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by Alexander A. Leung, Tracey Bushnik, Deirdre Hennessy, Finlay A. McAlister, and Douglas G. Manuel

Abstract

Background: Hypertension (or high blood pressure) affects almost one in four adults in Canada. Quantifying risk factors associated with hypertension may help to inform prevention efforts.

Data and methods: Data from the first four cycles of the Canadian Health Measures Survey (including 13,407 respondents) were used to identify hypertension status by systolic and diastolic blood pressure levels and the use of antihypertensive medications. Logistic regression analysis was employed to estimate the association between six cardiovascular risk factors (individually and as a composite score) and hypertension.

Results: Engaging in less than 150 minutes per week of moderate-to-vigorous physical activity, eating fruits and vegetables fewer than five times per day, being overweight or obese, having diabetes, and having chronic kidney disease were all independently associated with an increased risk of hypertension. When these factors were combined into a risk score, there was a linear increase in the predicted risk of hypertension with each additional risk factor. The predicted prevalence of hypertension for those with all six risk factors was 55% in women and 44% in men aged 20 to 39 years, and 80% in women and 76% in men aged 70 to 79 years. Being overweight or obese, consuming fruits and vegetables less often, being inactive, and having diabetes contributed to the largest attributable fractions for hypertension in the Canadian population.

Interpretation: Physical activity, diet, body mass index, the presence of diabetes, and the presence of chronic kidney disease were strong risk factors for hypertension. Many of these risk factors are modifiable and highlight targets for future prevention strategies.

Keywords: hypertension, risk, prevalence, survey, cross-sectional, lifestyle, exercise, diet, obesity, diabetes, chronic kidney disease, cholesterol, prevention

Hypertension (or high blood pressure) is a leading modifiable risk factor for cardiovascular disease and accounts for more than 10% of the population-attributable fraction (PAF) for mortality worldwide.[1,2] Hypertension affects almost 1 in 4 Canadian adults,[2,3] and the lifetime incidence of developing high blood pressure is estimated to be 90%.[4]

Over the last several decades, impressive gains have been made in improving hypertension detection, treatment, and control,[5-10] but comparatively little work has been done in promoting primary prevention, a subject of growing interest. Encouragingly, accumulating evidence suggests that healthy lifestyle factors (such as a healthy diet and increased physical activity) contribute to lowering blood pressure[11-14] and that managing these risks can offset, at least to some extent, genetic predisposition towards hypertension and the development of subsequent cardiovascular sequelae.[15] Further, community-based approaches can be effective in reducing blood pressure along with other cardiovascular risk factors in the population.[16,17]

The possible impact of an aging population,[18] worsening levels of obesity,[19] sedentary lifestyles,[20] and high sodium consumption[21] on the burden of hypertension calls for a better understanding of the major risk factors associated with hypertension. Previous studies have commonly reported older age,[22-28] female sex,[22,24,27] increased body mass index or waist circumference,[22-28] and family history of hypertension or premature cardiovascular disease[22,24,25,27] to be significant predictors of high blood pressure. However, many existing prediction models were limited to people of white ethnicity[22-24,28] and individuals without diabetes.[22-25] As a result, their generalizability is limited. Moreover, few models have examined the association of nutrition, physical activity, or lifestyle with hypertension, and none have been derived in Canada. Quantifying the major risk factors for hypertension by means of high-quality measured data in Canada is important for informing health policy and targeted interventions nationally. To this end, using data from the first four cycles of the Canadian Health Measures Survey (CHMS), this study examined the major risk factors for hypertensive status among Canadians aged 20 to 79 years, and employed a composite risk score to predict hypertension in women and men across a wide range of ages.

Data and methods

Data source

The data are from the first (2007 to 2009), second (2009 to 2011), third (2012 to 2013), and fourth (2014 to 2015) cycles of the Canadian Health Measures Survey (CHMS). The CHMS is an ongoing survey designed to provide comprehensive direct health measures at the national level, and it collects information from community-dwelling individuals. Full-time members of the Canadian Armed Forces and people living on reserves or in other Aboriginal settlements, in institutions and in some remote regions are excluded (collectively representing approximately 3% of the Canadian population).[29] The CHMS involves an in-person household interview and a subsequent visit to a mobile examination centre (MEC). The household interview gathers general demographic and socioeconomic data and detailed health, nutrition and lifestyle information. At the MEC,

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direct physical measurements are taken, including collection of blood and urine samples. Information about medication use is obtained during the household interview and also at the MEC. CHMS participants receive an accelerometer to wear for one week to monitor activity levels. Detailed information about the CHMS is available online.[30-34]

The four cycles combined had a total of 13,533 respondents aged 20 to 79. The combined non-response rate for 20- to 79-year-olds in the four cycles was 52%. For the present study, 108 subjects were excluded because of pregnancy, and another 18 were excluded because of missing values for their systolic blood pressure (SBP) and diastolic blood pressure (DBP). The resulting analytical sample size was 13,407.

Measures

Blood pressure. SBP and DBP were measured with the BpTRU™ BPM-300 device (BpTRU Medical Devices Ltd., Coquitlam, British Columbia) at the MEC. The BpTRU™ is an automated electronic monitor that has been validated and recommended for use by Hypertension Canada.[35,36] Although the BpTRU™ SBP and DBP readings have been found to be slightly lower than conventional manual blood pressure readings, the BpTRU™ readings may estimate blood pressure status more accurately.[37] Following a five-minute rest period, six measurements were taken at one-minute intervals for each participant while unattended, and the last five measurements were averaged together to determine the average SBP and DBP levels.[38] During the home interview, 56 respondents aged 20 to 79 who could not visit the MEC had their blood pressure measured with the BpTRU™ BPM-100 device.

Medication use. Current medications were recorded during the household and clinic interviews, and these were assigned to codes from the Anatomical Therapeutic Chemical (ATC) classification system, corresponding to beta blockers, agents acting on the renin-angiotensin system, thiazide diuretics, calcium channel antagonists, and other antihypertensive agents.[39]

Diabetes. Respondents were categorized as having diabetes if their measured serum glycated hemoglobin A1c was 6.5% or higher, if they used glucose-lowering medication (ATC codes in category A10), or if they reported a diagnosis of diabetes from a health care provider.[40]

Hypertension. Respondents were considered hypertensive if their mean SBP was 140 mm Hg or higher or mean DBP was 90 mm Hg or higher, or if they had been taking an antihypertensive medication in the month prior to the measurement being taken. Hypertensive respondents were considered controlled if they were taking antihypertensive medication and had mean SBP lower than 140 mm Hg and mean DBP lower than 90 mm Hg.

Covariates

Sociodemographic characteristics. Age was categorized into bands (20 to 39, 40 to 59, 60 to 69, and 70 to 79 years). Marital status was defined as "married or living common law," vs. not. Highest level of education was defined as "less than secondary school graduation," vs. "secondary school graduation or higher." Household income (n=2,720 cases were imputed) was adjusted for household size and was categorized according to the lowest household income quintile, vs. above the lowest quintile. White or non-white ethnicity was based on respondents' answer to which racial or cultural group they belonged.

Personal and family history. Having a regular medical doctor was categorized as "yes" or "no." Smoking status was classified as "smoking daily or occasionally," vs. "not smoking." Cardiovascular disease was defined by self-reported heart disease, heart attack, and/or stroke. Family history of high blood pressure was categorized as "yes," "no," or "not known" (respondents with missing information [n=887] were assigned to the category "not known"). Family history of early cardiovascular disease was defined as an immediate family member being diagnosed with heart disease or stroke before the age of 60.

Risk factors. Risk factors were selected a priori according to a predefined protocol and informed by clinical reasoning. Exercise was categorized as less than 150 minutes per week of moderate-to-vigorous physical activity, vs. 150 minutes or more per week. This variable was based on four valid days of accelerometry data (and respondents with less than four valid days of data [n=3,063] were assigned to the category "not known").

Fruit and vegetable consumption was categorized as fewer than five times per day, vs. five or more times per day (an indicator of diet quality).[41] This was derived from the sum of the frequency of daily consumption of the following: 100% fruit juices; fruit; tomatoes or tomato sauce (excluding tomato paste, ketchup, and pizza sauce); lettuce or green leafy salad; potatoes (including baked, boiled, and mashed potatoes, and potato salad, but excluding sweet potatoes); spinach, mustard greens or collards (excluding kale); and "other" types of vegetables (not mentioned here).

Respondents were overweight or obese if they had a body mass index (BMI) based on measured height and weight of 25.0 kg/m^2 or more. The presence of diabetes was determined as described above. Chronic kidney disease (CKD) was defined as an estimated glomerular filtration rate of less than 60 mL/min/1.73 m^2.[42] Cholesterol was categorized according to non-fasting non-high-density lipoprotein (HDL) cholesterol of 4.3 mmol/L or higher, vs. lower than 4.3 mmol/L (calculated by subtracting participants' HDL blood measure of cholesterol from their blood measure of total cholesterol).[43] These factors were summed into a risk score with values ranging from 0 (no risk factors were present) to 6 (all six risk factors were present) to determine whether the component risk factors were additive.

Data were missing for some analytical variables: marital status (n=8), education (n=139), having a regular doctor (n=4),

smoking (n=41), fruit and vegetable consumption (n=66), overweight or obesity (n=48), CKD (n=194), non-HDL cholesterol (n=192), risk score (n=342), and systolic blood pressure (n=8).

Statistical analysis

Descriptive statistics were used to examine the characteristics of the study population and the prevalence of hypertension. Two sets of logistic regression models were run separately for women and men, and relative risks (RRs) were estimated. Model 1 estimated the association between the risk factors and hypertension, adjusting for other covariates. Model 2 estimated the association between the risk score and hypertension, adjusting for other covariates. Model 1 was rerun six times, including an interaction term between age group and one risk factor at a time, to test whether age modified the risk factor's association with hypertension. Model 2 was also rerun, including an interaction term between age group and the risk score. To account for the survey's complex sampling design, all analyses were weighted on the basis of the combined survey weight from cycles 1, 2, 3 and 4 of the CHMS.[34] Replicate weights generated by Statistics Canada were used to perform the variance estimation (95% confidence interval [CI]) and significance testing.[30-33] The data were analyzed with SAS 9.3 and SUDAAN 11.0 (46 denominator degrees of freedom in the SUDAAN procedure statements were used).

To estimate the proportion of cases of hypertension due to a given risk factor, population-attributable fractions (PAFs) were calculated according to a modification of Levin's formula:[44] $PAF = P_e (RR_e\text{-}1) / [1 + P_e (RR_e\text{-}1)]$, where P_e is the prevalence of the exposure in the population (e.g., proportion of patients with diabetes) and RR_e is the relative risk of hypertension due to that exposure. For this study, the prevalence estimates were taken from Table 1, and the RR_es were based on adjusted RRs from Table 2. For example, the PAF attributable to diabetes among men was calculated from the prevalence of 9.4% (Table 1) and an adjusted RR of 1.68 (Table 2) to produce the estimate of 6.0% from [0.094 (1.68-1)] / [1 + 0.094 (1.68-1)].

Two sensitivity analyses were conducted. First, the average BpTRU™ blood pressure readings were adjusted on the basis of the following correction factors: adjusted BpTRU™ SBP=11.4+(0.93 × BpTRU™ SBP) and adjusted BpTRU™ DBP=15.6+(0.83 × BpTRU™ DBP).[37] These adjusted values were then used to define hypertension with the 140 mm Hg SBP and 90 mm Hg DBP thresholds. This allowed for comparability between the present study and others based on manual blood pressure readings. Second, the SBP threshold of 130 mm Hg and the DBP threshold of 80 mm Hg were applied to the SBP and DBP components of the definition of hypertension, for them to be consistent with the recent blood pressure clinical guidelines from the American College of Cardiology and American Heart Association.[45] Under this revised definition, overall prevalence and the association between the risk factors or risk score and hypertension were examined.

Results

The population prevalence of hypertension among Canadians aged 20 to 79 was found to be significantly higher for men (24.5%, 95% CI: 22.7% to 26.4%) than for women (21.5%, 95% CI: 19.8% to 23.2%). Men were slightly younger, on average, than women, and were more likely to be smokers, have cardiovascular disease, eat fruits and vegetables fewer than five times per day, be overweight or obese, have diabetes, and have non-HDL cholesterol at a level of 4.3 mmol/L or higher (Table 1). However, women were more likely than men to engage in less than 150 minutes per week of moderate-to-vigorous physical activity, have a family history of high blood pressure or early cardiovascular disease, or have CKD. Men had, on average, a higher average risk score (2.3, 95% CI: 2.2 to 2.3) than women (2.1, 95% CI: 2.0 to 2.1).

After covariate adjustment, five out of six of the candidate risk factors were significantly associated with an increased risk of hypertension among women aged 20 to 79 (Table 2): being less physically active (RR, 1.26, 95% CI: 1.05 to 1.51), eating fruits and vegetables fewer than five times per day (RR, 1.15, 95% CI: 1.00 to 1.34), being overweight or obese (RR, 1.57; 95% CI: 1.35 to 1.83), having diabetes (RR, 2.25, 95% CI: 1.92 to 2.65), and having CKD (RR, 1.49, 95% CI: 1.21 to 1.83). Among men aged 20 to 79, being less physically active (RR, 1.19, 95% CI: 1.01 to 1.39), eating fruits and vegetables fewer than five times per day (RR, 1.18, 95% CI: 1.02 to 1.36), being overweight or obese (RR, 1.45, 95% CI: 1.18 to 1.78), and having diabetes (RR, 1.68, 95% CI: 1.41 to 2.01) were significantly associated with an increased risk of hypertension.

The proportion of cases of hypertension in the population attributable to each risk factor (PAF) was then estimated (Table 2). For both men and women, being overweight or obese was the leading risk factor for having hypertension, this factor contributing to 24% of all cases. Eating fruits and vegetables fewer than five times per day accounted for 9% of cases of hypertension in women and 12% in men. The fraction of hypertension attributable to diabetes was similar in women (8%) and men (6%). In contrast, being less physically active contributed to more cases of hypertension in women, at 12%, than in men, at 7%. In women, around 3% of cases of hypertension were attributable to CKD. Less than 1% of hypertension could be attributed to CKD in men and to elevated non-HDL cholesterol levels in either sex.

The strength of association for many risk factors varied according to age group. Among those aged 70 to 79, none of the individual risk factors were associated with hypertension in men, and only diabetes was significantly associated with hypertension in women (Appendix Table 1). Furthermore, being overweight or obese was a risk factor for women predominantly at ages 40 to 69, whereas having CKD was a risk factor largely at

Table 1
Characteristics of household population aged 20 to 79, by sex, 2007 to 2015

	Women				Men			
			95% confidence interval				95% confidence interval	
	Sample size	%	from	to	Sample size	%	from	to
Hypertensive	**1,720**	**21.5**	**19.8**	**23.2**	**1,832†**	**24.5**	**22.7**	**26.4**
Sociodemographic characteristics								
Age in years (mean)	6,925	46.5	46.2	46.8	6,482†	45.7	45.5	46.0
20 to 39 years	2,414	36.1	35.5	36.6	2,135†	37.8	37.6	38.1
40 to 59 years	2,335	40.4	40.0	40.7	2,272	40.2	40.0	40.5
60 to 69 years	1,352	15.4	14.6	16.2	1,395	14.9	14.2	15.6
70 to 79 years	824	8.2	7.5	8.9	680†	7.0	6.4	7.6
Married/Common-law	4,202	64.9	62.5	67.1	4,531	66.0	63.7	68.3
Less than secondary school graduation	916	11.8	10.3	13.6	854	13.3	11.5	15.3
In lowest income quintile	1,674	21.4	19.3	23.6	1,151†	17.4	15.2	19.9
White	5,601	78.3	73.5	82.4	5,245	78.4	73.3	82.8
Personal and family history								
Has regular doctor	6,229	88.9	87.2	90.4	5,317†	79.3	76.9	81.5
Current smoker (daily or occasional)	1,346	20.3	18.4	22.2	1,566†	26.9	25.2	28.6
Cardiovascular disease	373	4.0	3.5	4.7	582†	7.5	6.7	8.4
Family history of high blood pressure	3,432	51.5	49.4	53.7	2,840†	46.5	44.1	48.9
Family history of early cardiovascular disease	1,585	22.0	19.9	24.2	1,302†	18.7	17.2	20.3
Risk factors								
Less than 150 minutes/week MVPA	3,616	51.2	48.5	53.9	2,829†	39.2	36.1	42.5
Eats fruits or vegetables fewer than five times per day	4,495	67.3	65.2	69.4	4,983†	77.5	75.8	79.2
Overweight or obese	4,058	56.3	53.3	59.2	4,650†	69.5	67.3	71.6
Diabetes	557	7.1	6.2	8.0	685†	9.4	8.3	10.6
Chronic kidney disease	485	5.6	4.7	6.7	347†	4.3	3.7	5.0
Non-HDL cholesterol 4.3 mmol/L or higher	1,358	18.5	16.7	20.4	1,720†	27.2	24.7	29.8
Risk score (mean)	**6,752**	**2.1**	**2.0**	**2.1**	**6,313†**	**2.3**	**2.2**	**2.3**
Zero risk factors	520	8.5	7.1	10.1	247†	4.2	3.3	5.5
One risk factor	1,562	23.9	21.9	26.1	1,167	21.9	19.9	24.0
Two risk factors	2,203	32.4	30.3	34.5	2,022	31.6	29.4	33.8
Three risk factors	1,689	24.7	22.7	26.7	1,936†	28.6	26.6	30.6
Four risk factors	659	9.4	8.0	11.0	831†	12.1	10.8	13.6
Five or six risk factors	119	1.1	0.8	1.5	110	1.6	1.2	2.1

† significantly different from estimate for females (p< 0.05)
SBP=systolic blood pressure
DBP=diastolic blood pressure
HDL=high-density lipoprotein
MVPA=moderate-to-vigorous physical activity
Notes: Hypertension is defined as SBP>=140 mm Hg and/or mean DBP>=90 mm Hg and/or antihypertensive medication use in the past month. The risk score is the sum of the following risk factors: less than 150 minutes/week in MVPA, fruits and vegetables fewer than five times/day, overweight or obese, diabetes, chronic kidney disease and non-HDL cholesterol 4.3 mmol/L or higher. Sample sizes are unweighted counts. Percentages, means and their confidence intervals are based on weighted estimates.
Source: Combined 2007-to-2009, 2009-to-2011, 2012-to-2013 and 2014-to-2015 Canadian Health Measures Survey.

ages 20 to 39. For men, consuming fruits and vegetables fewer than five times per day was a risk factor at ages 40 to 59, while being less active and being overweight or obese were risk factors primarily at ages 60 to 69. Having non-HDL cholesterol at a level of 4.3 mmol/L or higher was not associated with increased risk of hypertension for adult men as a whole; however, it was associated with a significantly reduced risk of hypertension among men aged 60 to 69.

When the risk factors were summed to create a risk score, the prevalence of hypertension increased significantly (p<0.05) with each unit increase in the score for women and men aged 20 to 79 (Figure 1).

The risk score was also associated with systolic blood pressure (SBP) levels. Among the non-hypertensive population, mean SBP rose significantly with each unit increase in the risk score (Figure 2). This gradient was not evident among those with a diagnosis of hypertension, mainly because most of these individuals were treated with anti-hypertensive medications (results not shown). In fact, none of the risk factors in the score were associated with hypertension control rates (Appendix Table 2).

Sensitivity analysis

Applying the correction factors to the BpTRU™ SBP and DBP values had almost no effect on the estimate of the prevalence of hypertension (women: 22%, 95% CI: 20% to 23%; men: 25%, 95% CI: 23% to 27%) when compared with the results presented in Table 1. Similarly, there was no impact on the association between the risk factors or risk score and hypertension (results not shown). Lowering the SBP threshold to 130 mm Hg and the DBP threshold to 80 mm Hg to define hypertension resulted in an absolute 9% increase in

Table 2
Model-adjusted association (risk ratios and confidence intervals) between risk factors and hypertension and population-attributable fractions, by sex, household population aged 20 to 79, 2007 to 2015

	Women					Men				
		95% confidence interval					95% confidence interval			
	Risk ratio	from	to	p-value	PAF, %	Risk ratio	from	to	p-value	PAF, %
Sociodemographic characteristics†										
20 to 39 years††	0.10	0.07	0.16	0.00	…	0.10*	0.07	0.14		
40 to 59 years††	0.34*	0.28	0.40	0.00	…	0.43*	0.36	0.50	0.00	…
60 to 69 years††	0.69*	0.58	0.82	0.00	…	0.72*	0.63	0.83	0.00	…
Married/Common-law	1.00	0.88	1.14	0.98	…	0.93	0.78	1.11	0.40	…
Less than secondary school graduation	0.97	0.80	1.16	0.71	…	1.27*	1.06	1.53	0.01	…
In lowest income quintile	1.07	0.92	1.25	0.35	…	1.07	0.90	1.27	0.46	…
White	1.07	0.89	1.29	0.47	…	0.99	0.80	1.22	0.90	…
Personal and family history†										
Has regular doctor	0.99	0.75	1.32	0.96	…	1.19	0.88	1.61	0.20	…
Current smoker (daily or occasional)	0.92	0.75	1.12	0.39	…	0.89	0.77	1.04	0.14	…
Cardiovascular disease	1.81*	1.49	2.21	0.00	…	2.00*	1.74	2.30	0.00	…
Family history of high blood pressure	1.65*	1.46	1.88	0.00	…	1.50*	1.33	1.69	0.00	…
Family history of early CVD	1.20*	1.05	1.38	0.01	…	0.87*	0.77	0.98	0.02	…
Risk factors†										
Less than 150 minutes/week MVPA	1.26*	1.05	1.51	0.01	11.8	1.19*	1.01	1.39	0.03	6.8
Eats fruits or vegetables fewer than five times per day	1.15*	1.00	1.34	0.05	9.4	1.18*	1.02	1.36	0.03	12.2
Overweight or obese	1.57*	1.35	1.83	0.00	24.4	1.45*	1.18	1.78	0.00	23.6
Diabetes	2.25*	1.92	2.65	0.00	8.1	1.68*	1.41	2.01	0.00	6.0
Chronic kidney disease	1.49*	1.21	1.83	0.00	2.7	1.18	0.97	1.44	0.10	0.8
Non-HDL cholesterol 4.3 mmol/L or higher	1.03	0.89	1.20	0.68	0.6	1.00	0.87	1.15	0.99	0.0

…not applicable
* significantly different from reference category ($p < 0.05$)
† the reference category is the absence of the characteristic or risk factor
†† the reference category is age group 70 to 79 years
PAF=population-attributable fraction
HDL=high-density lipoprotein
CVD=cardiovascular disease
MVPA=moderate-to-vigorous physical activity
Notes: Each sex-specific model included age group, marital status, education, income quintile, ethnicity, having a regular doctor, smoking, CVD, family history of high blood pressure, family history of early CVD, all six risk factors, and the cycle of the CHMS.
Source: Combined 2007-to-2009, 2009-to-2011, 2012-to-2013 and 2014-to-2015 Canadian Health Measures Survey.

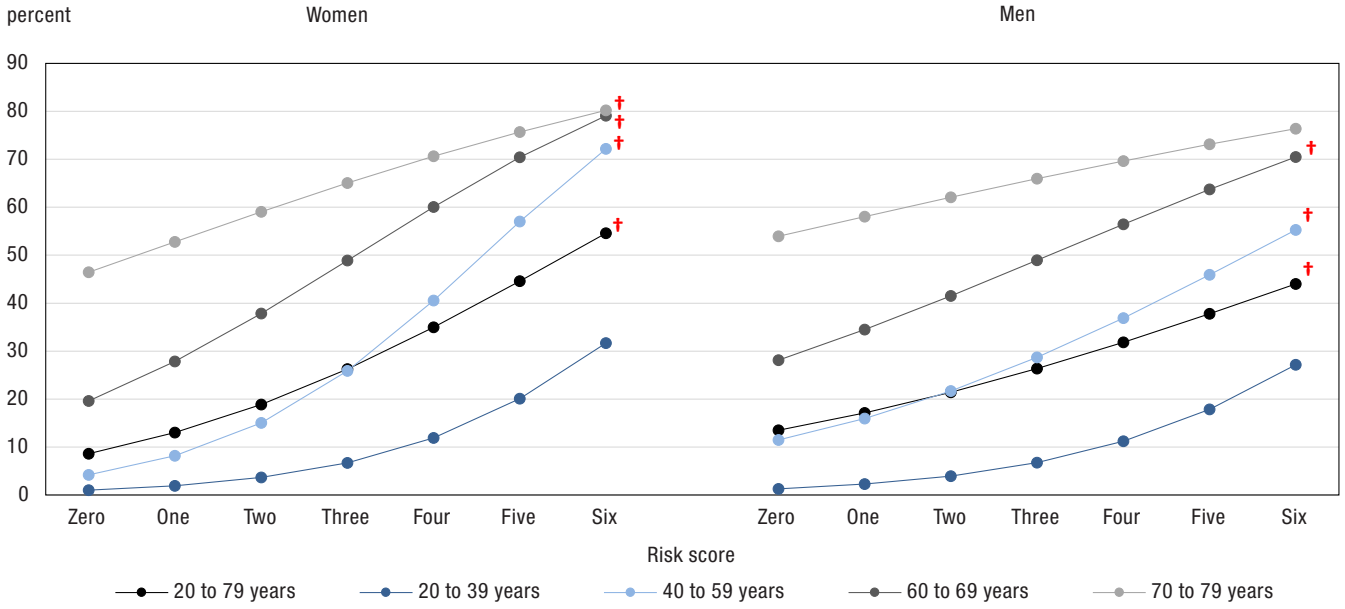
the prevalence of hypertension among women (31%, 95% CI: 28% to 34%) and an absolute 17% increase in prevalence among men (41%, 95% CI: 39% to 44%). In terms of risk factors, non-HDL cholesterol at a level of 4.3 mmol/L or higher became significantly associated with the risk of hypertension for both women and men, while eating fruits and vegetables fewer than five times per day became only marginally significant for men (Appendix Table 3). Although the predicted prevalence of hypertension according to risk score was higher overall, a positive gradient similar to that found in Figure 1 was still present.

Discussion

In this study, nearly one-quarter of Canadians aged 20 to 79 were found to be hypertensive. Engaging in less than 150 minutes per week of moderate-to-vigorous physical activity, eating fruits and vegetables fewer than five times per day, being overweight or obese, having diabetes, and having CKD were independently associated with higher blood pressure levels and an increased risk of hypertension. When these risk factors were combined into a composite risk score (where the presence of each risk factor represented one point), a strong positive gradient was present for predicting hypertension. It is important to note that being overweight or obese, consuming fruits and vegetables less often, being less active, and having diabetes were the leading risk factors contributing to the greatest attributable fraction of hypertension cases in the population. The fact that these risk factors were not associated with hypertension control rates reflects the very high rates of awareness and antihypertensive therapy use among patients with hypertension in this population.

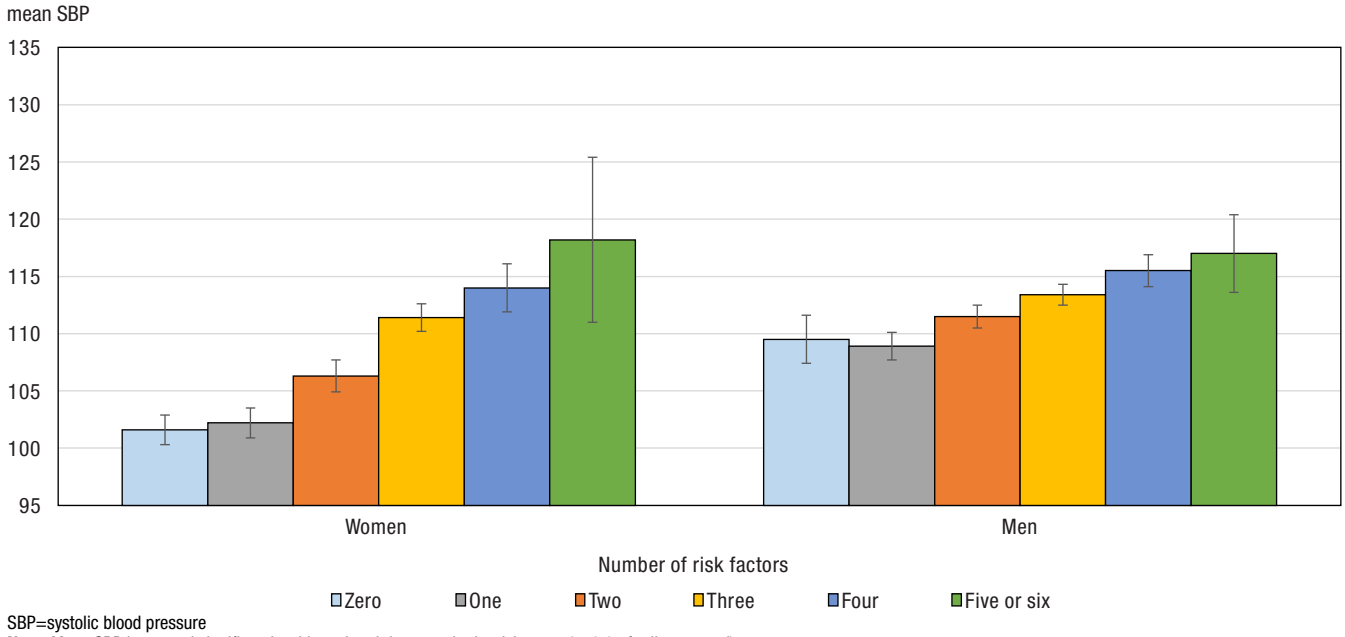
These findings are consistent with, and extend, those of other reports, relating healthy lifestyle and behaviours to better blood pressure control.[11-13] Participation in moderate-intensity physical activity,[46,47] consumption of a diet rich in fruits and vegetables,[48-50] and maintenance of a healthy body weight[51-53] have all been described as lowering blood pressure. In addition, counselling interventions promoting healthy behaviours (such as physical activity, healthful diet and weight management) are effective in reducing blood pressure in individuals who do not have hypertension or known cardiovascular risk factors.[14] However,

Figure 1
Predicted prevalence of hypertension according to risk score, by age group, by sex, household population aged 20 to 79, 2007 to 2015



† Logistic regression model for hypertension prevalence according to risk score. Each unit increase in the risk score was associated with a significant increase in the predicted prevalence of hypertension (p≤0.05).
Notes: The estimates for individuals aged 20 to 79 were produced from sex-specific models that included age group, marital status, education, income quintile, ethnicity, having a regular doctor, smoking, cardiovascular disease (CVD), family history of high blood pressure, family history of early CVD, and the cycle of the CHMS. The estimates for each age group were produced from sex-specific models that included the main effects of, and the interaction term between, the risk score and age group, adjusted for marital status, education, income quintile, ethnicity, having a regular doctor, smoking, CVD, family history of high blood pressure, family history of early CVD, and the cycle of the CHMS.
Source: Combined 2007-to-2009, 2009-to-2011, 2012-to-2013 and 2014-to-2015 Canadian Health Measures Survey.

Figure 2
Mean SBP (mm Hg) according to the risk score, by sex, non-hypertensive household population aged 20 to 79, 2007 to 2015



SBP=systolic blood pressure
Note: Mean SBP increased significantly with each unit increase in the risk score (p≤0.05 for linear trend).
Source: Combined 2007-to-2009, 2009-to-2011, 2012-to-2013 and 2014-to-2015 Canadian Health Measures Survey.

determining the independent effects of the individual components of a healthy lifestyle on blood pressure is challenging, as these risk factors are highly interrelated. Many positive effects may be due to described physiological mechanisms.[11,12] Additional benefits may be realized through a greater tendency to adhere to medical advice and treatment among individuals who engage in healthy lifestyles. In the present study, physical activity was a stronger risk factor for hypertension among women, whereas eating fruits and vegetables was more important for men. The observed risk of hypertension in younger people is noteworthy because targeted interventions for these individuals may be particularly effective.

The associations between high blood pressure and having diabetes, having CKD, and exhibiting elevated non-HDL cholesterol are complex. Diabetes and hypertension commonly coexist. More than half of patients with diabetes also have hypertension,[54] and people with elevated blood pressure are nearly 2.5 times more likely to develop diabetes.[55] Indeed, diabetes was the strongest risk factor associated with high blood pressure in the present analysis, conferring a twofold increased risk of hypertension overall, and the greatest risk was observed in younger individuals, even after accounting for possible differences in blood pressure thresholds (i.e., 140/90 mm Hg or higher vs. 130/80 mm Hg or higher). In contrast, CKD was associated with a greater RR of hypertension among women, independent of diabetes, whereas this was not the case for men. The differences in risk between men and women may, in part, reflect the complex relationship between CKD and hypertension. For instance, the prevalence of high blood pressure among individuals with CKD varies according to the etiology of renal dysfunction,[56] between ethnicities,[57,58] and according to various socioeconomic factors.[58] Finally, elevated non-HDL cholesterol by itself was not significantly associated with high blood pressure. However, when incorporated into the risk score, it incrementally increased the risk of hypertension along with other risk factors. The importance of isolated hypercholesterolemia in hypertension prediction is uncertain and warrants further investigation.

Risk factors for hypertension are often modifiable. Most prevention efforts to date have focused on individual-level interventions promoting physical activity,[46,47] healthy diet,[48-50] and weight loss.[52,53] However, achieving clinically meaningful reductions in blood pressure may require large lifestyle changes,[14] which may be beyond what an average person is able to independently sustain. Accordingly, public policy promoting the requisite conditions for healthy living (e.g., by supporting walkability through the built environment; improving access to, and affordability of, fruits and vegetables; modifying food preparation to reduce dietary salt) is important.[16,17]

There are many strengths to this study. This is the first population-based study conducted in Canada examining preventable risks associated with hypertension. This study is also the first to quantify the PAF of preventable risks for hypertension. In addition to examining individual risk factors for high blood pressure, this study further demonstrates a strong additive effect associated with cumulative risk factors. This suggests that many cases of hypertension in Canada are largely preventable. Data were drawn from a nationally representative sample of Canadians whose blood pressure was measured with an automated device in accordance with a standardized technique. As well, all other clinical data used in the analysis were prospectively collected in keeping with systematic methodologies.

This study has a number of limitations. First, although strong associations were observed between a number of risk factors and hypertension, the data were cross-sectional, and temporal relationships could not be established. Second, the presence of certain comorbidities, use of medications, and dietary intake were self-reported and not independently verified, and therefore open to misclassification. Third, it is likely that some of the risk factors contributed to high blood pressure through cumulative exposure. A single measurement of these factors merely provides a crude estimation of true lifetime exposure and may not be representative of day-to-day variation (e.g., in diet or physical activity). Fourth, although being overweight or obese was associated with nearly one-quarter of attributed cases of hypertension, it should be acknowledged that many of the identified risk factors were strongly interrelated (e.g., body mass index, diet

What is already known on this subject?

- Despite substantial improvements in hypertension treatment and control, hypertension affects almost one in four Canadian adults.
- Primary prevention may be an appropriate strategy to reduce the burden of hypertension.

What does this study add?

- Four cycles of the Canadian Health Measures Survey allow for sex- and age-specific analysis of risk factors associated with hypertension status.
- A number of factors related to lifestyle and behaviour, including physical activity, diet, and body mass index, were associated with hypertension in women and men.
- Hypertension was associated with the presence of diabetes and chronic kidney disease in women and with the presence of diabetes in men.
- The risk score is significantly associated with hypertension risk in both women and men.
- The largest fraction of attributable risk for hypertension is from being overweight or obese, eating fruits and vegetables fewer than five times per day, being inactive, and having diabetes.

and physical activity) and difficult to separate. Consequently, successful policy and interventions will likely need to account for the joint effects of multiple risk factors. Fifth, accelerometry data were used to estimate physical activity, and around one-quarter of respondents had less than four valid days of data available. Missing data were handled by dummy coding, and differential information bias could not be excluded. Sixth, dietary sodium intake and alcohol consumption were not accounted for in this study because of difficulties in accurately quantifying exposure. Finally, for certain exposures with low prevalence, such as having CKD, stratified analyses according to sex and age bands were not possible.

Conclusion

This study found that physical inactivity, a diet low in fruits and vegetables, being overweight or obese, the presence of diabetes, and the presence of CKD were strong risk factors for high blood pressure, and the risk of hypertension increased linearly with each additional exposure. Many of these risk factors are modifiable. Therefore, these findings may be important for health policy and clinical practice. Further study is needed to determine whether hypertension can be delayed or even prevented with early interventions targeting these risk factors. ■

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Appendix

Table A

Model-adjusted association (risk ratios and confidence intervals) between risk factors and hypertension, by age group, by sex, household population aged 20 to 79, 2007 to 2015

	<150 hours/week MVPA			Fruits/vegetables <5 times/day			Overweight or obese			Diabetes			Chronic kidney disease			Non-HDL >=4.3 mmol/L		
		95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval	
	Risk ratio	from	to	Risk ratio	from	to	Risk ratio	from	to	Risk ratio	from	to	Risk ratio	from	to	Risk ratio	from	to
Women																		
20 to 79 years	**1.26***	**1.05**	**1.51**	**1.15***	**1.00**	**1.34**	**1.57***	**1.35**	**1.83**	**2.25***	**1.92**	**2.65**	**1.49***	**1.21**	**1.83**	**1.03**	**0.89**	**1.20**
20 to 39 years	2.75	0.24	31.92	0.95	0.26	3.49	1.88	0.46	7.66	8.12*	3.32	19.82	6.03*	2.83	12.84	1.37	0.45	4.21
40 to 59 years	1.40	0.94	2.07	1.35	0.93	1.95	2.06*	1.41	3.02	3.14*	2.32	4.25	1.85	1.00	3.43	1.13	0.86	1.49
60 to 69 years	1.22	0.93	1.60	1.11	0.89	1.39	1.71*	1.36	2.14	1.93*	1.62	2.30	1.25	0.86	1.82	1.00	0.83	1.21
70 to 79 years	0.89	0.66	1.22	1.09	0.86	1.37	1.08	0.87	1.33	1.30*	1.03	1.65	1.34	0.95	1.89	0.86	0.66	1.10
Men																		
20 to 79 years	**1.19***	**1.01**	**1.39**	**1.18***	**1.02**	**1.36**	**1.45***	**1.18**	**1.78**	**1.68***	**1.41**	**2.01**	**1.18**	**0.97**	**1.44**	**1.00**	**0.87**	**1.15**
20 to 39 years	1.05	0.44	2.50	1.34	0.41	4.40	F	F	F	5.02*	2.00	12.57	F	F	F	1.43	0.69	2.95
40 to 59 years	1.27	0.95	1.70	1.41*	1.01	1.97	1.43	0.87	2.33	2.00*	1.48	2.71	F	F	F	1.08	0.84	1.40
60 to 69 years	1.28*	1.00	1.64	1.01	0.85	1.20	1.53*	1.20	1.94	1.61*	1.36	1.90	F	F	F	0.78*	0.67	0.92
70 to 79 years	1.00	0.80	1.25	1.09	0.90	1.32	1.10	0.86	1.42	1.12	0.91	1.38	F	F	F	0.98	0.79	1.23

F too unreliable to be published
* significantly different from reference category ($p < 0.05$)
The reference category is the absence of the risk factor.
MVPA=moderate-to-vigorous physical activity
HDL=high-density lipoprotein
CVD=cardiovascular disease
Notes: Each sex-specific model included the main effects of, and the interaction term between, the specified risk factor and age group, adjusted for marital status, education, income quintile, ethnicity, having a regular doctor, smoking, CVD, family history of high blood pressure, family history of early CVD, the other risk factors, and the cycle of the Canadian Health Measures Survey.
Source: Combined 2007-to-2009, 2009-to-2011, 2012-to-2013 and 2014-to-2015 Canadian Health Measures Survey.

Table B

Model-adjusted association (risk ratios and confidence intervals) between risk factors and hypertension control, by sex, household population aged 20 to 79, 2007 to 2015

	Women			Men		
		95% confidence interval			95% confidence interval	
	Risk ratio	from	to	Risk ratio	from	to
Risk factors†						
Less than 150 minutes/week in MVPA	1.02	0.85	1.23	0.93	0.85	1.02
Eats fruits or vegetables fewer than five times per day	0.95	0.83	1.10	0.97	0.90	1.05
Overweight or obese	0.99	0.85	1.16	1.02	0.89	1.17
Diabetes	1.03	0.88	1.19	1.04	0.97	1.11
Chronic kidney disease	1.00	0.85	1.17	1.06	0.98	1.14
Non-HDL cholesterol 4.3 mmol/L or higher	0.99	0.85	1.16	0.95	0.85	1.06

† the reference category is the absence of the risk factor
MVPA=moderate-to-vigorous physical activity
HDL=high-density lipoprotein
Notes: The sex-specific risk factor models included all risk factors along with the age group (only three age categories for men–20 to 59, 60 to 69, and 70 to 79–given the small numbers), marital status, education, income quintile, ethnicity, having a regular doctor, smoking, cardiovascular disease (CVD), family history of high blood pressure, family history of early CVD, and the cycle of the Canadian Health Measures Survey.
Source: Combined 2007-to-2009, 2009-to-2011, 2012-to-2013 and 2014-to-2015 Canadian Health Measures Survey.

Table C
Model-adjusted association (risk ratios and confidence intervals) between risk factors and hypertension (SBP >=130 mm Hg or DBP >=80 mm Hg or taking antihypertensive medication) and predicted hypertension prevalence according to risk score, by sex, household population aged 20 to 79, 2007 to 2015

	Women			Men		
		95% confidence interval			95% confidence interval	
	Risk ratio	from	to	Risk ratio	from	to
Risk factors†						
Less than 150 minutes/week MVPA	1.15*	1.00	1.32	1.08	0.98	1.20
Eats fruits or vegetables fewer than five times per day	1.18*	1.03	1.35	1.11	0.99	1.24
Overweight or obese	1.64*	1.45	1.86	1.41*	1.22	1.62
Diabetes	1.82*	1.56	2.12	1.49*	1.30	1.71
Chronic kidney disease	1.32*	1.11	1.57	1.17	0.93	1.47
Non-HDL cholesterol 4.3 mmol/L or higher	1.13*	1.01	1.27	1.11*	1.00	1.23
	Predicted prevalence	95% confidence interval		Predicted prevalence	95% confidence interval	
		from	to		from	to
Risk score						
Zero	14.0	11.1	17.4	25.2	21.5	29.4
One	20.4	17.7	23.4	31.3	28.3	34.5
Two	28.6	26.0	31.3	38.1	35.7	40.6
Three	38.3	34.7	42.0	45.4	42.6	48.3
Four	49.0	43.4	54.7	53.0	48.8	57.1
Five	60.0	52.1	67.3	60.4	54.7	65.9
Six	70.2	60.7	78.3	67.6	60.3	74.1

* significantly different from reference category ($p < 0.05$)
† the reference category is the absence of the risk factor
SBP=systolic blood pressure
DBP=diastolic blood pressure
MVPA=moderate-to-vigorous physical activity
HDL=high-density lipoprotein
Notes: Each unit increase in the risk score was associated with a significant increase in the predicted prevalence of hypertension ($p < 0.05$). The sex-specific risk factor models included all risk factors along with age group, marital status, education, income quintile, ethnicity, having a regular doctor, smoking, cardiovascular disease (CVD), family history of high blood pressure, family history of early CVD, and the cycle of the Canadian Health Measures Survey (CHMS). The sex-specific risk score models included age group, marital status, education, income quintile, ethnicity, having a regular doctor, smoking, CVD, family history of high blood pressure, family history of early CVD, and the cycle of the CHMS.
Source: Combined 2007-to-2009, 2009-to-2011, 2012-to-2013 and 2014-to-2015 Canadian Health Measures Survey.