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Inside this issue

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Cancers attributable to excess body weight in Canada in 2010

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Abstract

Introduction: Excess body weight (body mass index [BMI] ≥ 25.00 kg/m^2) is an established risk factor for diabetes, hypertension and cardiovascular disease, but its relationship to cancer is lesser-known. This study used population attributable fractions (PAFs) to estimate the cancer burden attributable to excess body weight in Canadian adults (aged 25 + years) in 2010.

Methods: We estimated PAFs using relative risk (RR) estimates from the World Cancer Research Fund International Continuous Update Project, BMI-based estimates of overweight (25.00 kg/m^2–29.99 kg/m^2) and obesity (30.00 + kg/m^2) from the 2000–2001 Canadian Community Health Survey, and cancer case counts from the Canadian Cancer Registry. PAFs were based on BMI corrected for the bias in self-reported height and weight.

Results: In Canada in 2010, an estimated 9645 cancer cases were attributable to excess body weight, representing 5.7% of all cancer cases (males 4.9%, females 6.5%). When limiting the analysis to types of cancer associated with high BMI, the PAF increased to 14.9% (males 17.5%, females 13.3%). Types of cancer with the highest PAFs were esophageal adenocarcinoma (42.2%), kidney (25.4%), gastric cardia (20.7%), liver (20.5%), colon (20.5%) and gallbladder (20.2%) for males, and esophageal adenocarcinoma (36.1%), uterus (35.2%), gallbladder (23.7%) and kidney (23.0%) for females. Types of cancer with the greatest number of attributable cases were colon (1445), kidney (780) and advanced prostate (515) for males, and uterus (1825), postmenopausal breast (1765) and colon (675) for females. Irrespective of sex or type of cancer, PAFs were highest in the Prairies (except Alberta) and the Atlantic region and lowest in British Columbia and Quebec.

Conclusion: The cancer burden attributable to excess body weight is substantial and will continue to rise in the near future because of the rising prevalence of overweight and obesity in Canada.

Highlights

- An estimated 9645 cancer cases or 5.7% of all cancers diagnosed in Canadian adults (aged 25 + years) were attributable to excess body weight in 2010.
- Cancers with the greatest proportion of cases attributable to excess body weight included esophageal adenocarcinoma, kidney, gastric cardia, liver, colon and gallbladder for males, and esophageal adenocarcinoma, uterus, gallbladder and kidney for females.
- Cancers contributing the greatest number of cases attributable to excess body weight were colon, kidney and advanced prostate for males, and uterus, postmenopausal breast and colon for females.
- The proportion of cancers attributable to excess body weight was highest in the Prairies (except Alberta) and the Atlantic region, and lowest in British Columbia and Quebec.

Keywords: *population attributable fraction, body mass index, overweight, obesity, cancer*

Introduction

The burden of cancer on the Canadian population is heavy. Currently, the lifetime risk of developing cancer is 45% for males and 42% for females,[1] and cancer is the leading cause of death in Canada, accounting for 30% of all deaths in 2012.[2] Consequently, understanding the main drivers of the cancer burden is a public health priority. Population attributable fractions (PAFs) can be used to quantify the impact of different factors on the occurrence of cancer in a population and thus are of value in prioritizing cancer control strategies. Assuming a causal relationship between a specific factor and cancer, the PAF estimates the proportion of cancer cases that could be prevented by eliminating the specific factor from the population.[3,4] In a recent British study using PAFs to estimate the proportion of cancers attributable to lifestyle and environmental risk factors, tobacco use, diet and excess body weight were identified as the top three risk factors, accounting for 19.4%, 9.2% and 5.5% of all cancers, respectively.[5]

Although excess body weight is an established risk factor for diabetes, hypertension and cardiovascular disease, its relationship to cancer is lesser-known.[6] In 2002, the International Agency for Research on Cancer concluded that excess body weight is associated with an increased risk of developing cancers of the colon, breast (postmenopausal), endometrium, kidney and esophagus (adenocarcinoma),[6] and more recent systematic reviews have identified additional cancers.[7-10] Cited potential carcinogenic mechanisms include hormonal and metabolic changes, elevated oxidative stress, stimulation of the body's inflammatory response and increased gastroesophageal reflux

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caused by the direct mechanical effects of central obesity.[6,7,11]

Several relatively recent studies have examined the proportion of cancers attributable to excess body weight in Canada[12,13] and also specifically in Ontario.[14] However, additional types of cancer have since been identified as having strong evidence of a causal relationship with excess body weight. As well, none of the previous research provided a comprehensive regional examination of PAFs in Canada. Considering the growing recognition of body weight as a risk factor for cancer and the rising prevalence of excess body weight in the Canadian population,[15] more current, comprehensive estimates of the proportion of cancers attributable to excess body weight are needed to guide cancer control strategies. The primary objective of this study is to estimate the proportion and number of new cancer cases attributable to excess body weight in Canadian adults, aged 25 years and older, in 2010.

Methods

Prevalence of excess body weight in the Canadian population

We used body mass index (BMI), a commonly used measure with established cut points for excess body weight[16] (defined as a BMI of 25.00+ kg/m^2; Table 1), to quantify the prevalence of overweight and obese Canadians. We used self-reported height and weight, obtained from the Canadian Community Health Survey (CCHS),[17] to calculate BMI (weight in kilograms divided by squared height in metres). The CCHS, a population-based survey initiated in 2000, was designed to provide reliable estimates at the health region and provincial levels for the population aged 12 years and older, with some exclusions representing less than 3% of the Canadian population. Canadian research has demonstrated that BMI based on self-report is biased downward because people overreport their height and underreport their weight.[18] Therefore, we adjusted BMIs for this study using correction formulas previously developed on a subsample of CCHS respondents who agreed to have their height and weight measured in addition to providing self-reports (Equations 1 and 2).[19,20]

TABLE 1
Body mass index categories

Category	Cut points
Underweight	< 18.50 kg/m^2
Normal	18.50–24.99 kg/m^2
Overweight	25.00–29.99 kg/m^2
Obese	30.00+ kg/m^2

Note: Categories defined according to the WHO Consultation on Obesity.[16]

To estimate the proportion of cancer cases in 2010 attributable to excess body weight, the prevalence of excess body weight in 2000 and 2001 was used to allow at least a 10-year latency period between exposure (excess body weight) and disease (cancer). For example, the proportion of cancers attributed to excess body weight among adults aged 45 to 54 years in 2010 was based on the prevalence of overweight and obese adults aged 35 to 44 years in 2000 and 2001. A 10-year latency was the longest possible period available using the CCHS, and is consistent with similar research[12,21,22] as well as the range of geometric mean duration of follow-up in a comprehensive meta-analysis examining the association between body weight and several types of cancer.[8] To acknowledge the sampling design of the CCHS, we weighted all estimates and obtained corresponding variance estimates using balanced repeated replication with the provided replicate weights. The national response rate for the CCHS in 2000 and 2001 was 84.7%.[17]

Associations between excess body weight and cancer

Cancers with strong evidence of a causal relationship with high BMI were identified through the World Cancer Research Fund (WCRF) International Continuous Update Project (CUP), an ongoing program analyzing global research on how diet, nutrition, physical activity and weight affect cancer risk and survival.[23] The CUP completes thorough systematic reviews and meta-analyses primarily of randomized controlled trials, cohort and nested case-control studies. Estimates of association that are most adjusted for confounding and have adequate data for dose-response are used in the meta-analyses. These reviews are evaluated by an independent expert panel who draw conclusions regarding the strength of evidence supporting the relationships. Strong evidence is considered strong enough to generally justify recommendations designed to reduce the incidence of cancer. At a minimum, strong evidence includes the following: proof from at least two independent cohort studies or at least five case-control studies; no substantial unexplained heterogeneity; good-quality studies that exclude the possibility of random or systematic error; and biological plausibility. Additional criteria include evidence from more than one study type; the presence of a dose-response association; and strong and plausible human or animal experimental evidence that typical human exposures can lead to cancer.[24]

According to the WCRF International CUP, there is strong evidence supporting a causal relationship between high BMI and 12 cancers (Table 2). The sex-specific relative risk (RR) estimates extracted for this study were those based on cohort studies examining incident cancer as the outcome. We converted RR estimates associated with a five-unit increase in BMI to RR estimates for a one-unit increase in BMI by assuming a linear relationship between the natural logarithm of the RR and BMI. For males, the relative risk (RR) of cancer associated with a one-unit increase in BMI ranged from a low of 1.02 for pancreatic, rectal and advanced prostate cancer to a high of 1.09 for esophageal adenocarcinoma. For females, the increased risk ranged from 1.01 for rectal and ovarian cancer to 1.08 for esophageal adenocarcinoma and uterine cancer.

Number of new cancer cases in Canada in 2010

We obtained counts of new cancer cases for each province and territory, except Quebec, for the most recent year with complete national data (2010) from the Canadian Cancer Registry (CCR) (data file based on *International Rules for Multiple Primary Cancers*,[35] released in September 2012). We downloaded case counts for Quebec in 2010 from Statistics Canada's website.[36]

Males	Corrected BMI = −1.07575 + 1.07592(self-reported BMI)	(Equation 1)
Females	Corrected BMI = −0.12374 + 1.05129(self-reported BMI)	(Equation 2)

TABLE 2
Relative risk of 12 types of cancer[a] associated with a one-unit increase in body mass index, by sex

	Relative risk (95% CI)	
	Males	Females
Esophageal adenocarcinoma[24]	1.09 (1.07–1.12)	1.08 (1.05–1.11)
Gastric cardia[25,b]	1.04 (1.01–1.07)	1.04 (1.01–1.07)
Liver[26]	1.04 (1.00–1.08)	1.04 (1.02–1.06)
Gallbladder[27]	1.04 (1.02–1.06)	1.05 (1.01–1.08)
Pancreas[28]	1.02 (1.01–1.04)	1.02 (1.01–1.03)
Colon[29]	1.04 (1.03–1.05)	1.02 (1.01–1.03)
Rectum[29]	1.02 (1.01–1.02)	1.01 (1.00–1.02)
Kidney[30]	1.05 (1.04–1.06)	1.05 (1.04–1.06)
Advanced prostate[31]	1.02 (1.01–1.02)	NA
Postmenopausal breast[32]	NA	1.02 (1.02–1.03)
Uterus[33]	NA	1.08 (1.07–1.10)
Ovary[34]	NA	1.01 (1.00–1.02)

Abbreviations: CI, confidence interval; NA, not applicable.

Note: Relative risk (RR) estimates associated with a five-unit increase in body mass index (BMI) were converted to RR estimates for a one-unit increase in BMI by assuming a linear relationship between the natural logarithm of the RR and BMI.

[a] Types of cancer identified by the World Cancer Research Fund International CUP.[23]

[b] Estimates are for males and females combined, as sex-specific estimates were based on too few studies.

Cancer definitions were aligned with the meta-analysis quantifying their association with BMI (Table 3). Because staging information was not complete for all prostate cancers, particularly in certain provinces, we obtained estimates of the proportion of stage III and stage IV prostate cancers by age group using all staged prostate cancers diagnosed in Canada (excluding Quebec) during 2010.

Case counts for Quebec needed to be adjusted for a few cancers not directly available through Statistics Canada's website. Specifically, we estimated the number of esophageal adenocarcinomas and cancers of the gastric cardia and liver (including intrahepatic bile duct) for Quebec using information available for all provinces and territories except Quebec. For example, the proportion of esophageal cancers that were adenocarcinomas in Quebec were estimated using sex- and age-specific proportions for all of Canada, except Quebec, in 2010. For confidentiality reasons, presented case counts were randomly rounded to an adjacent multiple of 5 using an unbiased random rounding scheme; actual case counts ending in 0 or 5 were not rounded.

Population attributable fractions (PAFs)

We estimated PAFs specific to cancer, region, sex and age group as per Equation 3.[4]

The RR associated with a BMI category was quantified relative to 21 kg/m^2, an accepted optimal value,[40] using Equation 4. We assumed no risk for BMI less than 25.00 kg/m^2.

The product of the PAF specific to cancer, region, sex and age group and corresponding incident cancers provided the number of cancer cases attributable to excess body weight. Thereafter, summations across relevant strata (e.g. type of cancer, region, sex and age) provided PAFs and

TABLE 3
Definitions for cancers associated with excess body weight[a]

Cancer	Topography	Histology	Other criteria
Esophageal adenocarcinoma[b]	C15.0–C15.9	8050, 8140–8147, 8160–8162, 8180–8221, 8250–8507, 8514, 8520–8551, 8560, 8570–8574, 8576, 8940–8941	
Gastric cardia	C16.0	excludes 9050–9055, 9140, 9590–9992	
Liver	C22.0, C22.1	excludes 9050–9055, 9140, 9590–9992	
Gallbladder	C23.9	excludes 9050–9055, 9140, 9590–9992	
Pancreas	C25.0–C25.9	excludes 9050–9055, 9140, 9590–9992	
Colon	C18.0–C18.9, C26.0	excludes 9050–9055, 9140, 9590–9992	
Rectum	C19.9, C20.9	excludes 9050–9055, 9140, 9590–9992	
Kidney	C64.9, C65.9	excludes 9050–9055, 9140, 9590–9992	
Prostate (advanced)	C61.9	excludes 9050–9055, 9140, 9590–9992	AJCC stage III and IV
Breast (postmenopausal)	C50.0–C50.9	excludes 9050–9055, 9140, 9590–9992	Age 50 years and older
Uterus	C54.0–C54.9, C55.9	excludes 9050–9055, 9140, 9590–9992	
Ovary	C56.9	excludes 9050–9055, 9140, 9590–9992	

Abbreviation: AJCC, American Joint Committee on Cancer.

Notes: Topography and histology are classified according to the International Classification of Diseases for Oncology.[37] Cancer definitions were aligned with the meta-analysis quantifying their association with BMI (see Table 2). When further clarification was needed, the Surveillance, Epidemiology and End Results Program Site Recode[38] was consulted.

[a] Defined as BMI ≥ 25.00 kg/m^2.

[b] Defined as per Howlader et al.[39]

$$PAF = \frac{[P_{OW}(RR_{OW} - 1) + P_{OB}(RR_{OB} - 1)]}{[1 + (P_{OW}(RR_{OW} - 1) + P_{OB}(RR_{OB} - 1))]} \quad \text{(Equation 3)}$$

where

P_{OW} = proportion classified as overweight 10 years prior to 2010

P_{OB} = proportion classified as obese 10 years prior to 2010

RR_{OW} = relative risk for the median BMI of the overweight category relative to 21 kg/m^2 assuming a log-linear relationship between RR and BMI

RR_{OB} = relative risk for the median BMI of the obese category relative to 21 kg/m^2 assuming a log-linear relationship between RR and BMI

$$RR_a = (RR)^{(b-21)} \quad \text{(Equation 4)}$$

where

RR_a = relative risk for BMI category *a*

RR = relative risk for a one-unit increase in BMI (see Table 2)

a = BMI category: overweight or obese

b = median BMI for BMI category *a*

attributable cases for subgroups of interest. Because the prevalence of excess body weight varies by region and sex, and the strength of the associations between BMI and cancer can vary by sex, we estimated the proportion and number of new cancers attributable to excess body weight by province and sex; we combined and analyzed the territories as one region. To allow for a 10-year latency and more stable estimates, age groups (in years) were defined as follows: 25 to 34, 35 to 44, 45 to 54, 55 to 64, 65 to 74, 75 to 84, and 85+. We did not estimate PAFs and attributable cases for the group aged 15 to 24 years because the prevalence of overweight and obesity in those aged 5 to 14 years in 2000 and 2001 were not available through the CCHS. To acknowledge the uncertainty in the magnitude of the relationship between excess body weight and the risk of cancer, a plausible range of values for PAFs and attributable cases were also estimated using the 95% confidence limits of the RRs in Table 2.

Results

Prevalence of excess body weight

A detailed examination of the prevalence of excess body weight was not the primary objective of this study. Rather, we estimated prevalence of excess body weight by region, sex and age group in order to estimate PAFs. Nonetheless, a few observations warrant mention because the prevalence of excess body weight is one of the main drivers of PAFs. First, across the country in 2000 and 2001, males were more likely than females to be overweight, but the proportion classified as obese was similar across the sexes (Figure 1). Second, the proportion of adults classified as overweight varied less across the country than the proportion of adults classified as obese. Specifically, British Columbia and Quebec had the lowest prevalence of obese adults, while Saskatchewan, Manitoba, the Atlantic region and the territories had the highest prevalence.

Cancers attributable to excess body weight

PAFs, attributable cases and plausible ranges are shown by type of cancer, sex and region in Table 4. Approximately 5.7% of all cancer cases, or 9645 cancer cases, diagnosed in Canadian adults in 2010 were attributable to excess body weight. After acknowledging the uncertainty in the RR estimates, the range of plausible values for the PAF was 4.1% to 7.6% and the number of cancer cases attributable to excess body weight ranged from 6980 to 12 845. The PAF for all types of cancer combined was slightly higher in females than males (6.5% vs. 4.9%) because of the common female-specific cancers associated with excess body weight (i.e. postmenopausal breast and uterus). When limiting the analysis to types of cancer associated with excess body weight (Table 2), the PAF for males exceeded that for females (17.5% vs. 13.3%) because males had higher RRs for some of the more common types of cancer (e.g. colon, rectum) and were more likely to be overweight in 2000 and 2001.

While the proportion of all cancers attributable to excess body weight may appear modest, for some specific cancers the impact of excess weight is substantial. For instance, an estimated 42.2% of esophageal adenocarcinomas, 25.4% of kidney cancers and about 20% of gastric cardia, liver, gallbladder and colon cancers were attributable to excess body weight in males. In females, 36.1% of esophageal adenocarcinomas, 35.2% of uterine cancers and almost 1 in 4 kidney and gallbladder cancers were attributable to excess body weight. Irrespective of type of cancer or sex, PAFs were lowest in British Columbia and Quebec and highest in the Prairies (except Alberta) and the Atlantic region, generally reflecting the prevalence of excess body weight in those regions in 2000 and 2001.

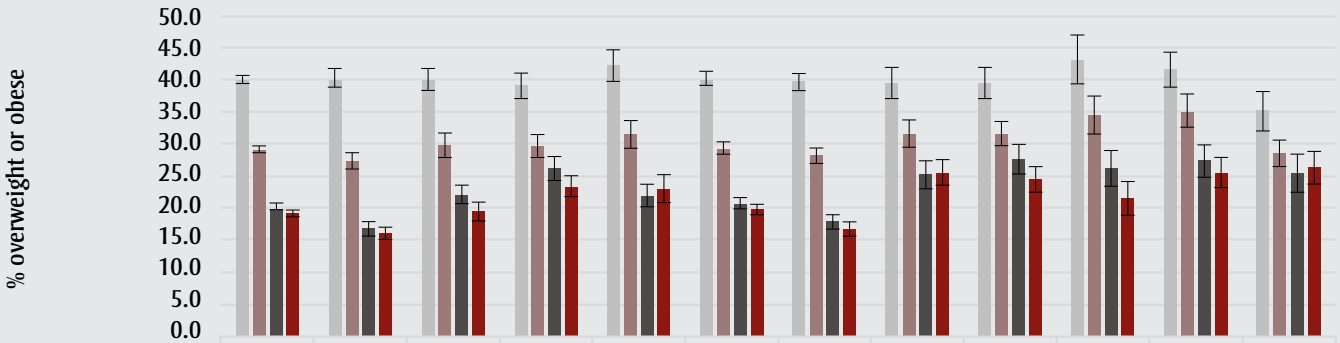
Finally, the distinction between PAFs and attributable cases needs to be acknowledged. Cancers with substantial case counts attributable to excess body weight do not necessarily have the highest PAFs. For males, colon cancer ranked fourth in terms of PAF but first in terms of number of attributable cases, accounting for about a third of all cancer cases attributable to excess body weight. For females, postmenopausal breast cancer ranked seventh in terms of PAF but second in terms of attributable cases, accounting for about a third of all cancer cases attributable to excess body weight.

Discussion

An estimated 5.7% or 1 in 18 cancer cases diagnosed in Canadian adults in 2010 were attributable to excess body weight (BMI ≥ 25.00 kg/m^2). This translates to nearly 10 000 cancer cases, a number expected to rise as the prevalence of overweight and obesity rises in Canada. After acknowledging the uncertainty in the magnitude of the relationship between excess body weight and the risk of cancer, the PAF ranged from 4.1% to 7.6% and attributable cancer cases ranged from 6980 to 12 845.

PAFs varied by type of cancer, sex and region. In males, PAFs were highest for

FIGURE 1
Percentage of Canadians aged 15 years and older classified as overweight or obese by sex, 2000–2001



	CA	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL	TE
Overweight males	40.2	40.4	40.1	39.2	42.4	40.4	39.8	39.6	39.7	43.3	41.7	35.2
Overweight females	29.2	27.4	29.9	29.7	31.5	29.4	28.3	31.7	31.7	34.5	35.3	28.6
Obese males	20.3	16.8	22.2	26.2	22.0	20.7	17.9	25.3	27.7	26.2	27.5	25.5
Obese females	19.2	16.2	19.6	23.4	23.1	19.8	16.8	25.6	24.6	21.6	25.6	26.4

Abbreviations: AB, Alberta; BC, British Columbia; BMI, body mass index; CA, Canada; MB, Manitoba; NB, New Brunswick; NL, Newfoundland and Labrador; NS, Nova Scotia; ON, Ontario; PE, Prince Edward Island; QC, Quebec; SK, Saskatchewan; TE, all three Canadian territories combined.

Notes: BMI was calculated using self-reported weight and height from the Canadian Community Health Survey.[17] BMI was corrected for self-report bias prior to being categorized according to WHO guidelines.[16] Overweight is defined as 25.00 kg/m^2 ≤ BMI ≤ 29.99 kg/m^2. Obese is defined as BMI ≥ 30.00 kg/m^2. Error bars represent 95% confidence intervals.

esophageal adenocarcinoma (42.2%), kidney cancer (25.4%), and cancers of the gastric cardia, liver, colon and gallbladder (about 1 in 5). In females, PAFs were highest for esophageal adenocarcinoma (36.1%), uterine cancer (35.2%), and cancers of the gallbladder and kidney (about 1 in 4). In general, PAFs were highest in the Prairies (except Alberta) and Atlantic Canada, and lower in British Columbia and Quebec, reflecting the regional prevalence of excess body weight in 2000 and 2001.

Comparisons with previous research are complicated because PAFs are affected by a variety of factors such as the number of different cancers included, the RR assigned to the overweight and obese categories, and the prevalence of overweight and obesity in the population. Arnold et al.[12] estimated the proportion of cancers attributable to excess body weight in 2012 using model-based BMI distributions, a theoretical-minimum-risk BMI distribution (mean = 22 kg/m^2, SD = 1 kg/m^2), and cancer-specific projected counts. For males, our PAFs were very similar to the estimates of Arnold et al.[12] for Canada. For females, however, the PAFs in the study by Arnold et al.[12] were notably higher than ours for esophageal adenocarcinoma (44.0% vs. 36.1%), gallbladder (49.0% vs. 23.7%), kidney (31.0% vs. 23.0%) and uterus (43.0% vs. 35.2%). Some of these differences can be attributed to methodological differences, including the aforementioned use of modelled data with its underlying assumptions, and the RR estimates used. For gallbladder and kidney, Arnold et al.[12] used RR estimates from Renehan et al.,[8] which were higher than more recent estimates reported by CUP. The difference was substantial for gallbladder: 1.59 versus 1.25 per 5 kg/m^2.

Some of our cancer- and sex-specific PAFs also differed from Brenner's[13] estimates for Canada in 2007. Our PAF for male esophageal adenocarcinoma was higher (42.2% vs. 32.3%) after we made additional calculations, based on assumptions, to adjust Brenner's estimate for all esophageal cancers. Our PAF for gallbladder cancer was higher for both males (20.2% vs. 13.9%) and females (23.7% vs. 13.0%). Our colon cancer estimate was substantially higher than Brenner's for males (20.5% vs. 10.6%) but not females (9.7% vs. 8.9%).

Several factors, in addition to the more recent time period examined in this study, may have contributed to these differences. First, for colon cancer, we used more recent sex-specific RR estimates, which are higher for males than females. Second, our method of assigning RRs to the overweight and obese category acknowledged the distribution of BMIs within the category, whereas Brenner[13] used RR estimates for a 5 kg/m^2 increase for the overweight category and squared this for the obese category. Third, Brenner's estimates were based on unadjusted BMIs, whereas our study adjusted for the bias in self-reported height and weight. Finally, Brenner's most specific PAFs, upon which all other PAFs and attributable cases were calculated, did not acknowledge region, whereas ours did.

Finally, previously published PAFs for Ontario in 2010 by Cancer Care Ontario[14] were similar to ours for pancreas (11.3% vs. 10.4%, respectively), kidney (22.8% vs. 24.7%), postmenopausal breast (10.3% after excluding breast cancers diagnosed prior to age 50 vs. 9.9%) and uterus (33.0% vs. 35.6%), but differed for esophageal adenocarcinoma (34.1% after excluding non-adenocarcinoma cases vs. 41.7%) and colorectal (8.2% vs. 15.3% for colon and 8.5% for rectum). Cancer Care Ontario corrected BMIs for self-report bias but other differences in methodology existed: we used sex-specific RR estimates including separate estimates for colon and rectal cancers, whereas Cancer Care Ontario did not; we used the median BMI of a weight category to assign its RR, whereas Cancer Care Ontario used an approach similar to

TABLE 4
Population attributable fractions and attributable cancer cases for excess body weight[a] in Canadian adults (aged 25+) in 2010, by sex and region

		Canada		British Columbia		Alberta		Prairies		Ontario		Quebec		Atlantic	
		PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])
All cancers	Total	5.7 (4.1–7.6)	9645 (6980–12 845)	5.1 (3.7–6.9)	1075 (770–1445)	5.8 (4.2–7.8)	850 (615–1125)	7.0 (5.1–9.2)	755 (550–995)	5.8 (4.2–7.6)	3715 (2700–4945)	5.3 (3.8–7.1)	2295 (1650–3085)	6.9 (5.0–8.9)	930 (680–1215)
	Males	4.9 (3.1–6.2)	4255 (2705–5350)	4.4 (2.7–5.6)	475 (290–610)	5.0 (3.1–6.3)	380 (235–475)	5.9 (3.9–7.3)	325 (210–405)	4.9 (3.1–6.2)	1605 (1015–2015)	4.7 (3.0–6.0)	1035 (660–1315)	5.9 (3.9–7.2)	430 (285–525)
	Females	6.5 (5.2–9.1)	5395 (4280–7495)	6.0 (4.8–8.4)	600 (480–840)	6.7 (5.4–9.3)	470 (375–650)	8.0 (6.3–11.1)	430 (340–595)	6.6 (5.3–9.2)	2110 (1685–2925)	5.9 (4.6–8.2)	1265 (995–1770)	7.9 (6.3–10.9)	505 (395–695)
Cancers associated with excess body weight	Total	14.9 (10.8–19.8)	9645 (6980–12 845)	13.4 (9.6–18.0)	1075 (770–1445)	15.2 (11.0–20.2)	850 (615–1125)	16.9 (12.3–22.3)	755 (550–995)	15.2 (11.1–20.3)	3715 (2700–4945)	13.8 (9.9–18.5)	2295 (1650–3085)	17.2 (12.6–22.4)	930 (680–1215)
	Males	17.5 (11.1–22.1)	4255 (2705–5350)	15.7 (9.6–20.0)	475 (290–610)	17.5 (11.0–22.1)	380 (235–475)	19.4 (12.7–24.1)	325 (210–405)	17.9 (11.3–22.5)	1605 (1015–2015)	16.7 (10.6–21.2)	1035 (660–1315)	19.9 (13.2–24.2)	430 (285–525)
	Females	13.3 (10.6–18.5)	5395 (4280–7495)	12.0 (9.6–16.8)	600 (480–840)	13.8 (11.0–19.1)	470 (375–650)	15.4 (12.1–21.2)	430 (340–595)	13.7 (10.9–19.0)	2110 (1685–2925)	12.1 (9.5–16.9)	1265 (995–1770)	15.4 (12.1–21.2)	505 (395–695)
Esophageal adenocarcinoma	Total	41.3 (32.8–51.8)	435 (345–540)	38.2 (30.0–48.4)	55 (45–70)	42.1 (33.6–52.6)	35 (30–45)	45.8 (37.0–56.5)	25 (20–30)	41.7 (33.0–52.3)	185 (145–230)	39.5 (31.2–49.7)	90 (75–115)	45.6 (36.5–56.4)	40 (35–50)
	Males	42.2 (34.3–52.6)	380 (305–475)	39.0 (31.5–49.1)	50 (40–60)	42.8 (34.8–53.2)	30 (30–40)	46.1 (37.8–56.7)	20 (20–25)	42.7 (34.7–53.1)	160 (130–195)	40.3 (32.6–50.5)	80 (65–105)	46.8 (38.4–57.5)	35 (30–45)
	Females	36.1 (23.6–47.0)	50 (35–70)	33.4 (21.6–44.0)	10 (5–10)	37.0 (24.2–48.1)	5 (0–5)	41.6 (27.8–53.4)	0 (0–5)	36.6 (24.0–47.6)	25 (15–35)	34.0 (22.1–44.7)	10 (10–15)	39.3 (26.1–50.6)	5 (5–10)
Gastric cardia	Total	20.2 (5.3–33.4)	175 (45–295)	18.5 (4.8–31.0)	25 (5–40)	20.6 (5.4–34.0)	15 (5–30)	23.1 (6.2–37.5)	20 (5–30)	20.4 (5.4–33.7)	60 (15–100)	19.0 (5.0–31.7)	40 (10–70)	22.4 (6.0–36.5)	15 (5–25)
	Males	20.7 (5.5–34.1)	140 (35–230)	19.2 (5.0–31.9)	20 (5–30)	21.2 (5.6–34.8)	10 (5–20)	23.5 (6.3–38.0)	15 (5–25)	20.8 (5.5–34.2)	45 (10–75)	19.5 (5.1–32.4)	35 (10–55)	22.5 (6.0–36.6)	15 (5–20)
	Females	18.7 (4.8–31.5)	40 (10–70)	16.1 (4.1–27.7)	5 (0–5)	18.8 (4.9–31.5)	5 (0–10)	21.4 (5.6–35.3)	0 (0–5)	19.3 (5.0–32.3)	15 (5–25)	17.5 (4.5–29.6)	10 (5–15)	22.1 (5.9–36.3)	5 (0–5)
Liver	Total	19.9 (2.9–34.5)	415 (60–725)	18.2 (2.5–32.0)	60 (10–100)	20.6 (2.8–35.7)	40 (5–65)	22.5 (4.2–37.7)	20 (5–35)	20.5 (2.7–35.7)	165 (25–285)	18.6 (3.0–32.3)	110 (20–190)	23.0 (3.7–38.8)	25 (5–45)
	Males[c]	20.5 (0.0–37.7)	300 (0–550)	18.7 (0.0–35.1)	40 (0–75)	21.2 (0.0–38.8)	30 (0–50)	23.1 (0.0–41.8)	15 (0–25)	21.0 (0.0–38.6)	125 (0–225)	19.3 (0.0–35.9)	75 (0–140)	23.5 (0.0–42.4)	20 (0–35)
	Females	18.5 (9.4–27.0)	120 (60–175)	16.8 (8.5–24.7)	15 (10–25)	19.2 (9.8–27.9)	10 (5–15)	21.4 (11.0–30.9)	10 (5–15)	19.1 (9.8–27.8)	40 (20–60)	17.1 (8.7–25.2)	35 (15–50)	21.8 (11.3–31.5)	10 (5–15)
Gallbladder	Total	22.5 (6.8–33.8)	110 (30–160)	20.1 (6.1–30.6)	15 (5–20)	22.7 (6.4–34.2)	10 (5–20)	26.4 (7.2–39.2)	15 (5–20)	23.0 (7.3–34.4)	40 (10–65)	20.9 (6.3–31.7)	20 (5–30)	24.8 (7.4–36.9)	10 (5–15)
	Males	20.2 (10.5–29.1)	35 (15–45)	18.5 (9.5–26.8)	5 (0–5)	20.0 (10.3–28.8)	5 (0–5)	22.1 (11.5–31.7)	0 (0–5)	20.8 (10.8–30.0)	15 (5–20)	19.0 (9.8–27.6)	5 (5–10)	22.2 (11.6–31.9)	0 (0–5)
	Females	23.7 (5.0–36.2)	75 (15–115)	20.9 (4.3–32.5)	10 (5–15)	23.7 (5.0–36.2)	10 (0–15)	27.6 (6.0–41.3)	10 (5–15)	24.4 (5.2–37.1)	30 (5–40)	21.9 (4.5–33.7)	15 (5–25)	26.0 (5.6–39.2)	5 (5–10)

Continued on the following page

TABLE 4 (continued)
Population attributable fractions and attributable cancer cases for excess body weight[a] in Canadian adults (aged 25+) in 2010, by sex and region

		Canada		British Columbia		Alberta		Prairies		Ontario		Quebec		Atlantic	
		PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])	PAF (plausible range[b])	N (plausible range[b])
Pancreas	Total	10.2 (5.2–17.5)	380 (195–655)	9.1 (4.6–15.9)	40 (20–70)	10.5 (5.3–18.1)	35 (15–60)	11.5 (5.9–19.6)	35 (20–55)	10.4 (5.3–17.7)	140 (70–240)	9.5 (4.8–16.4)	95 (50–170)	11.6 (5.9–19.6)	35 (15–55)
	Males	10.6 (5.4–20.5)	200 (105–385)	9.6 (4.8–18.6)	20 (15–45)	10.9 (5.6–21.0)	20 (10–40)	11.9 (6.1–22.7)	20 (10–35)	10.9 (5.6–21.0)	75 (35–140)	10.0 (5.1–19.3)	50 (25–100)	12.3 (6.3–23.4)	15 (10–30)
	Females	9.7 (4.9–14.4)	185 (95–270)	8.7 (4.4–12.9)	15 (10–25)	10.0 (5.1–14.8)	15 (10–25)	11.1 (5.7–16.4)	15 (10–25)	9.9 (5.0–14.7)	70 (35–100)	9.0 (4.6–13.4)	45 (20–70)	11.1 (5.6–16.3)	15 (10–25)
Colon	Total	15.1 (10.3–19.8)	2120 (1445–2770)	13.8 (9.4–18.0)	230 (155–300)	15.6 (10.6–20.3)	180 (125–235)	16.8 (11.4–21.9)	170 (115–225)	15.3 (10.4–20.0)	775 (530–1015)	14.3 (9.7–18.6)	540 (370–705)	17.1 (11.7–22.3)	220 (150–285)
	Males	20.5 (15.7–25.1)	1445 (1105–1770)	18.7 (14.3–23.0)	160 (120–195)	21.0 (16.0–25.7)	125 (95–155)	22.8 (17.5–27.8)	115 (85–140)	20.7 (15.9–25.4)	525 (405–645)	19.4 (14.8–23.8)	370 (285–455)	23.1 (17.8–28.2)	150 (115–180)
	Females	9.7 (4.9–14.4)	675 (340–1000)	8.6 (4.3–12.8)	70 (35–105)	9.9 (5.0–14.7)	60 (25–85)	11.2 (5.7–16.5)	60 (30–90)	9.9 (5.0–14.6)	245 (125–370)	8.9 (4.5–13.3)	165 (80–245)	11.2 (5.7–16.5)	75 (35–110)
Rectum	Total	8.5 (3.4–10.3)	590 (235–715)	7.8 (3.2–9.3)	70 (30–80)	9.0 (3.8–10.5)	55 (25–65)	9.5 (3.7–11.7)	50 (20–60)	8.5 (3.3–10.4)	205 (80–250)	7.9 (3.2–9.6)	150 (60–180)	9.9 (4.0–11.8)	65 (25–80)
	Males[c]	10.8 (5.5–10.8)	465 (240–465)	9.7 (4.9–9.7)	55 (30–55)	10.9 (5.6–10.9)	45 (25–45)	12.0 (6.1–12.0)	40 (20–40)	11.0 (5.6–11.0)	160 (80–160)	10.1 (5.1–10.1)	115 (55–115)	12.2 (6.3–12.2)	55 (25–55)
	Females[c]	4.8 (0.0–9.5)	125 (0–250)	4.2 (0.0–8.4)	15 (0–25)	4.9 (0.0–9.6)	10 (0–20)	5.7 (0.0–11.2)	10 (0–25)	4.8 (0.0–9.6)	45 (0–90)	4.5 (0.0–8.9)	30 (0–60)	5.7 (0.0–11.2)	15 (0–30)
Kidney	Total	24.5 (20.0–28.9)	1195 (975–1410)	22.3 (18.1–26.4)	90 (75–105)	24.8 (20.2–29.2)	100 (80–115)	27.4 (22.4–32.2)	105 (85–120)	24.7 (20.1–29.1)	445 (360–525)	22.9 (18.6–27.0)	310 (255–365)	27.6 (22.6–32.4)	140 (115–165)
	Males	25.4 (20.8–29.9)	780 (635–915)	23.1 (18.7–27.2)	60 (55–75)	25.8 (21.1–30.4)	70 (55–80)	28.1 (23.1–32.9)	70 (55–80)	25.6 (20.9–30.1)	290 (235–340)	23.9 (19.4–28.1)	200 (160–235)	28.4 (23.3–33.2)	90 (75–105)
	Females	23.0 (18.6–27.2)	420 (340–495)	20.8 (16.8–24.7)	30 (25–35)	23.1 (18.7–27.3)	35 (30–40)	26.2 (21.3–30.9)	35 (30–45)	23.2 (18.8–27.5)	155 (125–180)	21.2 (17.1–25.2)	115 (90–135)	26.4 (21.5–31.1)	45 (40–55)
Advanced prostate	Males[c]	10.8 (5.5–10.8)	515 (265–515)	9.8 (5.0–9.8)	60 (30–60)	11.1 (5.6–11.1)	50 (25–50)	12.0 (6.1–12.0)	35 (20–35)	11.1 (5.6–11.1)	220 (110–220)	9.9 (5.0–9.9)	95 (50–95)	12.3 (6.3–12.3)	50 (25–50)
Post-meno-pausal breast	Females[c]	9.7 (9.7–14.4)	1765 (1765–2615)	8.6 (8.6–12.9)	210 (210–310)	10.0 (10.0–14.8)	160 (160–235)	11.2 (11.2–16.5)	130 (130–195)	9.9 (9.9–14.7)	690 (690–1020)	8.9 (8.9–13.2)	415 (415–615)	11.3 (11.3–16.7)	160 (160–235)
Uterus	Females	35.2 (31.2–42.6)	1825 (1620–2210)	31.9 (28.2–39.0)	215 (190–265)	35.9 (31.9–43.4)	160 (135–190)	39.9 (35.6–47.8)	150 (130–180)	35.6 (31.7–43.1)	745 (665–900)	32.8 (29.0–40.0)	400 (350–485)	40.1 (35.8–48.0)	165 (145–195)
Ovary	Females[c]	4.6 (0.0–9.2)	110 (0–225)	4.2 (0.0–8.3)	15 (0–25)	4.8 (0.0–9.4)	5 (0–15)	5.4 (0.0–10.6)	10 (0–15)	4.7 (0.0–9.2)	45 (0–95)	4.3 (0.0–8.5)	25 (0–55)	5.6 (0.0–11.1)	5 (0–15)

Abbreviations: N, attributable cases; PAF, population attributable fraction.

Note: Prairies includes Saskatchewan and Manitoba; Atlantic region includes New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador. Due to low case counts, the territories are not displayed but are included in Canada. Case counts may not sum to totals due to random rounding using a base of 5. Attributable cases can be the same as the lower or upper end of the plausible range because of random rounding.

[a] Defined as BMI ≥ 25.00 kg/m^2.

[b] Plausible range estimated using the 95% confidence limits of the relative risks in Table 2.

[c] Because relative risks were estimated to two decimal places, the lower end will be zero for male liver cancer and female rectal and ovarian cancer, and the point estimate will be the same as the lower or upper end for male rectal and advanced prostate cancer and postmenopausal breast cancer.

Brenner's;[13] and we obtained Ontario cancer counts from a snapshot of the CCR released in September 2012, whereas Cancer Care Ontario obtained cancer counts directly from the Ontario Cancer Registry.

Strengths and limitations

This study has several strengths compared to previously published Canadian research. First, our study included PAFs for additional cancers with strong evidence of a causal relationship with excess body weight. Second, the RR assigned to the overweight and obese categories acknowledged the BMI distribution within the categories relative to an optimal BMI (21 kg/m^2). Third, we provided PAFs and counts of cancer cases attributable to excess body weight for regions within Canada in addition to the whole country. Fourth, we corrected BMI for self-report bias using formulas developed and validated with CCHS respondents. Using corrected BMIs increased the overall PAF by about 20% from 4.8% (males 4.2%, females 5.4%) to 5.7% (males 4.9%, females 6.5%).

Some limitations, however, should be acknowledged when interpreting the results of this study.

First, BMI does not distinguish between weight associated with muscle or fat; thus, the relationship between BMI and body fat varies with body build, sex, age and ethnicity.[16]

Second, BMI measurements at a specific point in time do not acknowledge potential cancer-specific, time-dependent effects of high BMI on cancer risk. Some research indicates that the risk of cancer from high BMI increases with the number of years lived with a high BMI, and that young adult BMI may be more strongly associated with cancer risk than BMI later in life.[41-43]

Third, the association between BMI and cancer may differ across populations.[44] The measures of association used in this study were not specific to Canada. Nevertheless, Renehan et al.[8] found that, for many cancers, the increased risk associated with increasing BMI were consistent across populations. A notable exception was breast cancer: increasing BMI increased the risk of pre-menopausal breast cancer in Asia-Pacific regions but decreased the risk in other regions; and the postmenopausal breast cancer risk associated with increasing BMI was greater in Asia-Pacific regions than other regions. The RR estimate used for postmenopausal breast cancer in this study, however, was consistent with that for North America.

Fourth, RRs used in Equation 3 should not be adjusted for confounding.[4] However, appropriate use of Equation 3 with adjusted RRs would require availability of exposure and disease data stratified by confounding variable(s), a situation generally not available. Interestingly, Renehan et al.[8] reported that repetition of analyses with minimally adjusted RRs rather than maximally adjusted RRs did not produce different results with respect to the association between BMI and cancer. Further, calculating PAFs within age- and sex-specific strata, two variables commonly used to adjust RRs, may mitigate the impact of using adjusted RRs in this study.[44]

Fifth, additional types of cancer (meningioma, thyroid and multiple myeloma), not included in this study, have recently been identified as having sufficient evidence of an association with excess body weight. Consequently, the PAFs and attributable cases reported in this study are probably underestimates of the true cancer burden of excess body weight in the Canadian adult population.[10]

Sixth, although the CCHS participation rate was high (84.7%), samples are vulnerable to nonresponse bias. PAFs and attributable cases reported in this study will be biased downward if nonparticipants were more likely to be overweight or obese than participants and vice versa.

Seventh, it should be noted that PAFs are not exact, error-free estimates. Rather, uncertainty exists due to variation in the RRs used and in the prevalence of overweight and obesity estimates, and the statistical uncertainty inherent in estimation. To acknowledge this uncertainty, plausible ranges were estimated for PAFs and attributable cancer cases using the 95% confidence limits of the RRs in Table 2.

Conclusion

An estimated 5.7% (1 in 18) of all new cancer cases diagnosed in Canadian adults in 2010 were attributable to high BMI after correcting for bias in self-reported height and weight. Since the prevalence of overweight and obesity continues to rise in Canada, the proportion of new cancer cases attributable to excess body weight will continue to rise in the near future. Increased public awareness regarding the relationship between body weight and cancer and effective interventions for maintaining healthy body weight are needed. Considering the interrelation of body weight, activity level and diet, public health initiatives promoting healthy body weight will likely result in additional benefits through increased activity levels and healthier diets.

Conflicts of interest

The authors declare no conflicts of interest.

Authors' contributions

Both authors contributed to study design, interpretation of the results, drafting the manuscript and critical revisions. DZ performed the analyses.

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Estimating multimorbidity prevalence with the Canadian Chronic Disease Surveillance System

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Abstract

Introduction: The Public Health Agency of Canada's Canadian Chronic Disease Surveillance System (CCDSS) uses a validated, standardized methodology to estimate prevalence of individual chronic diseases, such as diabetes. Expansion of the CCDSS for surveillance of multimorbidity, the co-occurrence of two or more chronic diseases, could better inform health promotion and disease prevention. The objective of this study was to assess the feasibility of using the CCDSS to estimate multimorbidity prevalence.

Methods: We used administrative health data from seven provinces and three territories and five validated chronic conditions (i.e. cardiovascular disease, respiratory disease, mental illness, hypertension and diabetes) to estimate multimorbidity prevalence. We produced age-standardized (using Canada's 1991 population) and age-specific estimates for two multimorbidity definitions: (1) two or more conditions, and (2) three or more conditions from the five validated conditions, by sex, fiscal year and geography.

Results: Among Canadians aged 40 years and over in the fiscal year 2011/12, the prevalence of two or more and three or more chronic conditions was 26.5% and 10.2%, respectively, which is comparable to other estimates based on administrative health data. The increase in multimorbidity prevalence with increasing age was similar across provinces. The difference in prevalence for males and females varied by province and territory. We observed substantial variation in estimates over time. Results were consistent for the two definitions of multimorbidity.

Conclusion: The CCDSS methodology can produce comparative estimates of multimorbidity prevalence across provinces and territories, but there are challenges in using it to estimate temporal trends. Further expansion of the CCDSS in the number and breadth of validated case definitions will improve the accuracy of multimorbidity surveillance for the Canadian population.

Keywords: *chronic disease, surveillance, prevalence, CCDSS*

Highlights

- The Canadian Chronic Disease Surveillance System (CCDSS) uses a standardized methodology based on administrative data to estimate the prevalence of chronic conditions, such as diabetes, for provinces and territories. We examined the feasibility of using the CCDSS for surveillance of multimorbidity, commonly defined as the co-occurrence of two or more chronic conditions.
- The overall prevalence of multimorbidity using this definition was 26.5% in 2011/12, based on data for five conditions (cardiovascular disease, respiratory disease, mental illness, hypertension, diabetes) from seven provinces and three territories. Age-specific trends were similar across jurisdictions, but changes over time showed substantial variation.
- The CCDSS will be increasingly useful for national multimorbidity surveillance as more chronic disease case definitions are added.

Introduction

Multimorbidity, the co-existence of two or more chronic diseases where one is not necessarily more central than the others,[1] is becoming increasingly common, particularly among older adults.[2-7] Multimorbidity prevalence is expected to rise, in Canada as in other countries, due to an aging population and an increasing prevalence of such chronic diseases as diabetes and hypertension.[8] Multimorbidity is an important issue for health care providers and policy makers to monitor because it has been linked with potentially negative health outcomes, including decreased health-related quality of life[9] and increased health care utilization and costs.[10,11]

The Canadian Chronic Disease Surveillance System (CCDSS) is a collaborative effort between the Public Health Agency of Canada (PHAC) and provincial and territorial governments. The goal of the CCDSS is to produce accurate estimates of chronic disease prevalence and incidence for such conditions as diabetes and hypertension. This information can be used in a number of ways, such as for assessing the impact of chronic disease on the health care system. The CCDSS produces comparative data using a population-based methodology that has been validated and standardized

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across provinces and territories. Currently, however, the CCDSS focusses on individual chronic diseases; it has not yet been investigated for multimorbidity surveillance.

At present, there is limited population-based information about multimorbidity in Canada. Roberts et al.[7] used data from the Canadian Community Health Survey (CCHS) to estimate multimorbidity prevalence for a single year and demonstrate its association with determinants of health such as age and income. Kuwornu et al.[12] used CCHS data to compare the prevalence and characteristics of multimorbidity in Canadian Aboriginal and non-Aboriginal Caucasian populations. However, no population-based studies have provided comparative estimates for all of Canada's provinces and territories. A few population-based studies have been conducted for individual provinces or territories,[6,13,14] but only one[6] of these has examined changes in multimorbidity over time, and none have examined variations across population subgroups. Given this background, the purpose of this study was to assess the feasibility of using the CCDSS to estimate multimorbidity prevalence across population groups defined by age, sex and geography, and over time.

Methods

Data sources

A total of 10 provinces and territories provided data for the analyses reported in this study: British Columbia (BC), Manitoba (MB), Ontario (ON), Quebec (QC), New Brunswick (NB), Nova Scotia (NS), Newfoundland and Labrador (NL), Yukon (YT), Northwest Territories (NT) and Nunavut (NU). These jurisdictions responded to the v2015 CCDSS data call as of April 2015. These provinces and territories represent about 86% of the entire Canadian population, including all of Canada's northern population.[15]

The administrative health databases we used to estimate multimorbidity prevalence included hospital records, physician billing claims and population registry files. Hospital records and physician billing claims provide information about diagnosed disease cases that are recorded with the International Classification of Diseases, Ninth Revision (ICD-9),[16] International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)[17] and International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Canada (ICD-10-CA).[18] Population registry files capture all residents of the provinces and territories with valid health insurance coverage, and also provide demographic information (i.e. age and sex). These three data sources can be anonymously linked via a resident's unique lifetime identifier (i.e. health insurance number).

Definitions of selected chronic conditions

Five chronic conditions were included in this study: (1) cardiovascular disease, which includes ischemic heart disease and heart failure; (2) respiratory disease, which includes asthma and chronic obstructive pulmonary disease (COPD); (3) mental illness, a CCDSS omnibus category (including ICD-9 290–319) that encompasses psychosis, neurotic disorders, personality disorders, other nonpsychotic mental disorders and mental retardation; (4) hypertension; and (5) diabetes. We chose these chronic conditions because validated case definitions had been developed by the CCDSS.[19-25] Additional chronic conditions that are prevalent in adults aged 40 years and over, such as arthritis and osteoporosis, are included in other multimorbidity definitions, but did not have validated CCDSS case definitions at the time of this study. All of the selected chronic conditions have been included in previous research about the measurement of multimorbidity.[26]

The selected chronic conditions were defined using case rules (Table 1) applied to administrative data for fiscal years 1995/96 and onward (a fiscal year extends from April 1 to March 31); prevalence estimates were produced for 2001/02 and 2011/12. Each case rule, which was developed by a CCDSS working group, describes the number and types of diagnosis codes that must be recorded in an administrative database in a specified period of time for an individual to be classified as a disease case. Fiscal year 2011/12 was the most current year for which data was available at the time the call for data was distributed to the provinces and territories.

We evaluated two definitions of multimorbidity. The first was the most common definition, which is the co-occurrence of two or more (2+) chronic conditions. The second definition was the co-occurrence of three or more (3+) conditions. This definition has also been investigated in previous research.[7]

Statistical analysis

We estimated the prevalence of multimorbidity for people aged 40 years and over by sex, five-year age group, province and territory, definition and fiscal year. We selected 40 years as the minimum age because it represents the common lower age limit among the chronic disease case definitions included in this research. We calculated age-standardized, age-specific and crude prevalence rates for each province and territory, and for all 10 provinces and territories combined. The age-standardized rates were calculated using Canada's 1991 population as the standard population. We calculated crude prevalence rates by dividing the number of people with multimorbidity by the total population as defined by the provincial or territorial population registry. We conventionally rounded prevalence counts to adjacent multiples of five (rounded to multiples of 10 for Ontario and overall data).

We described the data in both tabular and graphic forms. Comparisons between jurisdictions over time and across population subgroups were conducted using percentages, ranks and the coefficient of variation, a statistical measure of dispersion. We produced 95% confidence intervals (95% CIs) for the estimates of the magnitude of the difference between subgroups using a large-sample chi-square (χ^2) distribution. We used the Spearman rank-order correlation to describe the association between the prevalence estimates obtained from the two multimorbidity definitions at the provincial/territorial level because the distribution of the estimates could not be assumed to follow a normal distribution. The nonparametric Mantel-Haenszel statistic, which asymptotically follows a χ^2 distribution, was used to test the linear trend over time. All statistical analyses were performed using SAS version 9.3.[27]

Results

Table 2 reports the estimated age-standardized prevalence of multimorbidity by definition (i.e. 2+ and 3+ conditions) for each province and territory, and for the 10 provinces and territories overall, in the first and last years of the study period. In 2011/12, the overall age-standardized prevalence of 2+ chronic conditions was

TABLE 1
CCDSS case definitions for the chronic conditions selected to estimate multimorbidity prevalence

Chronic condition	Algorithm	Age range (years)	Case date	Hospital & physician codes		Exclusions
				ICD-9-CM	ICD-10-CA	
Cardiovascular						
Ischemic heart disease	One or more hospitalizations or two or more physician codes within one year	20+	Hospital separation or last physician visit (whichever comes first)	410–414	I20–I25	None
Heart failure	One or more hospitalizations or two or more physician codes within one year	40+	Hospital separation or last physician visit (whichever comes first)	428	I50	None
Respiratory						
Asthma	One or more hospitalizations or two or more physician claims within two years	1+	Hospital separation or last physician visit (whichever comes first)	493	J45, J46	None
COPD	One or more hospitalizations or one or more physician claims	35+	Hospital separation or last physician visit (whichever comes first)	491, 492, 496	J41–J44	None
Mental illness						
Omnibus	One or more hospitalizations or one or more physician claims within one year	0+	Hospital separation or last physician visit (whichever comes first)	290–319	F00–F99	None
Hypertension						
	One or more hospitalizations or two or more physician claims within two years	20+	Hospital separation or last physician visit (whichever comes first)	401–405	I10–I13, I15	Pregnancy-induced hypertension in women aged 20 to 54 years
Diabetes						
	One or more hospitalizations or two or more physician claims within two years	1+	Hospital separation or last physician visit (whichever comes first)	250	E10-E14	Gestational diabetes in women aged 10 to 54 years

Abbreviations: CCDSS, Canadian Chronic Disease Surveillance System; COPD, chronic obstructive pulmonary disease; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; ICD-10-CA, International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Canada.

26.5%. This was a 29.3% relative increase over the 2001/02 estimate of 20.5%. The overall age-standardized prevalence of 3+ chronic conditions was 10.2% in 2011/12 which was a 50.0% increase over the 2001/02 estimate of 6.8%. The linear trend in the prevalence of 2+ conditions was statistically significant ($p < .001$); the same was true for 3+ conditions ($p < .001$). There was a strong association between the prevalence estimates obtained from the two multimorbidity definitions at the provincial/territorial level using the Spearman correlation coefficient; the estimated correlation was 0.94 in 2001/02 (data not shown).

For the multimorbidity definition of 2+ chronic conditions, the lowest estimate across the provinces and territories was 6.5% (NU) in 2001/02 and 24.0% (NT) in 2011/12. The highest estimate was 23.5% in 2001/02 and 30.3% in 2011/12, both from NS. For the multimorbidity definition of 3+ conditions, the lowest estimate in 2001/02 was 1.4% (NU) and in 2011/12 it was 9.1% (BC). The highest estimate in 2001/02 was 7.8% (NS) and in 2011/12 it was 12.0% (NU). The ranking of the provinces and territories in terms of the percentage increase between 2001/02 and 2011/12 was similar for both definitions of multimorbidity. NU showed the largest increase, at 326.2% for 2+ conditions and 757.1% for 3+ conditions between the two study years. The smallest increase was in NL: it was 24.9% for 2+ chronic conditions and 39.7% for 3+ chronic conditions.

Figure 1 shows the 2011/12 age-standardized prevalence of 2+ chronic conditions by sex and province/territory. The overall prevalence was 1.1 percentage points (95% CI: 1.1–1.2) higher for men than for women. Men had a higher prevalence than women in several of the provinces. However, prevalence was higher for women than men in all of the territories. The smallest absolute difference in estimated prevalence between men and women was observed for NL (0.1%). The largest absolute difference was observed for NU (3.8%). The overall prevalence of 3+ diseases was 1.4 percentage points

TABLE 2
Age-standardized multimorbidity prevalence[a] estimates (%) and 95% CIs, stratified by multimorbidity definition and fiscal year

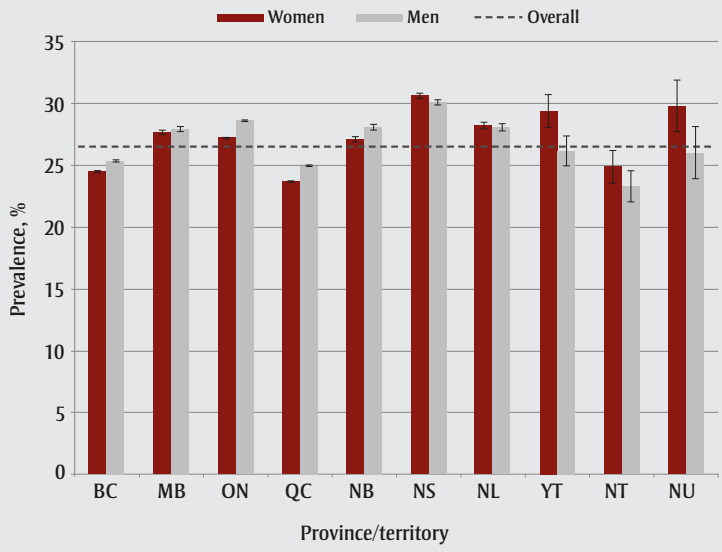
Province or territory	Multimorbidity definition (# of chronic conditions)					
	2+ conditions			3+ conditions		
	2001/02 % (95% CI)	2011/12 % (95% CI)	% Increase (rank)	2001/02 % (95% CI)	2011/12 % (95% CI)	% Increase (rank)
BC	17.4 (17.4–17.5)	24.8 (24.8–24.9)	42.5 (3)	5.2 (5.1–5.2)	9.1 (9.1–9.2)	75.0 (3)
MB	20.4 (20.3–20.5)	27.7 (27.6–27.8)	35.8 (5)	6.4 (6.3–6.4)	10.3 (10.3–10.4)	60.9 (5)
ON	22.2 (22.2–22.2)	27.8 (27.8–27.9)	25.2 (9)	7.6 (7.6–7.6)	10.9 (10.9–10.9)	43.4 (9)
QC	19.0 (18.9–19.0)	24.3 (24.2–24.3)	27.9 (8)	6.3 (6.3–6.3)	9.2 (9.2–9.2)	46.0 (8)
NB	19.6 (19.5–19.8)	27.5 (27.4–27.7)	40.3 (4)	6.5 (6.4–6.5)	10.4 (10.3–10.5)	60.0 (6)
NS	23.5 (23.4–23.6)	30.3 (30.1–30.4)	28.9 (7)	7.8 (7.7–7.8)	11.8 (11.7–11.9)	51.3 (7)
NL	22.5 (22.3–22.7)	28.1 (27.9–28.3)	24.9 (10)	7.3 (7.2–7.5)	10.2 (10.1–10.3)	39.7 (10)
YT	19.3 (18.3–20.2)	27.6 (26.8–28.5)	43.0 (2)	6.1 (5.6–6.7)	10.9 (10.4–11.5)	78.7 (2)
NT	17.7 (16.8–18.6)	24.0 (23.1–24.9)	35.6 (6)	6.3 (5.8–6.9)	10.2 (9.6–10.8)	61.9 (4)
NU	6.5 (5.6–7.5)	27.7 (26.3–29.2)	326.2 (1)	1.4 (1.0–2.0)	12.0 (11.0–13.1)	757.1 (1)
Overall	20.5 (20.5–20.5)	26.5 (26.5–26.5)	29.3	6.8 (6.8–6.8)	10.2 (10.1–10.2)	50.0

Data source: Public Health Agency of Canada Canadian Chronic Disease Surveillance System data files contributed by the provinces and territories as of April 2015. Alberta, Saskatchewan and Prince Edward Island data were unavailable.

Abbreviations: BC, British Columbia; CI, confidence interval; MB, Manitoba; NB, New Brunswick; NL, Newfoundland and Labrador; NS, Nova Scotia; NT, Northwest Territories; NU, Nunavut; ON, Ontario; QC, Quebec; YT, Yukon.

[a] Prevalence counts were conventionally rounded to an adjacent multiple of 5 (rounded to an adjacent multiple of 10 in ON). Age-standardized rates were calculated with unrounded prevalence counts.

FIGURE 1
Age-standardized prevalence[a] (%) of the co-occurrence of two or more chronic conditions among people aged 40 years and over, by sex and province/territory, 2011/12



Data source: Public Health Agency of Canada, using Canadian Chronic Disease Surveillance System data files contributed by the provinces and territories as of April 2015. Alberta, Saskatchewan and Prince Edward Island data were unavailable.

Abbreviations: BC, British Columbia; MB, Manitoba; NB, New Brunswick; NL, Newfoundland and Labrador; NS, Nova Scotia; NT, Northwest Territories; NU, Nunavut; ON, Ontario; QC, Quebec; YT, Yukon.

Note: I signifies a 95% confidence interval.

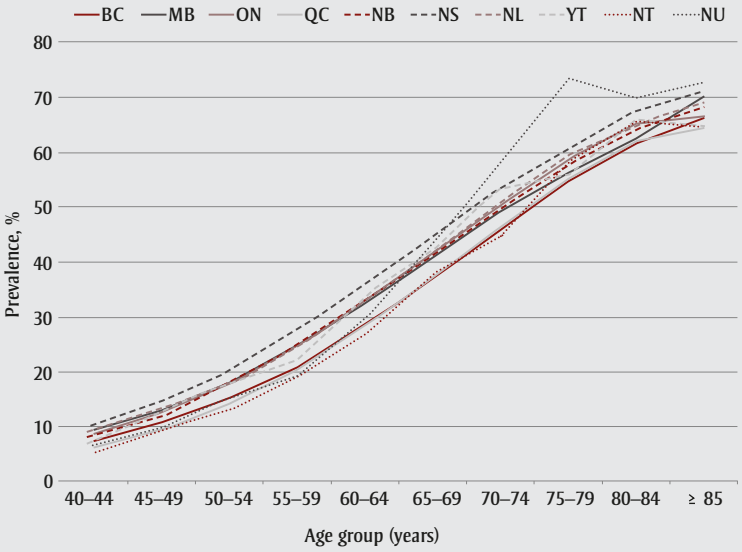
[a] Prevalence counts were conventionally rounded to an adjacent multiple of 5 (rounded to an adjacent multiple of 10 in ON). Age-standardized rates were calculated with unrounded prevalence counts.

(95% CI: 1.3–1.4) higher for men than for women; prevalence was greater among men than women for all of the provinces, but was greater among women than men in all of the territories (data not shown).

The age-specific prevalence of the co-occurrence of 2+ chronic conditions for each province and territory in 2011/12 is shown in Figure 2. The overall prevalence in the oldest age group (≥ 85 years) was 66.3%. This was 58.6% higher than the overall prevalence in the youngest age group (i.e. 40–44 years; 7.8%). In 2001/02 (data not shown), the overall prevalence was 5.5% in the youngest age group and 52.1% in the oldest age group. In 2011/12, the overall prevalence of 3+ conditions was 1.4% in the youngest age group and 35.6% in the oldest age group (data not shown).

The trend across age groups showed an S-shaped pattern for all provinces and territories. The coefficient of variation for the provinces and territories was similar in 2001/02 across age groups; it was 0.28 in the group aged 40 to 44 years and 0.27 in the group aged 85 years and over. In 2011/12, the coefficient of variation was 0.24 in the youngest age group and just slightly lower, at 0.14, in the oldest age

FIGURE 2
Prevalence[a] (%) of the co-occurrence of two or more chronic conditions, by age group and province/territory, 2011/12



Data source: Public Health Agency of Canada, using Canadian Chronic Disease Surveillance System data files contributed by the provinces and territories as of April 2015. Alberta, Saskatchewan and Prince Edward Island data were unavailable.

Abbreviations: BC, British Columbia; MB, Manitoba; NB, New Brunswick; NL, Newfoundland and Labrador; NS, Nova Scotia; NT, Northwest Territories; NU, Nunavut; ON, Ontario; QC, Quebec; YT, Yukon.

[a] Prevalence counts were conventionally rounded to an adjacent multiple of 5 (rounded to an adjacent multiple of 10 in ON). Age-standardized rates were calculated with unrounded prevalence counts.

group. A similar pattern was observed for 3+ conditions, in that the coefficient of variation for 2011/12 was higher in the youngest age group (0.72) and lower in the oldest age group (0.30). In 2001/02, the coefficient of variation was 0.57 in the youngest age group and 0.20 in the oldest age group for 3+ conditions.

Discussion

Of the population aged 40 years and over from the 10 provinces and territories that submitted study data to the CCDSS, about one-quarter had at least two of the five validated chronic conditions and about 10% had at least three of the five validated conditions for which CCDSS data were collected. Our overall estimate of 26.5% (for 2+ conditions) in 2011/12 is lower than a recent study that estimated Canadian multimorbidity prevalence to be 42.6% for the population aged 18 years and older[28] using national electronic medical record (EMR) data. Fortin et al.[29] observed that multimorbidity prevalence estimates derived for primary care populations tend to be higher than for the general population. As well, that study used a list of 20 chronic conditions to identify patients with multimorbidity compared to the list of five chronic conditions used in our study. Using 2011/12 CCHS data, Roberts et al.[7] estimated the national prevalence of 2+ conditions to be 12.9%, and the prevalence of 3+ conditions to be 3.9%; these estimates are substantially lower than ours and may reflect the impact of self-report bias on measurement of chronic diseases.[30] The difference in estimates may also be partially explained by the difference in age groups studied; Roberts et al.[7] included people aged 20 years and over, whereas we only estimated multimorbidity prevalence for people aged 40 years and over. A study from Ontario[6] that used administrative health data to estimate multimorbidity prevalence (2+ conditions) reported a value of 24.3% in 2009. However, the Ontario study included a broader range of chronic conditions (16 in total) than the ones included in the CCDSS study, and also included a broader range of ages (0 to 105 years).

Using CCDSS data, we observed no consistent pattern of differences between males and females across the jurisdictions. Previous research has also shown that the magnitude of the difference between males and females will reflect the choice of health conditions used to measure multimorbidity.[31]

We found that the age-standardized prevalence of multimorbidity increased substantially over time. To date, there have been no longitudinal studies of multimorbidity prevalence in Canada against which we might compare our findings. In fact, there have been few international studies that have focussed on longitudinal trends in multimorbidity prevalence. One exception is the study by Uijen and van de Lisdonk,[32] which used electronic primary care data from the Netherlands and found that multimorbidity prevalence doubled over a 20-year period. Our results show increases between 25.2% and 78.7% in an 11-year period for all provinces and territories studied with the exception of Nunavut; further investigation is needed to determine why these increases have occurred. Wong et al.[33] cautioned that there is the opportunity for an increased number of false positive cases to accrue over time, which may contribute to inflated rates of increasing prevalence across study years. For Nunavut, the large increases in prevalence may reflect the fact that Nunavut officially became a territory in 1999 and therefore its administrative databases may not have had time to sufficiently capture prevalent cases by 2001/02. In other words, the first study year may be more likely to underestimate prevalence than in other provinces where administrative data from fiscal year 1995/96 onward were used for case ascertainment.

Strengths and limitations

The key strengths of this study are the use of the CCDSS's standardized and validated methodology, and the production of multimorbidity prevalence estimates for more than 80% of the Canadian population of adults aged 40 years and over. One limitation is that our study is based on validated case definitions for individual chronic conditions rather than an overall validated case definition for multimorbidity, and we were limited to five health conditions that were defined at the time of the provincial/territorial call for data. Fortin et al.[31] have suggested that limiting the conditions to fewer than seven chronic diseases may result in underestimation of the multimorbidity prevalence; these authors recommend including 12 or more chronic diseases. Diederichs et al.[34] identified 11 conditions that they recommend

including in studies about multimorbidity. Diabetes, depression, hypertension, heart disease, and COPD are included in their list, as they were in our study. Additional conditions, such as arthritis, stroke, cancer and osteoporosis, which are found in other definitions, did not have validated CCDSS case definitions at the time of the call for data, but developmental work on case definitions for many of these conditions is underway or has been completed.

Table 3 summarizes the strengths and weaknesses of using the CCDSS to estimate multimorbidity. The CCDSS methodology facilitates comparisons across major determinants of health, including age, sex and region. These comparisons are useful for describing the absolute and relative impact of multimorbidity on different population groups, and can help target health promotion and disease prevention activities. However, the use of the CCDSS and administrative health data to measure multimorbidity presents some challenges. The methodology does not presently allow for comparisons across other important determinants of health, such as socioeconomic status.[7,12,13] There is the potential for misclassification error in diagnoses recorded in administrative data, which can bias prevalence estimates.[35,36] Administrative data do not capture individuals who have not had contact with the health care system for their chronic condition(s).

In addition, the finding that multimorbidity prevalence increased over time may be at least partially explained by changes in the quality and availability of administrative health data in the provinces and territories. Prevalence rates over time may also be influenced by the presence of individuals who have been incorrectly diagnosed with one or more chronic conditions.[6] Furthermore, provinces and territories that have only a single diagnosis code in physician billing claims may underestimate multimorbidity prevalence, as there is a decreased probability for multiple diagnosis codes to be captured in these data.[37] Finally, we should note that information about the severity of chronic conditions is not available in administrative data.

Conclusion

We applied validated methods for national surveillance of individual chronic diseases to provide comparative estimates of multimorbidity in selected provinces and territories over more than a decade. Our results showed several patterns that were consistent with previous research, including increases in multimorbidity over the lifespan.[2-7] While there was no consistent pattern across provinces and territories, higher rates tended to occur in eastern Canada than western Canada, which is not unexpected based on previous research.[38,39] Our findings suggest that the estimates have face validity. In terms of the increases in prevalence over time, there are few studies to which we can compare ours, and none based on Canadian data; trend estimates should be interpreted with caution.

We demonstrated the feasibility of using the CCDSS for individual chronic conditions to produce estimates of multimorbidity prevalence. However, its reach should be expanded with additional validated chronic disease case definitions to provide a more comprehensive profile of multimorbidity in Canada.

TABLE 3
Key strengths and weaknesses of using the CCDSS to estimate multimorbidity prevalence in Canada

Strengths	Weaknesses
• The CCDSS uses standardized and validated methodology in all provinces and territories	• The methodology does not currently allow for comparisons across some determinants of health, including socioeconomic status and ethnicity
• The CCDSS uses routinely collected administrative health data	• There is the potential for misclassification error in diagnoses recorded in administrative health data[34,35]
• Using CCDSS data allows for comparisons across age, sex, region and time	• CCDSS does not contain information on laboratory results, which may reduce misclassification errors, or chronic disease lifestyle risk factors (i.e. physical activity, smoking, etc.), which may in turn influence multimorbidity risk[36,40]
• Conducting research using administrative health data is more economical than engaging in primary data collection[36,40]	• CCDSS does not capture individuals who have not received a diagnosis for the chronic condition(s) under investigation
• CCDSS data is not influenced by recall bias	• A limited number of validated chronic conditions are currently included in the CCDSS methodology

Abbreviation: CCDSS, Canadian Chronic Disease Surveillance System.

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Conflicts of interest

The authors declare no conflict of interest.

Authors' contributions

AF contributed to the literature review, study design, statistical analyses and manuscript preparation. LL contributed to the study design, statistical analyses and manuscript preparation. KR contributed to the study design and manuscript preparation. All authors have read and approved the final manuscript.

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Commentary

Is the future of "population/public health" in Canada united or divided? Reflections from within the field

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This article has been peer reviewed.

Introduction

"Are population and public health truly a unified field, or is population health simply attaching itself to public health as a means of gaining credibility?"

This commentary was prompted by the above question, which was asked during K. L.'s PhD candidacy exam. In response, K. L. cited recent developments in the field to support her conviction that population and public health (PPH) existed positively as a unified discipline. However, through conversations that ensued over the subsequent weeks and months, we concluded that this issue goes deeper than the existence of departments and organizations labelled "population and public health," and may benefit from debate and discussion, particularly for the incoming generation of PPH scholars. In this commentary, we argue that (1) the PPH label at times implies a coherence of ideas, values and priorities that may not be present; (2) it is important and timely to work towards a more unified PPH; and (3) both challenges to and opportunities for a more unified PPH exist, which we illustrate using the broad areas of research funding, the public health workforce and PPH ethics.

Argument 1: The PPH label implies a coherence that may not be present

In our experience, the PPH label at times conveys the impression of a coherence of ideas, values and priorities that may not exist. The impression of coherence is conveyed in many ways; for example, by PPH graduate training programs that exist in universities in Calgary,[1] Vancouver,[2] Ottawa[3] and Waterloo;[4] by the existence of PPH departments within health systems;[5,6] and by various historical developments (see Table 1). Yet, the coherence is not always present in practice. K. L., for example, recalls meeting a fellow graduate student at a national public health meeting who remarked that they were used to "no one knowing what [population health] is" and that they "usually just say public health," thus implying that they are—at least to some extent or to some audiences—the same. A contrasting example is L. M.'s experience, as an academic who would describe herself as a "population/public health researcher," of being regarded by colleagues within public health as "not really a public health person" because she does not have a health professional degree. Therefore, the need to clarify the boundaries and future of PPH remains, particularly due to the increasing number of trainees in this field.

Argument 2: It is important and timely to work towards a more unified PPH

A key question at the heart of our commentary is whether PPH *should* be a unified discipline. Some have asserted that the answer is "no."[7] Arguments against a unified PPH include important points such as the concern that PPH is too broad in scope to be useful or that it carries the potential of diluting the urgency of public health.[7]

We disagree, and feel that efforts toward a more unified PPH are both important and timely. These efforts are important because embracing the social determinants of health (SDOH) and thinking critically about health inequities, which PPH aims to do,[8] is necessary to accept a holistic conceptualization of health and to overcome professional and organizational silos that prevent intersectoral action on health and health equity. In some cases, overcoming silos includes offsetting historical changes to the public health system. For example, in many Canadian jurisdictions, "health" presently constitutes its own ministry (e.g. Alberta Health or Health Canada), implying a separation from other determinants of well-being, whereas formerly it was broader in scope (e.g. the federal Department of Pensions and National Health [1928] and Department of National Health and Welfare [1944]).[9,10]

It is timely to work towards a more unified PPH. Unlike even 20 years ago, there are now many programs of study in

Highlights

- Despite the supposed integration of "population and public health" (PPH), issues in the areas of research funding, the public health workforce and ethics continue to present challenges to the field's unity.
- The authors argue that overcoming these challenges is a worthwhile goal for the future of population well-being in Canada.

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Canadian universities for students who do not necessarily intend to go into public health in its conventional sense (e.g. public health nursing or a public health and preventive medicine specialty) but rather who wish to pursue an academic career, or to apply principles of PPH in a range of sectors. The Bachelor of Health Sciences Program at the University of Calgary, and in particular the Health and Society specialization within that program, is an excellent example. We disclose that this relatively recent trend describes us: we were both drawn to the idea of a unified PPH because it represented a way to bring together health and social sciences/humanities in a way that is connected to, but importantly steps outside of, the formal health sector and professions.

Argument 3: Important challenges and opportunities for an integrated field to exist

To permit reflection on PPH, we identify three (of potentially many) areas that appear to create cleavage in the field: research funding, the public health workforce and PPH ethics. For each area, with the intention of opening a dialogue, we identify what we see as key challenges and opportunities.

1. Research funding

Challenge: The 2009 announcement by the Social Sciences and Humanities Research Council of Canada that they would no longer fund health research created a challenge for PPH as an interdisciplinary field, as it left many social scientists working within PPH to navigate the different funding landscape and procedures of the Canadian Institutes of Health Research (CIHR).[11] This change highlighted the different norms and expectations for social sciences versus traditional health research (e.g. structure of research grant applications, authorship, length and pace of publications, emphasis on theory),[12] as well as the areas of research considered viable and worthwhile. These differences, arguably, may particularly disadvantage those who are most poised to contribute rich theoretical and critical scholarship to PPH.

Opportunity: The integration of social and health sciences is essential to PPH. As a national funding agency and guiding body for health research in Canada, CIHR provides a forum where challenges to integration can be overcome. One example is the significant efforts that have been made by CIHR's Institute of Population and Public Health (IPPH) to shift the peer review landscape to facilitate fair and transparent evaluation of interdisciplinary applicants by reviewers with appropriate expertise through specific, priority-driven competitions.[13] Though the challenges noted above have not disappeared, it seems that important progress is being made.

2. Public health workforce

Challenge: To a large extent, the public health workforce (e.g. physicians, public health inspectors, laboratory workers, nurses) remains situated within the health sector (i.e. in health services organizations or ministries of health). This arrangement presents a challenge for action on the SDOH and health equity, which is at the forefront of PPH and by definition goes beyond the regulatory and legal frameworks of public health. Action on the SDOH may fall outside the scope of day-to-day public health work providing services and programs to the public.[14] Additionally, the legislative framework that mandates public health in jurisdictions may not support an integrative PPH. For example, Alberta's *Public Health Act: Revised Statues of Alberta 2000*[15] makes no mention of the SDOH, or even of chronic disease. These issues may present a source of cleavage between the large number of experts working within public health's core functions (e.g. disease prevention, and communicable disease prevention in particular) and the stated aim of PPH to broadly influence population health (i.e. via social policy interventions, outside of the health system).

Opportunity: Despite these sources of cleavage, significant opportunities do exist and in some cases progress has been made within the professional and regulatory arms of public health towards a more unified field. Brassolotto, Raphael and Baldeo,[14] for instance, have documented that in Ontario some health units actively pursue advocacy and action on the SDOH in addition to their delivery of more traditional public health services. Public Health Ontario, for example, has incorporated addressing determinants of health and reducing health inequities throughout the *Ontario Public Health Standards.*[16]

Legislative progress has also been made in some jurisdictions. In British Columbia, the *Public Health Act (SBC 2008)* includes chronic disease as a health impediment, which at least in theory allows for the minister to incorporate the social determinants of health or equity concerns when developing a plan "to identify, prevent and mitigate" its adverse effects.[17] Quebec's *Public Health Act (S-2.2)* goes further, by allowing the minister of health, public health director and institutions to intervene not only to prevent disease and trauma, but also to consider "social problems that have an impact on the health of the population"[18,p.4] through acting on the SDOH. An example of this is Quebec's promotion and implementation of healthy public policies through health impact assessment.[19] Finally, in recent years, the Public Health Agency of Canada has attempted to define the ever-expanding PPH workforce, through core competencies for public health work and the harmonization of information on the diverse postsecondary and postgraduate training opportunities that exist in PPH.[20,21] Such attempts present the opportunity to better understand some of the features of PPH that permit intersectoral action and build on them, toward a more integrative PPH workforce and field of practice.

3. Efforts to advance the ethical foundations of PPH

Challenge: As public health practice is predominantly situated within the health care system, its ethical guidelines have traditionally been sanctioned by bioethical principles (i.e. autonomy, beneficence, nonmaleficence, respect for human rights) and guided by the moral theory of utilitarianism (i.e. the public good).[22] However, as noted elsewhere,[23,24] these bioethics principles have proven inadequate to fully meet the challenges of PPH, where intervention activities include structural interventions that apply to whole populations and may therefore conflict with the will of the public to the benefit of the population (e.g. community water fluoridation). This tension has led to the creation of critical subdisciplines (e.g. public health ethics) to encourage advancements to ethical thinking in ways that respond to this need (e.g. the Nuffield Council on Bioethics' stewardship model).[25]

Opportunity: There is an exciting trend in evolving critical scholarship on some of the unique challenges that exist for population

health interventions sanctioned under public health ethical frameworks. For instance, there is scholarly debate around the merits and drawbacks of population-wide, or universal, interventions in PPH that, on the one hand, identifies potential negative consequences of the population-level approach,[26,27] and, on the other, argues for the leverage and potential equity of that approach.[28] This work will contribute to an increasingly robust intellectual foundation for PPH. Relatedly, some ethical frameworks that better incorporate aspects of population health have emerged that respond to the field's need for transparency and minimal restriction, social justice and equity.[23,29-31] Such work may facilitate greater unification of PPH, as it begins to tackle the issue

TABLE 1
Historical timeline of key events in the development of "population and public health," 1974–2004

Year	Event	Contribution to field of PPH
1974	Lalonde Report[32] published	Influences a number of developments in health promotion
1975	National Health Research and Development Program is established	Stimulates and supports research into national health issues
1978 (UK)	Marmot, Rose, Shipley and Hamilton.[33] publish findings from Whitehall I	Introduces the notion of the social gradient into epidemiological research
1982 (CAN)	Canadian Institute for Advanced Research is established	Serves as a "think tank" for developing new conceptual frameworks
1985 (UK)	Rose publishes *Sick Individuals and Sick Populations*[34]	Introduces the population strategy of prevention
1986 (Intl.)	Ottawa Charter for Health Promotion[35] published	Facilitates developments in health promotion and introduces the prerequisites for health
(CAN)	Epp Report[36] published	Canadian government departments begin to adopt health promotion in their programs
1987 (CAN)	Canadian Institute for Advanced Research establishes a population health program	Reflects changes in government and in PPH; public health is shifting away from health promotion towards population health
1989 (CAN)	Canadian Institute for Advanced Research introduces population health concept	Considers complex interaction of determinants of health
1991 (CAN)	Mustard and Frank[37] publish *The Determinants of Health*	Concludes that major determinants of health lie beyond the reach of the medical care system, at the individual and population levels
1991 (UK)	Marmot, Davey Smith, Stansfeld et al.[38] publish findings from Whitehall II	Brings language of health inequality to the forefront of population-level research
1994 (CAN)	Evans, Barer and Marmor[39] publish *Why are Some People Healthy and Others Not?*	Provides epidemiological support to explain the influence of social and economic factors on health
1994 (CAN)	Federal, provincial, and territorial ministers of health publish *Strategies for Population Health: Investing in the Health of Canadians*[40]	Population health approach is officially endorsed by governments
1996 (CAN)	Hamilton and Bhatti[41] produce Population Health Promotion: An Integrated Framework for Population Health Promotion	Combines ideas of population health and health promotion
1997 (CAN)	Federal, Provincial, and Territorial Advisory Committee on Population Health is formed	Provides government definition of population health
1998 (CAN)	Hayes and Dunn[42] publish systematic review on population health in Canada	Identifies multiple ways that population health can be conceived, as a perspective, research, framework, or approach
1998 (CAN)	Poland, Coburn, Robertson, and Eakin[43] publish *Wealth, Equity and Health Care: A Critique of a "Population Health" Perspective on the Determinants of Health*	Critiques the population health model for being atheoretical and reductionist
2000 (USA)	National Committee on Vital Health and Statistics at the Centers for Disease Control considers Canadian Institute for Advanced Research concept of population health in their vision for health statistics	Exemplifies international spread of the population health concept
2000 (CAN)	Canadian Institutes for Health Research established through an Act of Parliament, replacing the National Health Research and Development Program	Includes the Institute for Population Health in 2000
2001 (CAN)	Health Canada's Health Promotion and Programs Branch produces a position paper for health promotion staff	Population health approach is adopted as a unifying force by Health Canada for its spectrum of health system interventions
2003 (CAN)	Coburn[44] publishes "Population Health in Canada: A Brief Critique"	Acknowledges that health promotion had been "squeezed out" by population health as a credible health policy discourse
2004 (CAN)	Public Health Agency of Canada formed	Adopts a population health approach and establishes regional offices of the Population and Public Health Branch to mobilize it

Abbreviations: CAN, Canada; Intl, international; PPH, population and public health; UK, United Kingdom.

of how to balance the utilitarian aspect of public health, which many view as its key asset, alongside thoughtful consideration of the possible unintended consequences of this approach toward improving health for all.

Conclusion

As PPH continues to evolve throughout the twenty-first century and enrollment in "population and public health" interdisciplinary graduate programs continues to grow, we believe that the question of whether and how to better integrate PPH will remain relevant and important. We recognize that the areas we have considered above (i.e. research, the public health workforce and PPH ethics) are not mutually exclusive and represent only a few examples among many others that likely exist.

We encourage future research and discussion on the topic and we hope that this paper prompts further debate and discussion among PPH leaders, workers and trainees.

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Researchers from the Public Health Agency of Canada also contribute to work published in other journals. Look for the following articles published in 2017:

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