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Estimates of the current and future burden of cancer attributable to lack of physical activity in Canada

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

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

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ABSTRACT

Physical activity reduces the risk of many cancers, yet the prevalence of inadequate physical activity among Canadians remains high. Here we estimated the current attributable and future avoidable burden of cancer related to inadequate physical activity among Canadian adults. Population attributable risk (PAR) for all cancers associated with inadequate physical activity were estimated using relative risks obtained from comprehensive reports, meta-analyses and pooled analyses. Cancer incidence data were acquired from the Canadian Cancer Registry. Physical activity data were taken from Canadian Community Health Survey (Cycle 2.1, 2003), in which respondents were classified as "physically inactive" (< 1.5 kcal/kg/day), "moderately active" (1.5–2.9 kcal/kg/day) or "physically active (≥3.0 kcal/kg/day). We defined "inadequate physical activity" as being either "physically inactive" or "moderately active" to determine the PAR of cancer due to inadequate physical activity. We estimated the future burden of inadequate physical activity using potential impact fractions and a series of intervention scenarios, including 10% to 50% reductions in inadequate physical activity from 2015 to 2042. For 2015, the total attributable burden due to inadequate physical activity for associated cancers was 10.6% and 4.9% for all cancers. A 50% reduction in inadequate physical activity could avoid 39,877 cumulative cases of cancer by 2042. Over 9000 cancer cases in 2015 were estimated to be attributable to inadequate physical activity and 5170 incident cases of cancer could be prevented with increases in physical activity levels by 2042. Policies aimed at increasing physical activity among Canadian could have a meaningful impact for cancer prevention.

1. Introduction

The World Health Organization estimates that inadequate physical activity results in 6% of deaths globally per year, making it the fourth leading risk factor for mortality (World Health Organization, 2010). Inadequate physical activity increases the risk of several non-communicable diseases, such as type 2 diabetes, cardiovascular diseases as well as several types of cancer (Lee et al., 2012). In 2018, the Third Expert

* Corresponding author at: Department of Cancer Epidemiology and Prevention Research, CancerControl Alberta, Alberta Health Services, Holy Cross Centre, Box ACB, 2210 2nd St SW, Calgary, Alberta T2S 3C3, Canada.
E-mail address: Christine.Friedenreich@albertahealthservices.ca (C.M. Friedenreich).

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

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Table 1
Relative risks of cancers for recreational physical activity.

Cancer site	Level of recreational physical activity	Relative risk (95% confidence interval)	
		Men	Women
Breast[a]	High	–	0.87 (0.81–0.94)
	Moderate	–	0.93 (0.90–0.97)
Lung[b]	High	0.82 (0.74–0.90)	0.83 (0.69–0.99)
	Moderate	0.91 (0.86–0.95)	0.91 (0.83–0.99)
Kidney[c]	High	0.88 (0.77–1.00)	0.88 (0.77–1.00)
	Moderate	0.94 (0.88–1.00)	0.94 (0.88–1.00)
Bladder[d]	High	0.81 (0.66–0.99)	0.81 (0.66–0.99)
	Moderate	0.90 (0.81–0.99)	0.90 (0.81–0.99)
Oesophagus[e]	High	0.79 (0.60–1.02)	0.79 (0.60–1.02)
	Moderate	0.88 (0.70–1.10)	0.88 (0.70–1.10)
Stomach[e]	High	0.82 (0.72–0.94)	0.82 (0.72–0.94)
	Moderate	0.91 (0.85–0.97)	0.91 (0.85–0.97)
Endometrium[f]	High	–	0.80 (0.69–0.92)
	Moderate	–	0.89 (0.83–0.96)
Colon[g]	High	0.87 (0.80–0.94)	0.87 (0.80–0.94)
	Moderate	0.93 (0.89(0.97)	0.93 (0.89(0.97)
Rectum[g, h]	High	0.88 (0.81–0.96)	0.88 (0.81–0.96)
	Moderate	0.94 (0.90–0.98)	0.94 (0.90–0.98)
Liver[g, h]	High	0.81 (0.61–1.09)	0.81 (0.61–1.09)
	Moderate	0.90 (0.78–1.04)	0.90 (0.78–1.04)
Small Intestine[g, h]	High	0.81 (0.62–1.05)	0.81 (0.62–1.05)
	Moderate	0.90 (0.78–1.02)	0.90 (0.78–1.02)
Myeloid Leukemia[g, h]	High	0.85 (0.73–0.97)	0.85 (0.73–0.97)
	Moderate	0.92 (0.85–0.98)	0.92 (0.85–0.98)
Myeloma[g, h]	High	0.87 (0.77–0.98)	0.87 (0.77–0.98)
	Moderate	0.93 (0.88–0.99)	0.93 (0.88–0.99)
Head and Neck[g, h]	High	0.85 (0.77–0.94)	0.85 (0.77–0.94)
	Moderate	0.92 (0.88–0.97)	0.92 (0.88–0.97)
Non-Hodgkin Lymphoma[g, h]	High	0.94 (0.85–1.04)	0.94 (0.85–1.04)
	Moderate	0.97 (0.92–1.02)	0.97 (0.92–1.02)

[a] Estimates from WCRF/ARIC CUP: Breast Cancer 2017 report.
[b] Estimates from Brenner and colleagues. (Brenner et al., 2016).
[c] Estimates from Behrens and colleagues. (Behrens and Leitzmann, 2013).
[d] Estimates from Keimling and colleagues.(Keimling et al., 2014).
[e] Estimates from Behrens and colleagues.(Behrens et al., 2014).
[f] Estimates from WCRF: Endometrial Cancer 2013 report.
[g] Estimates from Moore and colleagues. (Moore et al., 2016).
[h] Used in sensitivity analysis.

Report produced by the World Cancer Research Fund (WCRF)/American Institute for Cancer Research (AICR) concluded that there is *strong convincing* evidence that relatively high levels of physical activity decreases the risk of colon cancer, and *strong probable* evidence that relatively high levels of physical activity decreases the risk of endometrial cancer and postmenopausal breast cancer (World Cancer Research Fund/American Institute for Cancer Research, 2018). Additionally, recent systematic reviews and meta-analyses provide evidence that physical activity reduces the risk of cancers of the bladder, esophagus, kidney, lung and stomach (World Cancer Research Fund/American Institute for Cancer Research, 2018).

The plausible biologic mechanisms whereby physical activity may lower the risk for associated cancer sites include reducing adiposity, endogenous sex and metabolic hormones, decreasing inflammatory markers and possibly improving immune system functions (World Cancer Research Fund International/American Institute for Cancer Research, 2018). In addition, several other mechanisms may be operative, including an impact on oxidative stress, DNA repair, telomere length, genomic stability (World Cancer Research Fund International/American Institute for Cancer Research, 2018). Increasing physical activity may impact other related lifestyle risk factors for cancers, such as controlling excess body weight (Behrens et al., 2014; Brenner et al., 2016) and sedentary behavior (Keimling et al., 2014).

The Canadian Physical Activity Guidelines for Adults recommends 150 min of moderate to vigorous intensity physical activity per week (Tremblay et al., 2011). To achieve health benefits, including reducing the risk of multiple cancers, the Canadian Cancer Society recommends that adults aim for 30 min of daily physical activity including moderate to vigorous intensity activity and strengthening exercises. Self-reported physical activity during leisure-time, as captured by the Canadian Community Health Survey (CCHS), suggest physical activity levels have remained relatively constant in Canada between 2001 and 2014, in which at least moderate physical activity during leisure time (defined in this survey as doing the equivalent of at least 30 min per day of walking) ranged annually from 50.3% to 57.6% among men and 43.0% to 52.8% among women (Statistics Canada, 2014). During the same time period (2001 to 2014), Canadian men were more likely to be moderately or vigorously physically active compared to women (Statistics Canada, 2014). However, accelerometer results from the Canadian Health Measures Survey which includes total physical activity reported in 2011, indicate that 85% of adults did not meet the Canadian Physical Activity Guidelines (Colley et al., 2011).

We previously estimated the number of cancer cases attributable to inadequate physical activity in Alberta in 2012 (Brenner et al., 2017). Suboptimal levels of physical activity, which refer to levels that do not meet Canada's Physical Activity Guidelines, were estimated to be attributable to 13.8% of associated cancers, which represents 7.2% of all cancers (Brenner et al., 2017). Since population attributable risk (PAR) estimates are time- and population-specific, and because Canadian-wide estimates of the current and future burden of cancer attributable to inadequate physical activity do not exist, the aim of this study was to generate these estimates. The objectives of this analysis were to

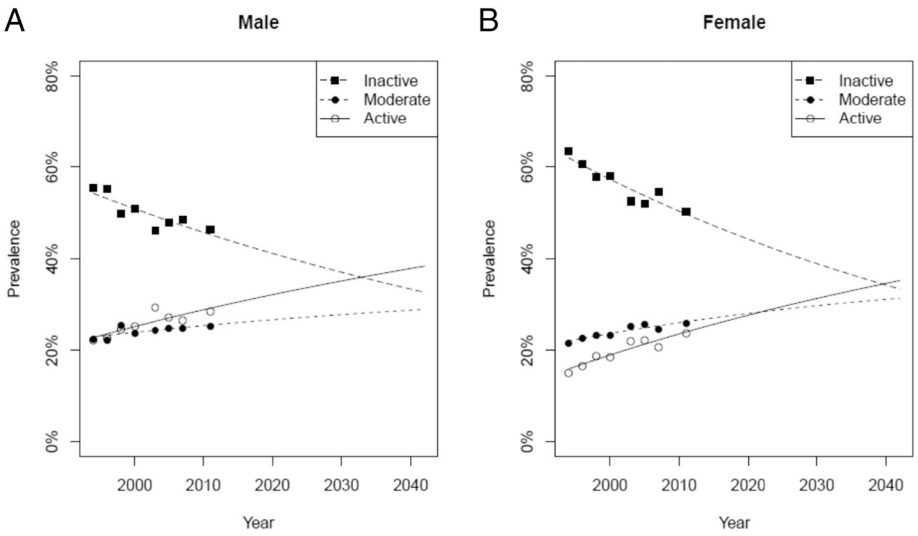

Fig. 1. Prevalence of active, moderately active, and inactive leisure-time physical activity for A) men and B) women projected to 2042.

Table 2
Prevalence of moderate and low recreational physical activity in Canada[a], (2003).

Age (years)	Physical activity Prevalence (95% confidence interval)	
	Moderate	Low
Men	24.1 (23.5–24.7)	46.7 (46.0–47.4)
20–34	24.1 (22.9–25.4)	40.4 (39.0–41.8)
35–44	24.4 (23.1–25.7)	48.8 (47.3–50.3)
45–64	24.5 (23.5–25.5)	50.7 (49.6–51.9)
≥ 65	22.7 (21.6–23.9)	45.9 (44.5–47.3)
Women	24.8 (24.2–25.3)	52.6 (51.9–53.2)
20–34	26.2 (25.1–27.4)	48.9 (47.5–50.2)
35–44	24.8 (23.4–26.1)	51.4 (49.8–52.9)
45–64	26.2 (25.2–27.2)	52.0 (50.9–53.1)
≥ 65	20.0 (19.1–20.9)	60.8 (59.6–61.9)
Total	24.5 (24.1–24.9)	49.7 (49.2–50.2)
20–34	25.2 (24.3–26.0)	44.6 (43.6–45.6)
35–44	24.6 (23.7–25.5)	50.1 (49.0–51.1)
45–64	25.4 (24.7–26.1)	51.4 (50.6–52.2)
≥ 65	21.2 (20.5–21.9)	54.2 (53.3–55.1)

[a] Data from cycle 2.1 of the Canadian Community Health Survey (2003).

estimate the current number of incident cancer cases in Canada in 2015 attributable to inadequate physical activity and to estimate the proportion and number of cancer cases that could be prevented by 2042 through the successful implementation of evidence-based counterfactual intervention scenarios in inadequate physical activity.

2. Methods

The methodologic framework for the methods used in this series has been previously published (Brenner et al., 2018). To estimate attributable risk and avoidable burden at both the national and provincial levels we required three different types of information: age- and sex-specific cancer incidence; measures of association such as risk estimates; and prevalence data on inadequate physical activity by age, sex and province.

2.1. Current population attributable burden

2.1.1. Latency period

As previously described (Brenner et al., 2018), a latency period is assumed between the effects of inadequate physical activity and subsequent cancer risk. We assumed a 12-year latency period in the present analyses. Thus, we applied estimates of inadequate physical activity from 2003 to cancer cases that occurred in 2015.

2.1.2. Risk estimates

We extracted relative risk (RR) estimates for the protective effect of physical activity from comprehensive reports, meta-analyses and pooled analyses (Table 1). RR estimates for breast cancer were obtained from the 2017 WCRF Continuous Update Report (World Cancer Research Fund/American Institute for Cancer Research, 2017, 2018). RR estimates for endometrial cancer were obtained from the 2013 WCRF Endometrial Cancer Report (World Cancer Research Fund/American Institute for Cancer Research, 2013). Additional cancer site estimates were obtained from systematic reviews and meta-analysis studies. The cancers that were included were lung (Brenner et al., 2016), kidney, stomach and esophagus (Behrens et al., 2014), bladder cancer (Keimling et al., 2014), colon, rectum, liver, small intestine, myeloid leukemia, myeloma, head and neck and non-Hodgkin lymphoma (Moore et al., 2010; Moore et al., 2016). Where possible, to quantify the effect of inadequate physical activity, we estimated the excess RR for each cancer associated with being physically inactive as (1/RR) - 1, where RR is the estimate for the protective effect of being physically active. For the moderately active group, we assumed that the risk had a linear dose-response on log scale. The quality of the meta-analyses used to obtain risk estimates was assessed using the Meta-analyses of Observational Studies in Epidemiology (MOOSE) guidelines (Stroup et al., 2000). The relative risk estimates extracted from these reviews and used in this analysis are provided in Table 1.

2.1.3. Prevalence of exposure data

To measure the prevalence of inadequate physical activity, we used provincial and national data from the Canadian Community Health Survey (CCHS). Specifically, Cycle 2.1 (2003) of the CCHS was used, which collected information on the type, frequency and duration of physical activity that participants engaged in during leisure-time [only]. Full details regarding survey methods for the CCHS have been published elsewhere (Beland, 2002). The CCHS is a nationally-representative, cross-sectional survey of the Canadian population over the age of 12; however, our analyses only focused on adult respondents aged 20 years and older.

In the CCHS, each type of recreational physical activity reported by participants was assigned a metabolic equivalent of task (MET) value using an approach adopted from the Canadian Fitness and Lifestyle Research Institute (Ainsworth et al., 2011). For each activity, the

Table 3
Cancer cases and proportions attributable to moderate and low recreational physical activity in Canada (2015) ***No Confidence Intervals.

Age at exposure	Age at Dx	Breast			Lung			Endometrium			Colon			Stomach			Kidney			Bladder			Esophagus[a]		
		Obs.	PAR	EAC	Obs.	PAR	EAC	Obs.	PAR	EAC	Obs.	PAR	EAC	Obs.	PAR	EAC	Obs.	PAR	EAC	Obs.	PAR	EAC	Obs.	PAR	EAC
Men																									
20–34	30–44				75	10.8	8				230	7.5	17	65	10.6	7	215	6.9	15	120	11.2	13	14	13.5	2
35–44	45–54				645	11.5	74				655	8.3	55	195	11.6	23	600	7.6	45	440	12.3	54	94	13.9	13
45–64	55–74				7390	11.8	875				4130	8.6	353	1100	11.9	131	2215	7.8	173	3825	12.7	484	644	14.3	92
≥65	≥75				4835	10.9	526				2930	7.8	230	865	10.9	95	785	7.1	56	3150	11.7	368	310	13.2	41
Total					12,945	11.5	1484				7945	8.2	655	2225	11.4	255	3815	7.6	289	7535	12.2	920	1062	14	148
Women																									
20–34	30–44	0		0	115	11.2	13	285	13.6	39	245	8.6	21	40	12	5	130	7.8	10	60	12.7	8	0	14.2	0
35–44	45–54	2925	8.6	252	855	11.4	98	970	13.7	133	595	8.7	52	120	12	14	315	7.9	25	165	12.8	21	11	14.5	2
45–64	55–74	12,685	8.9	1125	7125	11.7	832	4035	14.0	564	3105	8.9	275	530	12.3	65	1135	8.1	91	1080	13.1	142	101	14.8	15
≥65	≥75	4705	9.4	444	4195	12.4	519	1050	14.7	155	3120	9.5	297	560	13.3	74	535	8.6	46	1030	14.1	145	106	15.8	17
Total		20,315	9	1822	12,290	11.9	1461	6340	14.0	890	7065	9.1	645	1250	12.7	159	2115	8.2	172	2335	13.5	315	218	15.3	33
Total																									
20–34	30–44	0		0	190	11.0	21	285	13.6	39	475	8.1	38	105	11.1	12	345	7.2	25	180	11.7	21	14	13.5	2
35–44	45–54	2760	9.3	257	1500	11.5	172	970	13.7	133	1250	8.5	106	315	11.7	37	915	7.7	70	605	12.5	76	105	14	15
45–64	55–74	11,220	9.2	1035	14,515	11.8	1707	4035	14.0	564	7235	8.7	629	1630	12	196	3350	7.9	264	4905	12.8	626	746	14.4	107
≥65	≥75	4545	9.6	438	9030	11.6	1045	1050	14.7	155	6050	8.7	526	1425	11.9	169	1320	7.7	102	4180	12.3	513	415	13.9	58
Total		18,525	9.3	1731	25,235	11.7	2945	6340	14.0	890	15,010	8.7	1299	3475	11.9	413	5930	7.8	461	9870	12.5	1235	1280	14.2	182

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

number of times that a respondent engaged in that particular activity was multiplied by its average duration. This product was then multiplied by the average energy cost of the activity (indicated by the MET value) and then divided by 365 (number of days per year). A derived daily energy expenditure variable was calculated by summing all the energy expenditures for each activity (kcal/kg/day). Participants were classified as "physically inactive" (energy expenditure of < 1.5 kcal/kg/day), "moderately active" (energy expenditure of 1.5–2.9 kcal/kg/day) or "physically active" (energy expenditure of ≥ 3.0 kcal/kg/day). The physical activity classification was set by the CCHS. The "physically active" category generally indicates a level of regular, daily physical activity lasting at least 30 min. Being classified as "physically inactive" or "moderately active" is considered substandard in terms of cancer prevention.

2.1.4. Statistical analysis - estimation of population attributable risk

We used Levin's equation (Levin, 1953) to estimate PARs associated with being either moderately inactive or inactive using the following equation:

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

where Pe_1 is the prevalence of moderate inadequate physical activity, Pe_2 is the prevalence of inadequate physical activity, ERR_1 is the excess RR associated with moderate inadequate physical activity and ERR_2 is the excess RR associated with inadequate physical activity.

To estimate the number of incident cancer cases in 2015 attributable to inadequate physical activity, we multiplied the PARs by the number of incident cancer cases. These estimates were also generated for each province and the territories combined. The total proportion of cancer cases estimated to be attributable to inadequate physical activity at each cancer site was estimated as the total number of attributable cases for that cancer across all sex and age groups, divided by the total number of observed cancers at that site.

2.2. Future avoidable burden

2.2.1. Prevalence of exposure projections

We extracted the historical prevalence of physical activity from both the National Population Health Survey (NPHS) (1994, 1996, and 1998) and the CCHS (2000, 2003, 2005, 2007, and 2011). The NPHS and CCHS used the same questionnaires for assessing recreational physical activities, and therefore their data can be combined in order to project the future prevalence of physical activity.

To project future prevalence of physical activity among Canadians aged 20 and over by sex, we regressed the prevalence of the inactive population for each sex group by years with a log-linear (log(prevalence) ~ year) and a log-log (log(prevalence) ~ log(year)) models, and then selected the model with the higher R-squared value. For the prevalence of the active population, we modeled the prevalence odds and the years in order to avoid the problem that the predicted prevalence may exceed 100%. We selected the model with best R-squared value from the linear (prevalence odds ~ year), log-linear (log(prevalence odds) ~ year), linear-log (prevalence odds ~ log(year)), and log-log (log(prevalence odds) ~ log(year)) models. The prevalence of being "moderately active" was estimated by 1 – prevalence of inactive – prevalence of active, so that the sum of the prevalence of each exposure level is 100%. We modeled the prevalence of being active and inactive, but not that of being moderately active, because the historical data demonstrated a more apparent trend for the former two, as indicated by the coefficients of a simple linear regression (Fig. 1). We assumed a latency period of 10 years and projected the prevalence at the national and provincial levels to the year 2032.

2.2.2. Projected cancer incidence

To estimate the number of future cancer cases attributable to

Table 4
Summary of cases and proportions of cancer in Canada in 2015 attributable to moderate and low recreational physical activity[a].

Exposure	Cancer site	Total			Men			Women		
		Observed cases[b]	Excess attributable cases[c]	% attributable[d]	Observed cases	Excess attributable cases	% attributable	Observed cases	Excess attributable cases	% Attributable
Moderate and low recreational physical activity	Breast	20,315	1822	9.0				20,315	1822	9.0
	Lung	25,235	2945	11.7	12,945	1484	11.5	12,290	1461	11.9
	Endometrium	6340	890	14.0				6340	890	14.0
	Colon	15,010	1299	8.7	7945	655	8.2	7065	645	9.1
	Kidney	5930	461	7.8	3815	289	7.6	2115	172	8.2
	Bladder	9870	1235	12.5	7535	920	12.2	2335	315	13.5
	Esophagus	1280	182	14.2	1062	148	14.0	218	33	15.3
	Stomach	3475	413	11.9	2225	255	11.4	1250	159	12.7
	All associated cancers[e]	87,455	9247	10.6	35,527	3750	10.6	51,928	5497	10.6
	All cancers[f]	187,070	9247	4.9	94,910	3750	4.0	92,160	5497	6.0

[a] Data on prevalence of physical inactivity from the Canadian Community Health Survey (2000/01).
[b] Number of observed cancer cases in Canada in 2015 at individual cancer sites from the Canadian Cancer Registry.
[c] Number of cancer cases at individual cancer sites that can be attributed to physical inactivity.
[d] Proportion of cancers at individual cancer sites attributable to physical inactivity.
[e] All associated cancers includes all cancers known to be associated with physical inactivity (as listed in the current table).
[f] All cancers includes all incident cancer cases in Canada for all ages in 2015.

inadequate physical activity, we projected cancer incidence to 2042 using methods previously described (Poirier et al., 2019) and as summarized in this issue (Brenner et al., 2018). In summary, projected Canadian cancer incidences were estimated based on 1983 to 2012 cancer incidence data and available projected population data from Statistics Canada (Brenner et al., 2018). A decision algorithm was used to determine the most appropriate model for the projections (Brenner et al., 2018; Poirier et al., 2019). All projections were assessed for statistical goodness-of-fit using the Pearson's Chi-squared test, including face validity based on expert opinion.

2.2.3. Counterfactual scenarios

Counterfactual scenarios model an ideal situation where population interventions alter the proportion of 'exposed' individuals across the population. For this analysis, we considered three intervention or "counterfactual" scenarios for the physical activity distribution: 10%, 25%, and 50% reduction in inadequate physical activity prevalence. The counterfactual distribution is the distribution in the prevalence of the exposure when change occurs or an intervention is implemented (Murray et al., 2003). The aim in varying the distributions of reduced inadequate physical activity is to estimate the number of cancer cases that could be prevented if such changes were realized across the population. We assumed that reductions in the proportion of Canadians from the "physically inactive" category were distributed equally into the other two categories. For example, a 10% reduction in prevalence means 10% of "moderately active" becomes "physically active", 5% of "physically inactive" becomes "moderately active" and another 5% becomes "physically active".

2.3. Estimation of potential impact fractions

To assess the future burden of preventable cancers attributable to inadequate physical activity, potential impact fraction (PIF) estimates were used. Potential impact fractions were estimated using the equation for proportion shift:

$$PIF = \frac{\sum_{c=1}^{n} P_c RR_c - \sum_{c=1}^{n} P_c^* RR_c}{\sum_{c=1}^{n} P_c RR_c}$$

where $n = 3$ (the 3 categories of physical activity level), P_c is the prevalence of inadequate physical activity in category c, RR_c is the RR for that category, and P_c^* is the counterfactual prevalence in category c. After intervention, the counterfactual cancer incidence rates are $I^* = (1 - PIF)I$, where I is the projected cancer incidence rates.

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 moderate and low recreational physical activity

The prevalence of moderate and low recreational physical activity available from the CCHS (Cycle 2.12003) among adults in Canada is presented in Table 2. We observed that, in all Canadian provinces, there is a decreasing trend in the "physically inactive" proportion of the population and an increasing trend in the "physically active" proportion. In Canada, the prevalence of moderately active adults in 2003 was 24.5% and the prevalence of physically inactive adults was 49.7% for all ages and men and women combined. For 8 of the 10 provinces, the prevalence of low physical activity was over 50% (Supplementary Table 1.) In general, the proportion of physically inactive Canadian adults increased with age, with the exception of males aged ≥65 years. The prevalence of inadequate physical activity among Canadian adults appeared to be slightly higher among females than males. For men and women and both sexes combined, moderate physical activity was lowest among the oldest age group ≥65 years. The lowest prevalence of inactive adults is seen among men aged 20 to 34 at 40.4%. The highest prevalence of inactive adults was seen among women aged ≥65 years at 60.8%.

3.2. Current attributable burden of inadequate physical activity on cancer

The estimated number of cases and proportions of cancers attributable to moderate and low levels of recreational physical activity combined are presented in Table 3 and Table 4. For cancers that are known to be associated with inadequate physical activity, 10.6% (9247) of observed incident cases were attributed to inadequate physical activity. This figure (9247) represented 4.9% of all cancers observed in 2015 for men and women combined. The cancers with the highest proportions of observed incident cases were attributed to inadequate physical activity, for both men and women combined were esophagus at 14.2% (182), endometrium at 14.0% (890) and bladder at 12.5% (1235). For men, we estimated that 10.6% (3750) of all associated and 4.0% (3750) of all-cancers were attributed to inadequate

Table 5
Projected cancer cases and proportions attributable to moderate and low recreational physical activity exposure and the proportion of cancer cases that could be prevented by 2042 with various changes in physical inactivity levels in 2042 in Canada.

Sex	Statistics	CTF [a]	All	Bladder	Breast	Colon	Endometrium	Lung	Kidney	Esophagus	Stomach
Men	Projected cases	Base	55,460	10,697		15,949		14,853	7230	2592	4139
	PAR(%)		8.7	10.4		7		9.7	6.3	11.9	9.7
	EAC		4836	1114		1117		1440	456	308	401
Women	Projected cases		89,574	3359	34,217	14,683	11,266	19,156	3797	523	2573
	PAR(%)		8.6	10.9	7.3	7.3	11.7	9.7	6.6	12.4	10.2
	EAC		7710	366	2515	1079	1314	1858	251	65	261
Both	Projected cases		145,035	14,057	34,217	30,631	11,266	34,008	11,028	3115	6712
	PAR(%)		8.6	10.5	7.3	7.2	11.7	9.7	6.4	12	9.9
	EAC		12,545	1480	2515	2196	1314	3298	708	373	663
Men	Projected cases	1	55,061	10,605		15,857		14,733	7192	2567	4106
	PIF(%)		0.7	0.9		0.6		0.8	0.5	1	0.8
	Prevented cases		400	92		91		120	38	25	33
	Cumulative cases		3083	701		681		979	291	189	241
Women	Projected cases		88,940	3329	34,011	14,594	11,158	19,002	3777	518	2551
	PIF(%)		0.7	0.9	0.6	0.6	1	0.8	0.5	1	0.8
	Prevented cases		634	30	206	88	108	153	21	5	22
	Cumulative cases		4893	233	1562	661	848	1234	162	39	155
Both	Projected cases		144,001	13,934	34,011	30,451	11,158	33,735	10,969	3085	6657
	PIF(%)		0.7	0.9	0.6	0.6	1	0.8	0.5	1	0.8
	Prevented cases		1034	122	206	180	108	273	59	30	55
	Cumulative cases		7975	934	1562	1342	848	2212	453	228	396
Men	Projected cases	2	54,461	10,467		15,720		14,553	7136	2529	4056
	PIF(%)		1.8	2.2		1.4		2	1.3	2.4	2
	Prevented cases		999	230		229		300	94	63	84
	Cumulative cases		7707	1753		1704		2447	728	473	603
Women	Projected cases		87,988	3284	33,702	14,461	10,996	18,772	3745	510	2519
	PIF(%)		1.8	2.3	1.5	1.5	2.4	2	1.4	2.5	2.1
	Prevented cases		1586	76	515	221	270	383	52	13	54
	Cumulative cases		12,232	582	3905	1652	2119	3084	404	98	388
Both	Projected cases		142,449	13,751	33,702	30,182	10,996	33,325	10,881	3039	6574
	PIF(%)		1.8	2.2	1.5	1.5	2.4	2	1.3	2.4	2.1
	Prevented cases		2585	306	515	450	270	683	147	76	138
	Cumulative cases		19,938	2335	3905	3356	2119	5530	1133	571	990
Men	Projected cases	3	53,462	10,237		15,492		14,253	7041	2467	3972
	PIF(%)		3.6	4.3		2.9		4	2.6	4.8	4
	Prevented cases		1999	460		457		600	189	126	167
	Cumulative cases		15,414	3505		3407		4893	1457	946	1205
Women	Projected cases		86,403	3208	33,186	14,240	10,725	18,389	3693	496	2464
	PIF(%)		3.5	4.5	3	3	4.8	4	2.7	5.1	4.2
	Prevented cases		3172	152	1031	442	540	767	104	27	109
	Cumulative cases		24,463	1164	7811	3304	4238	6168	809	195	775
Both	Projected cases		139,864	13,445	33,186	29,732	10,725	32,642	10,734	2963	6436
	PIF(%)		3.6	4.4	3	2.9	4.8	4	2.7	4.9	4.1
	Prevented cases		5170	612	1031	900	540	1366	293	152	276
	Cumulative cases		39,877	4669	7811	6711	4238	11,061	2265	1142	1980

Abbreviations: AC = Attributable cases due to exposure, PAR = Population attributable risk, CTF = counterfactual scenario PIF = Potential impact fraction.
[a] Base = continuing prevalence trends with no change. Scenario 1 = 10% reduction in physical inactivity by 2032. Scenario 2 = 25% reduction in physical inactivity by 2032. Scenario 3 = 50% reduction in physical inactivity by 2032.

physical activity. For women, 10.6% (5497) of all associated and 6.0% (5497) of all-cancers were attributed to inadequate physical activity in 2015. We also conducted a sensitivity analysis using the Canadian Health Measures Survey (CHMS) that included accelerometer data and found very small differences between these estimates and those produced with the CCHS data. However, it is important to note that the CHMS includes total physical activity, not only recreational physical activity. The PAR estimates for Canadian provinces are presented in Supplementary Table 2. Canadian PAR estimates with 95% confidence intervals are presented in Supplementary Table 3.

3.3. Future avoidable burden of cancer

The projected proportions of cancer cases by sex at the national level that could be prevented by 2042 with three different counterfactual scenarios applied to physical activity are presented in Table 5 and Fig. 2. Reductions in the distributions of inadequate physical activity coincided with increasing proportions of preventable cancers for both males and females across Canada. A scenario of a 50% reduction in inadequate physical activity resulted in the highest PIF percentages for all-cancers and site-specific cancers for males and females, both at the national and provincial levels, compared to smaller reductions of inadequate physical activity. We estimate that reductions in inadequate physical activity of 10%–50% by 2032 could prevent 1034 to 5170 cancers in 2042. For men, we estimated that reductions in inadequate physical activity of 10%–50% by 2032 could prevent 400 to 1999 cancers in 2042. For women, we estimate that 10%–50% reductions in inadequate physical activity prevent 634 to 3172 cancers by 2042. By 2042, a 10%–50% reduction in inadequate physical activity could cumulatively prevent 7975 to 39,877 cancers in men and women combined. For common associated cancers, a 10%–50% reduction in inadequate physical activity could avoid 206 to 1031 breast cancer cases, 273 to 1366 lung cancer cases, and 180 to 900 colorectal cancer cases by 2042 among both sexes combined. Provincial estimates of the future burden of cancer attributable to a lack of physical activity are presented in Supplementary Table 4. The projected proportions of cancer cases in Canadian provinces that could be prevented by 2042 with three different counterfactual scenarios applied to physical activity are

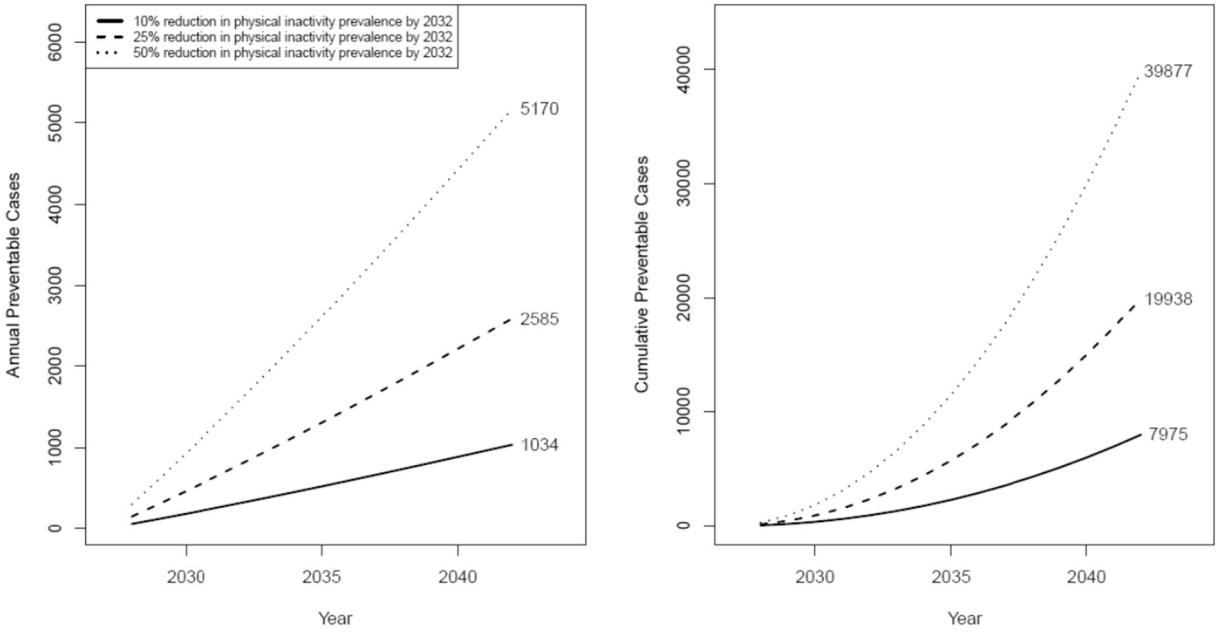

Fig. 2. Projected A) annual and B) cumulative preventable cancer cases with various changes in physical activity in Canada.

presented in Supplementary Table 5.

4. Discussion

The prevalence of inadequate physical activity in Canada is high, with 49.7% of Canadian adults engaged in low levels of recreational physical activity (< 1.5 MET-hours/day) and 24.5% participating in moderate (1.5–3 MET-hours/day) recreational physical activity in 2003. Inadequate physical activity is consistently associated with several common cancers, including breast, colon, and endometrium, which our results reflect from previous findings (Brenner, 2014; Brenner et al., 2017). We included cancers with emerging strong evidence of association with inadequate physical activity, including lung, bladder, kidney, esophagus, and stomach. Our analysis estimated that 4.9% of all cancers and 10.6% of site-specific associated cancers are attributable to inadequate recreational physical activity across the Canadian population in 2015. In a sensitivity analysis, we added seven more cancers that were suggested to be associated with physical activity, including rectum, liver, myeloma, myeloid leukemia, small intestine, head and neck, and non-Hodgkin's lymphoma (Supplementary Table 6). Inclusion of these cancers resulted in a total of 11,553 attributable cases, which represented 6.2% of all cancers in 2015. We estimated that 3.6% of associated cancers among men and women could be avoided by 2042 if inadequate physical activity was reduced by 50%. Furthermore, a 25% reduction in inadequate physical activity could prevent 1.8% of all cancers, and a 10% reduction could prevent 0.7% by 2042 among both sexes.

Similar studies in estimating the attributable burden of inadequate physical activity have been conducted in Australia and the United Kingdom (UK). National studies of population attributable risk (PAR) estimated that incident cancer cases (post-menopausal breast, endometrial and colon) diagnosed in 2010 in the United Kingdom and Australia, were related to inadequate physical activity (Olsen et al., 2015a; Parkin, 2011). Olsen and colleagues estimated that in 2010, insufficient physical activity accounted for 1.6% (1814) of all cancers for the Australian population (Olsen et al., 2015b). Parkin and colleagues estimated that 1.0% (3275) of all cancers in the UK in 2010 were attributable to inadequate physical activity (Parkin, 2011). Our result of 6.5% of all cancers in Canada being attributed to inadequate physical activity in 2015 was higher than the findings in Australia and the UK. There are several reasons for this difference. We included additional cancer sites (e.g. liver, kidney, lung) based on current evidence which had not been previously considered. In addition, both the UK and Australian studies took into consideration the intensity of physical activity performed which we were unable to do in this analysis. Hence, our analysis is less precise with respect to intensity of activity than the previous studies. However, we were able to include daily energy expenditure in our calculations and the RRs that we used to estimate population attributable risk were greater than those previously used.

This analysis provides current attributable and future avoidable burden of cancers related to inadequate physical activity across Canada. The inclusion of multiple cancer additional sites beyond the previous efforts to estimated PARs related to inadequate physical activity is a strength. Since past studies on this topic have been published there have been several WCRF/AICR updates, as well as numerous meta-analyses and large pooled analyses, thereby providing the evidence for a larger number of cancer sites to be included in this analysis. All estimates used the latest available cancer incidence data from high quality provincial cancer registries in Canada. Additionally, the availability of nationally representative population survey data, paired with repeated historical data, allowed for the estimation of both current and future burden of cancers attributable to inadequate physical activity.

There are some limitations to this analysis. Firstly, physical activity data were obtained from self-reported surveys. Studies have found discrepancies between self-reported and measured physical activity, (Prince et al., 2008) and self-reports tend to over-estimate physical activity compared to measurements via accelerometers (Dyrstad et al., 2014). Secondly, only recreational physical activity data were used. Physical activity relating to transportation, commuting, occupation, or household activities was not included because no national prevalence exposure data were available for these other types of physical activity. Future studies could examine total physical activity and utilize accelerometer data. Consequently, total physical activity could not be analyzed and we may have underestimated the full effect of physical activity on cancer incidence. Thirdly, physical activity as a cancer risk factor was examined separately from other lifestyle factors that may also contribute to cancer, and thus residual confounding may exist. Fourth, we assumed equal impacts of a counterfactual intervention from inactive to moderately active and active, which could have led to overestimations of our PIFs. Lastly, the CCHS also does not include data

from individuals living on reserve land, penitentiaries, or who were serving in the armed forces at the time of the survey. While there are limitations in using self-reported data over accelerometer data, the CCHS contains a large sample size that represents up to 98% of the Canadian adult population. Recreational physical activity data were not available for groups that were not surveyed, and the results are not generalizable to those sub-populations.

4.1. Conclusion

This study provides quantitative estimates of current and future burden of cancer that could be avoided by reducing inadequate physical activity levels in Canada. These data are directly relevant for cancer prevention programs and interventions that are focused on inadequate physical activity and provide evidence for policy makers, health practitioners, and community leaders to reduce inadequate physical activity as a risk factor for cancer. Sustained efforts are needed to increase physical activity levels at the population level as a worthwhile means for cancer prevention.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.03.008.

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