 (1% Reduction)	
	% Population with RF	# Individuals with RF	% Population with RF	# Individuals with RF	% Population with RF	# Individuals with RF
Males						
Smokers						
Light	8.3%	1,435,035	7.6%	1,594,064	6.3%	1,305,506
Moderate	5.9%	1,024,846	5.6%	1,159,318	4.6%	950,121
Heavy	6.5%	1,129,249	6.1%	1,263,547	5.0%	1,033,028
Subtotal - Male Smokers	20.7%	3,589,130	19.3%	4,016,929	15.8%	3,288,655
Excess Weight						
Overweight	34.7%	6,046,660	35.0%	7,306,670	31.7%	6,605,100
Obese	16.0%	2,773,601	15.6%	3,258,843	12.9%	2,679,466
Subtotal - Male Excess Weight	50.7%	8,820,261	50.7%	10,565,513	44.5%	9,284,567
Inactive	41.1%	7,149,313	41.6%	8,683,597	34.5%	7,183,620
Subtotal						
Females						
Smokers						
Light	7.0%	1,227,115	6.5%	1,372,665	5.3%	1,124,630
Moderate	5.0%	867,893	4.7%	994,982	3.8%	816,662
Heavy	3.0%	530,887	2.9%	611,023	2.4%	501,892
Subtotal - Female Smokers	15.0%	2,625,894	14.0%	2,978,670	11.5%	2,443,184
Excess Weight						
Overweight	22.5%	3,987,187	23.7%	4,927,711	21.9%	4,556,455
Obesity	12.8%	2,258,665	13.2%	2,754,174	10.9%	2,271,475
Subtotal - Female Excess Weight	35.3%	6,245,852	36.9%	7,681,885	32.8%	6,827,931
Inactive	47.5%	8,409,362	48.8%	10,358,354	40.4%	8,585,838
Both Sexes						
Smokers						
Light	7.6%	2,662,149	7.0%	2,966,729	5.8%	2,430,136
Moderate	5.4%	1,892,739	5.1%	2,154,300	4.2%	1,766,783
Heavy	4.8%	1,660,137	4.5%	1,874,569	3.6%	1,534,920
Subtotal - Smokers	17.9%	6,215,024	16.6%	6,995,599	13.6%	5,731,839
Excess Weight						
Overweight	28.6%	10,033,847	29.4%	12,234,381	26.8%	11,161,556
Obesity	14.4%	5,032,267	14.4%	6,013,017	11.9%	4,950,942
Subtotal - Excess Weight	42.9%	15,066,113	43.8%	18,247,398	38.7%	16,112,497
Inactive	44.3%	15,558,675	45.2%	19,041,951	37.5%	15,769,458

these RFs is $50.3 billion ($15.4/$34.9 billion in direct/indirect costs).

Figure 2 represents the RF-specific burden graphically, with additional information on the components that constitute the indirect costs. The indirect burden related to premature mortality dominates as an outcome of tobacco smoking ($9.7 billion, or 68% of $14.3 billion in total indirect costs for that RF) and is also marginally higher than disability in the case of physical inactivity. The reverse is true for excess weight, where the economic burden of disability ($8.1 billion) outstrips the costs of premature mortality ($5.5 billion).

This analysis indicates that the disaggregated economic burden for excess weight in Canada in 2012 at $19.0 billion remains lower than the economic burden related to tobacco smoking at $21.3 billion.

It appears that cardiovascular diseases tend to dominate the disease burden that is attributable to these RFs. Of the $50.3 billion in annual economic burden, $21.0 billion (41.8%) is associated with cardiovascular diseases, $9.8 billion (19.4%) with cancers, $9.3 billion (18.5%) with musculoskeletal diseases, $6.6 billion (13.2%) with respiratory diseases and $3.2 billion (6.4%) with diabetes (see Figure 3).

Table 3 provides a summary of the estimated number of individuals in Canada with the RFs in 2012 and compares them to 2031 with either an assumption of no change or a 1% relative annual reduction in RF prevalence. With a 1% reduction, the proportion of Canadians who smoke would decrease from 17.9% in 2012 to 13.6% in 2031. In terms of absolute numbers of Canadians who smoke, the decrease would be from 6.2 million in 2012 to 5.7 million in 2031. The proportion of Canadians with excess weight would decrease from 42.9% to 38.7% while the proportion of physically inactive Canadians would decrease from 44.3% to 37.5%.

The economic burden associated with these RFs in Canada would increase from $50.3 billion in 2012 to $59.2 billion in 2031 (in constant 2012 dollars), assuming no change in RF prevalence, i.e., based solely on population growth (see Table 4). A 1% relative annual reduction in each of the three RFs would result in this projected economic burden of $59.2 billion decreasing to $50.8 billion (-$8.5 billion) in 2031. This reduction consists of $3.2, $3.1 and $2.1 billion, respectively, for decreases in excess weight, tobacco smoking and physical inactivity (see Figure 4). Over the 20-year period from 2012 to 2031, a 1% relative annual reduction in these RFs would result in an estimated cumulative reduction in economic burden of $78.0 billion (consisting of $31.2, $26.4 and $20.3 billion, respectively, for decreases in excess weight, tobacco smoking and physical inactivity).

Sensitivity analysis

The point estimates for RR are used in the base model results presented above. We used the lower and upper bounds of the 95% CI for the RR associated with each RF and disease in a sensitivity analysis. Using the lower bounds resulted in a decrease in the total estimated economic burden in 2012 from $50.3 billion to $41.6 billion (or -17.3%) while applying the upper bounds increased the total economic burden to $58.7 billion in 2012 (or +16.7%) (see Table 5).

DISCUSSION

The annual economic burden of the RFs of tobacco smoking, excess weight and physical inactivity in Canada are estimated at

Table 4. Projected economic burden of smoking, excess weight and physical inactivity, Canada, 2012 compared with 2031 (no change) & 2031 (1% reduction), 2012 constant dollars

	2012			2031 (No Change)			2031 (1% Reduction)		
	Total direct cost of RF (M$'s)	Total indirect cost of RF (M$'s)	Total cost of RF (M$'s)	Total direct cost of RF (M$'s)	Total indirect cost of RF (M$'s)	Total cost of RF (M$'s)	Total direct cost of RF (M$'s)	Total indirect cost of RF (M$'s)	Total cost of RF (M$'s)
Males									
Smokers									
Light	$1,100	$2,294	$3,394	$1,222	$2,548	$3,770	$1,058	$2,211	$3,269
Moderate	$1,311	$2,735	$4,046	$1,483	$3,094	$4,577	$1,285	$2,686	$3,971
Heavy	$1,805	$3,707	$5,512	$2,019	$4,148	$6,168	$1,746	$3,596	$5,342
Subtotal - Male Smokers	$4,216	$8,736	$12,952	$4,724	$9,790	$14,515	$4,089	$8,493	$12,582
Excess Weight									
Overweight	$945	$2,827	$3,772	$1,142	$3,416	$4,558	$1,033	$3,088	$4,121
Obese	$1,567	$3,838	$5,406	$1,842	$4,510	$6,352	$1,514	$3,708	$5,222
Subtotal - Male Excess Weight	$2,513	$6,665	$9,178	$2,984	$7,926	$10,910	$2,547	$6,796	$9,343
Inactive	$1,397	$3,020	$4,417	$1,696	$3,669	$5,365	$1,403	$3,035	$4,438
Subtotal	$8,125	$18,422	$26,547	$9,405	$21,385	$30,789	$8,039	$18,324	$26,363
Females									
Smokers									
Light	$836	$1,676	$2,512	$935	$1,875	$2,810	$814	$1,634	$2,448
Moderate	$992	$2,009	$3,002	$1,138	$2,303	$3,441	$992	$2,010	$3,002
Heavy	$930	$1,891	$2,822	$1,071	$2,177	$3,248	$934	$1,901	$2,835
Subtotal - Female Smokers	$2,759	$5,577	$8,336	$3,144	$6,356	$9,499	$2,740	$5,544	$8,285
Excess Weight									
Overweight	$1,020	$2,730	$3,750	$1,261	$3,374	$4,634	$1,166	$3,120	$4,285
Obesity	$1,901	$4,209	$6,109	$2,318	$5,132	$7,450	$1,912	$4,233	$6,144
Subtotal - Female Excess Weight	$2,921	$6,939	$9,859	$3,578	$8,506	$12,084	$3,077	$7,352	$10,429
Inactive	$1,603	$3,968	$5,571	$1,975	$4,888	$6,862	$1,637	$4,051	$5,688
Subtotal	$7,282	$16,484	$23,766	$8,697	$19,749	$28,446	$7,454	$16,948	$24,402
Both Sexes									
Smokers									
Light	$1,936	$3,970	$5,906	$2,157	$4,423	$6,580	$1,872	$3,845	$5,717
Moderate	$2,303	$4,744	$7,048	$2,621	$5,397	$8,018	$2,277	$4,696	$6,973
Heavy	$2,735	$5,599	$8,334	$3,090	$6,325	$9,416	$2,681	$5,496	$8,177
Subtotal - Smokers	$6,974	$14,313	$21,288	$7,868	$16,146	$24,014	$6,829	$14,038	$20,867
Excess Weight									
Overweight	$1,965	$5,557	$7,522	$2,403	$6,790	$9,193	$2,198	$6,208	$8,406
Obesity	$3,468	$8,047	$11,515	$4,159	$9,642	$13,801	$3,426	$7,941	$11,367
Subtotal - Excess Weight	$5,433	$13,604	$19,037	$6,562	$16,432	$22,994	$5,624	$14,148	$19,772
Inactive	$3,000	$6,988	$9,988	$3,671	$8,556	$12,227	$3,040	$7,086	$10,126
Total	$15,408	$34,906	$50,313	$18,101	$41,134	$59,235	$15,493	$35,272	$50,765

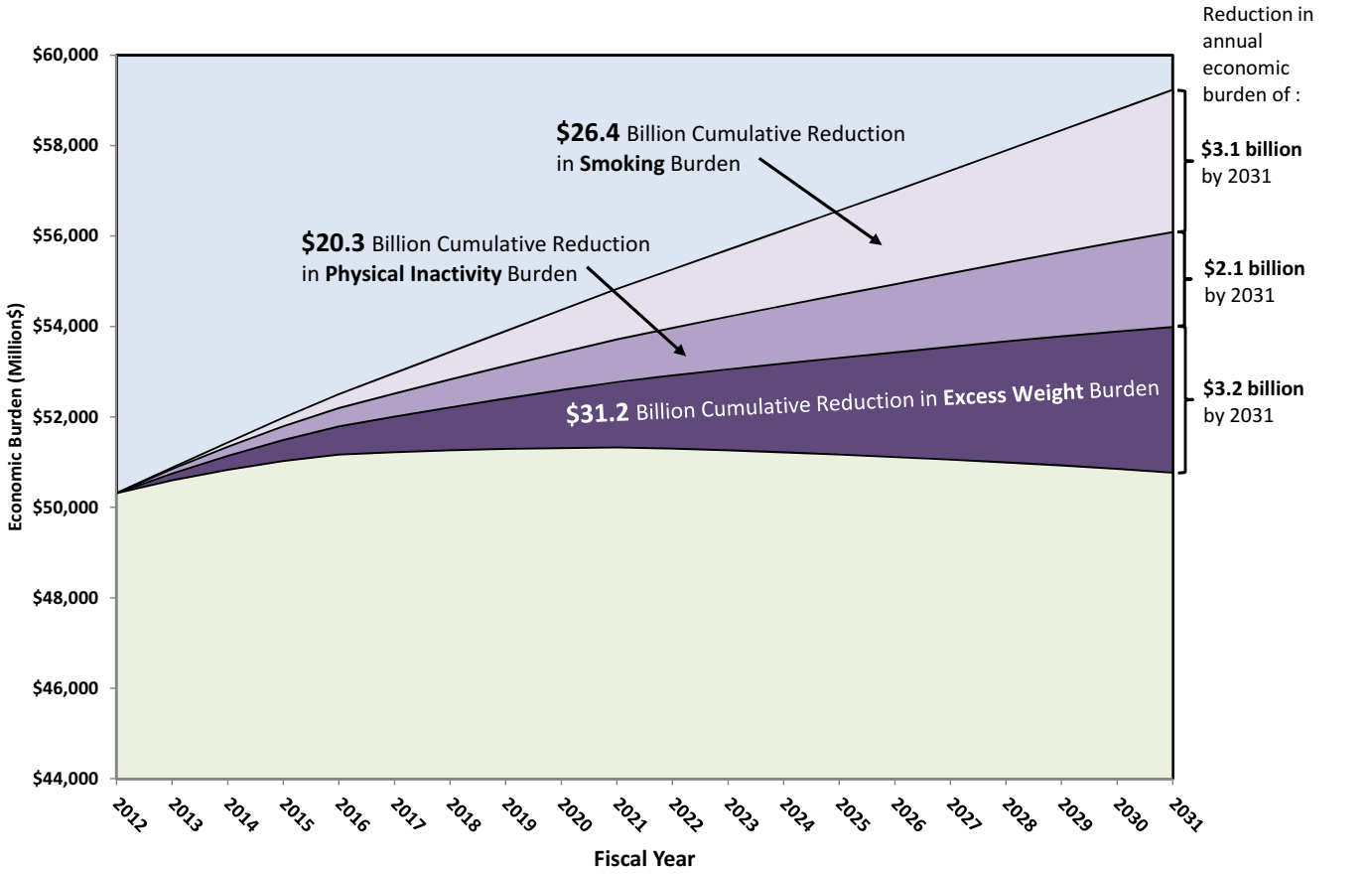
RF = Risk factor.

$50.3 billion in 2012 ($15.4/$34.9 billion in direct/indirect costs). Of this amount, $21.3 billion is attributable to tobacco smoking ($7.0/$14.3 billion in direct/indirect costs), $19.0 billion is attributable to excess weight ($5.4/$13.6 billion in direct/indirect costs), and $10.0 billion is attributable to physical inactivity ($3.0/$7.0 billion in direct/indirect costs).

Total health care expenditures in Canada in 2012 are estimated at $207.4 billion.[25] The total direct health care costs attributable to tobacco smoking, excess weight and physical inactivity of $15.4 billion represents 7.4% of this total. Kaiserman estimated smoking attributable health care costs in Canada in 1991 to be $2.5 billion,[12] or about 3.8% of the $66.3 billion total health care costs in Canada that year.[25] Similarly, Rehm and colleagues estimated smoking attributable health care costs in Canada in 2002 to be $4.4 billion,[31] or 3.8% of the $115.1 billion total health care costs in Canada that year.[25] Our finding of 3.4% ($7.0 of $207.4 billion) may be at least partially attributable to a reduction in smoking prevalence from 25.9% to 19.9% of the population aged 12 and over in Canada during the last decade[32] as well as adjustments made to avoid double counting. Katzmarzyck and Janssen estimated the direct health care costs attributable to physical inactivity and obesity to be $1.6 billion *each* in 2001,[9] or 1.5% of the $107.2 billion total health care costs in Canada that year.[25] Our estimate of 2.6% for excess weight includes both overweight and obesity. Including just obesity would reduce direct care costs to 1.7% ($3.5 of $207.4 billion), or slightly higher than the 1.5% estimated by Katzmarzyck and Janssen. Anis and colleagues estimated the combined direct costs of overweight and obesity in Canada in 2006 to be $6.0 billion, or 4.0% of the $150.8 billion total health care costs in Canada that year.[25] Of the $6.0 billion, approximately $4.0 billion (or 2.6% of $150.8 billion) is attributable to obesity. Our estimate of 1.4% ($3.0 billion of $207.4 billion) attributable to physical inactivity is somewhat lower than previous estimates of 1.5%.[9] Lower estimates of the direct costs attributable to tobacco smoking, excess weight and physical inactivity observed in the current study compared with previous Canadian studies may be at least partially due to addressing double counting when assessing the economic impact of multiple RFs within the population. In addressing double counting, the aggregate economic burden was 13.4% lower than the total that would be generated by crude summation of costs generated by each of the three RFs.

Another important result, generated by having access to sex-specific RF prevalence and RR data, is the difference between males and females in contributing to the total economic burden. Of the $50.3 billion, $26.5 billion (52.8%) is attributable to males and $23.8 billion to females. The costs associated with tobacco smoking, however, are higher for males ($13.0 billion) than for females ($8.3 billion), which is a reflection of the continuing higher prevalence of tobacco smoking among men (20.7% vs. 15.0%

Figure 4. Changes in economic burden of smoking, excess weight and physical inactivity, 1% reduction in risk factor prevalence compared to no reduction, Canada, 2012-2031 (constant million $)



among women) and the fact that a higher proportion of men are heavy smokers (6.5% vs. 3.0%). The overall sex-specific distribution for the burden of key modifiable RFs has important implications for prevention planning and public health messaging.

Our analysis suggests that even a modest 1% annual relative reduction in the RFs of tobacco smoking, excess weight and physical inactivity can have a substantial health and economic impact over time at the population level. Indeed, such a change could bend the cost curve over a 20-year period to the point where the economic burden associated with these RFs would remain essentially constant despite the projected growth in Canada's population from 33 million in 2012 to 42 million in 2031.

The analysis of the economic burden related to the RF system and the individual RFs is the first phase of any attempt to project the potential economic impact of applying known primary prevention initiatives. A key question is whether a 1% annual relative reduction in these RFs, as assumed in the current analysis, is achievable over the long term. Between 2001 and 2011, smoking rates in Canada fell from 25.9% to 19.9% for the population aged 12 and over[32] (a 2.6% relative annual reduction). There are also a number of promising approaches worldwide which include addressing the RFs of excess weight and physical inactivity,[33] such as the experience in North Karelia, Finland.[34,35]

The quality of the results derived from a PAF analysis is inevitably limited by the quality of the inputs, specifically RR and prevalence data. A potential weakness in this study is the lack of RR information based on Canadian data. A sensitivity analysis using the 95% CI associated with each RR indicates the importance of using robust and accurate RR estimates. The economic modelling also uses older data from CIHI and the *EBIC* for cost allocation purposes, requiring the assumption that the distribution of costs have not changed significantly for specific cost categories over time. Similarly, the method of scaling up from direct costs to indirect costs depends on the assumption that the ratios of costs between different co-morbidities are the same for direct and indirect costs.

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Table 5. Estimated total economic burden for multifactorial system, and disaggregated costs by RF, Canada, 2012, by sex, sensitivity analysis ($Millions)

	Best Estimate of RR	Low Estimate of RR	Variance	% Var.	High Estimate of RR	Variance	% Var.
Males							
Smokers							
Light	$3,394	$3,014	-$380	-11.2%	$3,770	$376	11.1%
Moderate	$4,046	$3,908	-$138	-3.4%	$4,177	$131	3.2%
Heavy	$5,512	$5,259	-$253	-4.6%	$5,762	$250	4.5%
Subtotal - Male Smokers	$12,952	$12,181	-$771	-5.9%	$13,710	$758	5.8%
Excess Weight							
Overweight	$3,772	$2,718	-$1,054	-27.9%	$4,671	$898	23.8%
Obese	$5,406	$3,919	-$1,487	-27.5%	$6,850	$1,445	26.7%
Subtotal - Male Excess Weight	$9,178	$6,638	-$2,541	-27.7%	$11,521	$2,343	25.5%
Inactive	$4,417	$3,504	-$913	-20.7%	$5,309	$892	20.2%
Subtotal	$26,547	$22,323	($4,224)	-15.9%	$30,540	$3,993	15.0%
Females							
Smokers							
Light	$2,512	$2,234	-$278	-11.1%	$2,794	$282	11.2%
Moderate	$3,002	$2,874	-$128	-4.3%	$3,129	$128	4.3%
Heavy	$2,822	$2,677	-$145	-5.1%	$2,975	$154	5.4%
Subtotal - Female Smokers	$8,336	$7,785	-$551	-6.6%	$8,899	$563	6.8%
Excess Weight							
Overweight	$3,750	$2,686	-$1,064	-28.4%	$4,757	$1,008	26.9%
Obesity	$6,109	$4,520	-$1,589	-26.0%	$7,766	$1,657	27.1%
Subtotal - Female Excess Weight	$9,859	$7,206	-$2,653	-26.9%	$12,524	$2,665	27.0%
Inactive	$5,571	$4,312	-$1,260	-22.6%	$6,735	$1,164	20.9%
Subtotal	$23,766	$19,303	($4,463)	-18.8%	$28,158	$4,392	18.5%
Both Sexes							
Smokers							
Light	$5,906	$5,248	-$658	-11.1%	$6,564	$658	11.1%
Moderate	$7,048	$6,782	-$265	-3.8%	$7,307	$259	3.7%
Heavy	$8,334	$7,936	-$398	-4.8%	$8,738	$404	4.8%
Subtotal - Smokers	$21,288	$19,966	-$1,321	-6.2%	$22,609	$1,321	6.2%
Excess Weight							
Overweight	$7,522	$5,405	-$2,117	-28.1%	$9,428	$1,906	25.3%
Obesity	$11,515	$8,439	-$3,076	-26.7%	$14,617	$3,101	26.9%
Subtotal - Excess Weight	$19,037	$13,844	-$5,193	-27.3%	$24,045	$5,007	26.3%
Inactive	$9,988	$7,816	-$2,172	-21.7%	$12,045	$2,057	20.6%
Total	$50,313	$41,626	($8,687)	-17.3%	$58,698	$8,385	16.7%

RF = Risk factor; RR = Relative risk.

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RÉSUMÉ

OBJECTIF : Le tabagisme, le surpoids et la sédentarité alourdissent beaucoup le fardeau des maladies évitables au Canada. Nous avons appliqué une démarche élaborée récemment afin d'aborder le problème du double comptage dans l'estimation du fardeau économique actuel combiné de ces trois facteurs de risque et d'estimer les avantages économiques de la réduction à long terme des facteurs de risque au Canada.

MÉTHODE : Notre démarche se fonde sur les fractions attribuables dans la population (FAP) pour estimer le fardeau économique associé aux divers facteurs de risque. Lorsqu'elles étaient disponibles, nous avons utilisé des données sur le risque relatif selon le sexe et des données de prévalence selon l'âge et le sexe pour la modélisation. Le surpoids a été modélisé en tant qu'exposition trichotome (sujet de poids normal, en surpoids, obèse), et le tabagisme, en tant qu'exposition tétrachotome (non-fumeur, fumeur léger, fumeur moyen, grand fumeur). Tous les coûts sont en dollars canadiens constants de 2012.

RÉSULTATS : Le fardeau économique annuel des facteurs de risque du tabagisme, du surpoids et de la sédentarité au Canada est estimé à 50,3 milliards de dollars en 2012. L'analyse de sensibilité suggère un intervalle de 41,6 à 58,7 milliards de dollars pour le fardeau économique. Sur ces 50,3 milliards, 21,3 (20 à 22,6) sont imputables au tabagisme, 19 (13,8 à 24) au surpoids et 10 (7,8 à 12) à la sédentarité. Une baisse annuelle relative de 1 % de chacun des trois facteurs entraînerait une réduction annuelle du fardeau économique de 8,5 milliards de dollars d'ici 2031.

CONCLUSION : Une modique baisse annuelle relative de 1 % dans les facteurs de risque du tabagisme, du surpoids et de la sédentarité peut avoir un impact sanitaire et économique considérable au fil du temps au niveau de la population.

MOTS CLÉS : fardeau économique; fraction attribuable dans la population; facteurs de risque; tabagisme; surpoids; sédentarité