

## Health Reports

# Metabolic health and body mass index phenotypes in adults



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# Metabolic health and body mass index phenotypes in adults

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## ABSTRACT

### Background

To better understand the interplay between adiposity and metabolic health, joint phenotypes have been used to categorize people as being metabolically healthy (MH) or metabolically unhealthy (MU) while having a body mass index (BMI) indicative of obesity, overweight, or normal weight. This study examines the prevalence of these phenotypes in adults, the factors associated with them, and their relationship with adverse health outcomes.

### Data and methods

Three cycles of the Canadian Health Measures Survey (from 2014 to 2019) were combined to characterize adults aged 20 to 79 years as MU if they had at least three out of five measures of elevated waist circumference, elevated triglycerides, reduced high-density lipoprotein cholesterol, elevated blood pressure, or elevated fasting glucose. Measured BMI, categorized as indicative of normal weight, overweight, or obesity, was combined with MH or MU to produce six joint phenotypes. Phenotype prevalence was examined across selected characteristics and separate multivariable logistic regression models estimated the association with self-reported health status and morbidity indicators.

### Results

One in four Canadian adults was either MU with obesity or MU with overweight. These phenotypes were more prevalent at older ages. Among MH adults, higher BMI was associated with worse self-rated general health. MU adults with obesity were 1.8 times more likely to report worse general health than MH adults with obesity. MU adults with obesity or with overweight were 1.2 times more likely to have higher levels of systemic inflammation than MH adults with obesity or overweight. Higher BMI, regardless of metabolic health, was associated with higher levels of systemic inflammation.

### Interpretation

Gaining insight into the population prevalence of metabolic health and BMI phenotypes and their association with health risks can help improve awareness and inform health promotion strategies.

### Keywords

body mass index, metabolic health, overweight, obesity, prevalence, adult, health surveys.

## AUTHORS

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### What is already known on this subject?

- Obesity is associated with increased morbidity, increased risk of long-term medical complications, high health care costs, and reduced life expectancy.
- Obesity is also associated with cardiometabolic abnormalities, including elevated waist circumference, elevated triglycerides, reduced high-density lipoprotein cholesterol, elevated blood pressure, and elevated fasting glucose.
- Joint phenotypes have been used to categorize people as being metabolically healthy (MH) or metabolically unhealthy (MU) while having a body mass index (BMI) indicative of obesity, overweight, or normal weight to better understand the interplay between adiposity and metabolic health and the associated risks of negative health outcomes.

### What does this study add?

- One in four Canadian adults is MU with obesity or with overweight, and these conditions are more common at older ages.
- Among MH adults, higher BMI is associated with poorer self-rated general health.
- MU adults with obesity report worse general health than MH adults with obesity.
- Higher BMI is associated with greater systemic inflammation, regardless of metabolic health.
- Adults who are MU with higher BMI show the highest levels of inflammation.

About one in four Canadian adults has a body mass index (BMI) indicative of obesity.<sup>1</sup> Obesity is a chronic complex disease defined by excessive adiposity that can impair health.<sup>2</sup> It is associated with reduced life expectancy; increased morbidity, including cancer and cardiovascular disease (CVD); and high health care costs.<sup>2,3</sup> Obesity is also associated with increased risk for CVD risk factors, such as type 2 diabetes, hypertension, and dyslipidemia.<sup>3</sup> These CVD risk factors result from impaired metabolic health, which is commonly defined as increased triglycerides, reduced high-density lipoprotein cholesterol (HDL-C), abdominal obesity, and elevated blood pressure (BP) or elevated fasting glucose.<sup>4,5</sup> Impaired metabolic health, in turn, is associated with increased risk of morbidity, including coronary heart disease,<sup>6</sup> cancer,<sup>7</sup> ocular diseases,<sup>8,9</sup> and fatty liver disease.<sup>10</sup>

The interplay between adiposity and metabolic health has been studied through joint phenotypes that categorize people as being metabolically healthy (MH) or metabolically unhealthy (MU) while having a BMI indicative of obesity, overweight, or normal weight.<sup>6,11-16</sup> Definitions of “metabolic health” in the literature are inconsistent and often include overlapping, but not identical, components of metabolic syndrome.<sup>17</sup> Some studies apply formal clinical definitions, while others use operational or modified versions, leading to varying population estimates of phenotype prevalence.<sup>4</sup> Liu et al. characterized metabolic health status based on the risk factors proposed by the International Diabetes Federation and the American Heart Association and National Heart, Lung, and Blood Institute.<sup>17</sup> They reported that 20% of adults in the United States were MH with overweight and 14% were MH with obesity, whereas 11% of adults were MU with overweight and 26% were MU with obesity.<sup>12</sup> Meanwhile, van Vliet-Ostapchouk et al. applied metabolic

health criteria proposed by the Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults<sup>18</sup> and reported age-standardized cohort-specific prevalence of MH obesity ranging from 2% for men and 12% for women in Finland to 19% of men and 21% of women in Italy.<sup>19</sup>

Studies have also found varying risk of negative health outcomes across phenotypes,<sup>20</sup> with systemic inflammation<sup>16</sup> and potential confounding factors, such as age, education,<sup>6</sup> smoking,<sup>21</sup> and physical activity<sup>3</sup> (PA), playing a role. Caleyachetty et al. reported that MH individuals with obesity had a higher risk of coronary heart disease, cerebrovascular disease, and heart failure than MH individuals with normal weight.<sup>14</sup> In their systematic review and meta-analysis, Kramer et al. concluded that compared with MH people with normal weight, people with obesity—even in the absence of metabolic abnormalities—were at increased risk of all-cause mortality and cardiovascular (CV) events.<sup>15</sup> However, Kip et al. suggested that the components of impaired metabolic health, and not higher BMI, are the main risk factors for an adverse CV event.<sup>16</sup>

Little is known about the population prevalence of these phenotypes and how they are associated with negative health outcomes in Canada. Using measured and self-reported data from the Canadian Health Measures Survey (CHMS), this study examines the prevalence of the phenotypes among adults aged 20 to 79 years, factors that may differentiate these phenotypes, and the association between the phenotypes and health status and morbidity indicators. Given that obesity is a costly public health issue that negatively affects physical and psychological health,<sup>2</sup> understanding who may be at additional risk owing to their metabolic health status can help inform health promotion strategies.

**Table 1**  
**Sample size and population characteristics, by sex, adults aged 20 to 79, Canada, excluding territories, 2014 to 2019**

	Total				Males				Females			
	Sample size	%	95% confidence interval		Sample size	%	95% confidence interval		Sample size	%	95% confidence interval	
			from	to			from	to			from	to
<b>Age group</b>												
20 to 79	4,588	100.0	...	...	2,341	50.1	49.7	50.6	2,247	49.9	49.5	50.3
20 to 39	1,471	35.9	35.0	36.8	751	36.7	35.9	37.5	720	35.2 †	33.9	36.5
40 to 59	1,520	38.0	37.4	38.6	783	38.0	37.3	38.6	737	38.1	37.2	39.0
60 to 79	1,597	26.0	25.6	26.5	807	25.3	24.8	25.9	790	26.7 †	26.2	27.3
<b>Metabolic health status</b>												
Metabolically healthy	3,321	73.3	70.4	76.0	1,669	72.6	69.3	75.7	1,652	74.0	70.0	77.6
Metabolically unhealthy	1,267	26.7	24.0	29.6	672	27.4	24.3	30.7	595	26.0	22.4	30.0
<b>Body mass index categories</b>												
Normal weight	1,465	33.7	30.7	36.8	612	29.1	25.5	32.9	853	38.3 †	34.8	42.0
Overweight	1,621	35.0	32.0	38.1	949	38.8	34.8	43.1	672	31.1 †	27.8	34.6
Obesity	1,502	31.3	28.4	34.4	780	32.1	27.6	36.9	722	30.6	27.3	34.1
<b>Components of impaired metabolic health</b>												
Elevated waist circumference	2,256	47.1	43.9	50.3	954	38.0	33.2	42.9	1,302	56.3 †	52.5	59.9
Elevated triglycerides	1,143	24.8	22.3	27.5	721	30.2	26.8	33.9	422	19.3 †	15.9	23.3
Reduced high-density lipoprotein cholesterol	1,246	25.6	22.8	28.6	546	22.5	20.0	25.1	700	28.8 †	24.5	33.5
Elevated blood pressure	1,484	30.5	28.0	33.1	826	33.7	30.4	37.1	658	27.3 †	24.2	30.6
Elevated fasting glucose	1,396	28.7	26.6	30.8	873	35.9	32.6	39.3	523	21.5 †	18.3	25.1
<b>Highest level of education</b>												
<b>Postsecondary graduate</b>												
No	1,221	29.9	27.1	32.9	625	31.8	28.6	35.1	596	28.1	24.3	32.2
Yes	3,334	70.1	67.1	72.9	1,694	68.2	64.9	71.4	1,640	71.9	67.8	75.7
<b>Health behaviours</b>												
<b>Daily smoker</b>												
Yes	544	14.5	12.6	16.7	319	19.5	16.5	22.8	225	9.5 †	7.5	12.1
No	4,028	85.5	83.3	87.4	2,017	80.5	77.2	83.5	2,011	90.5 †	87.9	92.5
<b>Met physical activity guidelines</b>												
No	2,001	43.6	39.3	48.0	933	40.2	35.5	45.1	1,068	46.9 †	41.3	52.7
Yes	2,571	56.4	52.0	60.7	1,401	59.8	54.9	64.5	1,170	53.1 †	47.3	58.7
<b>Health status</b>												
<b>General health</b>												
Poor or fair	530	10.6	9.2	12.2	266	12.0	10.0	14.3	264	9.3 †	7.6	11.2
Good, very good, or excellent	4,058	89.4	87.8	90.8	2,075	88.0	85.7	90.0	1,983	90.7	88.8	92.4
<b>Mental health</b>												
Poor or fair	364	8.0	6.9	9.3	157	7.0	5.6	8.8	207	9.0	7.0	11.4
Good, very good, or excellent	4,212	92.0	90.7	93.1	2,177	93.0	91.2	94.4	2,035	91.0	88.6	93.0
<b>Morbidity indicators</b>												
<b>Cardiovascular disease conditions</b>												
None	4,269	94.5	93.7	95.3	2,140	92.9	91.1	94.3	2,129	96.2 †	94.7	97.3
One or more	319	5.5	4.7	6.3	201	7.1	5.7	8.9	118	3.8 †	2.7	5.3
<b>Non-cardiovascular chronic conditions</b>												
None	2,849	65.6	62.7	68.3	1,577	68.0	63.8	71.9	1,272	63.1 †	60.2	65.9
One	1,154	23.7	20.9	26.8	553	24.0	20.5	28.0	601	23.4	20.3	26.7
Two or more	585	10.8	9.2	12.5	211	8.0	5.9	10.7	374	13.5 †	11.7	15.6
<b>Inflammation</b>												
Low	1,746	40.1	36.9	43.4	964	41.9	37.9	46.0	782	38.3	33.7	43.2
Moderate	1,683	37.1	34.5	39.8	881	39.3	35.3	43.5	802	34.9	31.3	38.7
High	1,078	22.7	20.6	25.0	462	18.8	15.7	22.4	616	26.8 †	24.2	29.5

... not applicable

† Indicates the difference between males and females statistically different from zero at  $p < 0.05$

**Notes:** Sample size is based on unweighted counts and proportion estimates produced using the combined survey weights for cycles 4, 5, and 6. Metabolic health status, body mass index categories, components of impaired metabolic health, and inflammation are based on measured data. All other data are self-reported.

**Source:** Statistics Canada, Canadian Health Measures Survey, 2014 to 2015, 2016 to 2017, and 2018 to 2019, combined.

## Data and methods

### Data

Data from Cycle 4 (January 2014 to December 2015), Cycle 5 (January 2016 to December 2017), and Cycle 6 (January 2018 to December 2019) of the CHMS were combined. The CHMS

is a cross-sectional survey that collects questionnaire data and directly measured health information from community-dwelling individuals aged 3 to 79 living in the 10 provinces. People living in the three territories or on reserves and settlements in the provinces, the institutionalized population, residents of certain remote regions, and full-time members of the Canadian Forces are excluded (about 4% of the Canadian population). The CHMS involves visiting a mobile examination

centre (MEC) following an in-person household interview. Prior to the household interview, some dwellings are randomly flagged to indicate that a respondent should fast for at least 10 hours before the MEC appointment. The household interview gathers detailed information on health, nutrition, and lifestyle. At the MEC, there is an interview, and direct physical measurements are taken— such as BP, height, and weight—and samples of blood and urine are collected.

Current medications are recorded during the household and clinic interviews and are assigned to codes from the Anatomical Therapeutic Chemical (ATC) classification system. Ethics approval for the CHMS was received from Health Canada’s Research Ethics Board.<sup>22</sup> Further information about the CHMS is available online.<sup>23</sup>

Those aged 20 to 79 years old who fasted prior to their visit to the MEC and were not pregnant at the time of data collection were eligible for this analysis: n=1,565 (Cycle 4), n=1,551 (Cycle 5), and n=1,569 (Cycle 6). Eligible respondents were excluded from the analysis if their BMI was less than 18.5 kg/m<sup>2</sup> or if it was not possible to derive a phenotype because of missing data for the components of impaired metabolic health (n=97). The final analytical sample sizes were n=1,528 (Cycle 4), n=1,523 (Cycle 5), and n=1,537 (Cycle 6) for a total analytical sample size of 4,588.

**Measures and definitions**

**Height:** Height was measured to the nearest 0.1 cm using a ProScale M150 digital stadiometer (Accurate Technology Incorporated, Fletcher, United States).

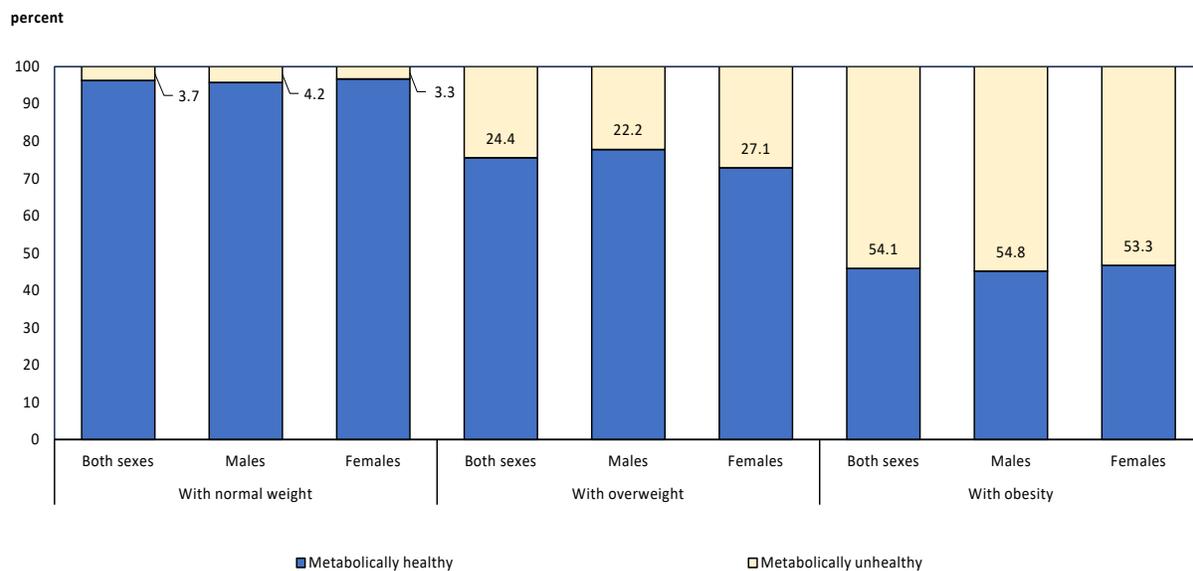
**Weight:** Weight was measured to the nearest 0.1 kg with a Mettler Toledo VLC with Panther Plus terminal scale (Mettler Toledo Canada, Mississauga, Canada).

**BMI:** BMI categories for respondents who reported being Korean, Filipino, Japanese, Chinese, South Asian, or Southeast Asian were defined as with normal weight (BMI of less than 23 kg/m<sup>2</sup>), overweight (BMI of 23 kg/m<sup>2</sup> to less than 25 kg/m<sup>2</sup>), or obesity (BMI of 25 kg/m<sup>2</sup> or greater).<sup>24</sup> BMI categories for the remaining respondents were defined as with normal weight (BMI of less than 25 kg/m<sup>2</sup>), overweight (BMI of 25 kg/m<sup>2</sup> to less than 30 kg/m<sup>2</sup>), or obesity (BMI of 30 kg/m<sup>2</sup> or greater).<sup>25</sup>

**BP:** Systolic BP (SBP) and diastolic BP (DBP) were measured with the BpTRU™ BPM-300 automated oscillometric device (BpTRU Medical Devices Ltd., Coquitlam, British Columbia) at the MEC. Six BpTRU™ readings were taken for each CHMS participant, with the last five averaged to determine the SBP and DBP levels.<sup>26</sup>

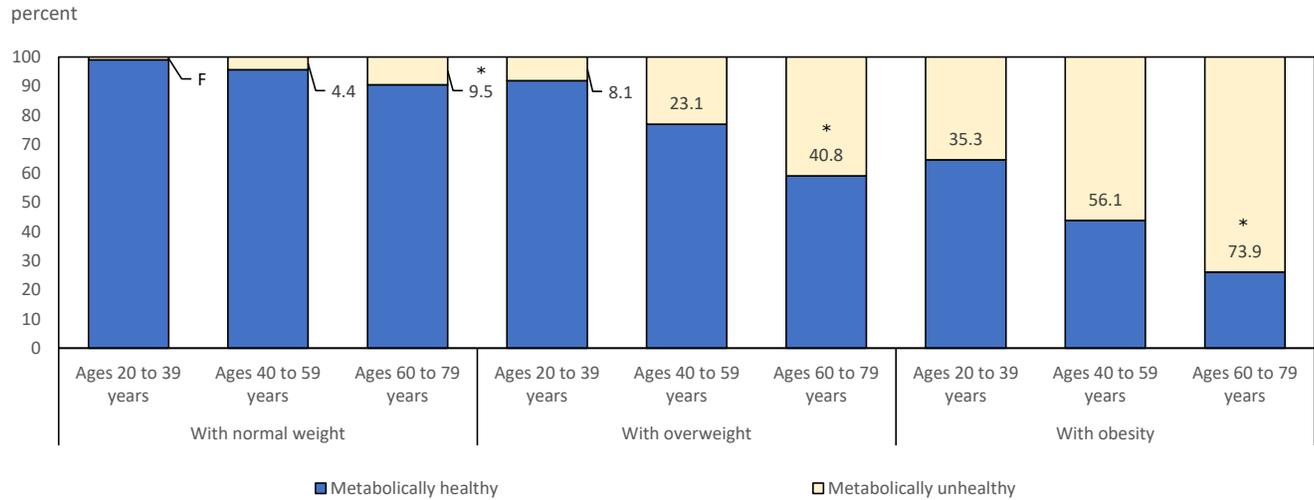
**Waist circumference (WC):** WC was measured to the nearest 0.1 cm, directly on the landmarked skin, with a flexible, inelastic measuring tape with an attached tension metre. The measure was taken at the highest point of the iliac crest.<sup>27</sup>

**Chart 1**  
**Prevalence of metabolically healthy and metabolically unhealthy individuals within body mass index categories, by sex, adults aged 20 to 79 years, Canada, excluding territories, 2014 to 2019**



**Notes:** Metabolic health status and body mass index categories are based on measured data.  
**Source:** Statistics Canada, Canadian Health Measures Survey, 2014 to 2015, 2016 to 2017, and 2018 to 2019, combined.

**Chart 2**  
**Prevalence of metabolically healthy and metabolically unhealthy individuals within body mass index categories, by age group, adults aged 20 to 79 years, Canada, excluding territories, 2014 to 2019**



F too unreliable to be published

\* linear test for trend across age groups statistically significant (p < 0.01)

Notes: Metabolic health status and body mass index categories are based on measured data.

Source: Statistics Canada, Canadian Health Measures Survey, 2014 to 2015, 2016 to 2017, and 2018 to 2019, combined.

Components of metabolic health: Based on the diagnostic risk factors for metabolic syndrome proposed by the International Diabetes Federation and the American Heart Association and National Heart, Lung, and Blood Institute, the following five criteria were included in this study as components of impaired metabolic health<sup>17</sup> and defined as follows:

1. Elevated WC for respondents who reported being South Asian, Chinese, Filipino, Southeast Asian, Korean, or Japanese was defined as 90 cm or greater for males and 80 cm or greater for females.<sup>17</sup> Elevated WC for the remaining respondents was defined as 102 cm or greater for males and 88 cm or greater for females.<sup>17</sup>
2. Elevated BP was defined as having SBP of 130 mmHg or greater or DBP of 85 mmHg or greater or taking medication in the past month corresponding to beta blockers (ATC codes in category C07, excluding C07AA07, C07AA12, and C07AG02), agents acting on the renin-angiotensin system (ATC codes in category C09), thiazide diuretics (ATC codes in category C03, excluding C03BA08 and C03CA01), calcium channel antagonists (ATC codes in category C08), or other antihypertensives (ATC codes in category C02, excluding C02KX01).<sup>17</sup>
3. Elevated triglycerides were defined as having triglycerides (measured in serum) of 1.7 mmol/L or greater or taking medication in the past month to treat

elevated triglycerides (fibrates: ATC codes in C10AB).<sup>17</sup>

4. Reduced HDL-C was defined as having HDL-C (measured in serum) less than 1.0 mmol/L in males and less than 1.3 mmol/L in females or taking medication in the past month for reduced HDL-C (nicotinic acid and derivatives: ATC codes in C04AC).<sup>17</sup>
5. Elevated blood glucose was defined as having fasting glucose (measured in serum) of 5.6 mmol/L or greater or taking medication in the past month to treat elevated glucose (ATC codes in A10).<sup>17</sup>

MH was defined as having two or fewer components of impaired metabolic health, consistent with the approach used by Liu et al.<sup>12</sup>

MU was defined as having at least three out of five components of impaired metabolic health, consistent with the approach used by Liu et al.<sup>12</sup>

Phenotypes refer to sets of characteristics that represent the interaction of genetic, environmental, and metabolic factors. Individuals were classified into six distinct phenotypes based on their combined metabolic health status and BMI category: (1) MH with normal weight, (2) MH with overweight, (3) MH with obesity, (4) MU with normal weight, (5) MU with overweight, and (6) MU with obesity.

**Table 2**  
**Proportion distribution of phenotypes, by sex, age group, highest level of education, smoking status, and physical activity, adults aged 20 to 79, Canada, excluding territories, 2014 to 2019**

	Metabolically healthy									Metabolically unhealthy								
	with normal weight			with overweight			with obesity			with normal weight			with overweight			with obesity		
	95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval		
	%	from	to	%	from	to	%	from	to	%	from	to	%	from	to	%	from	to
<b>Overall</b>	32.5	29.5	35.6	26.4	23.4	29.7	14.1	12.4	16.6	1.2	0.9	1.7	8.5	7.1	10.2	16.9	14.9	19.2
<b>Sex</b>																		
Male (ref.)	27.9	24.3	31.7	30.2	26.1	34.7	14.5	11.4	18.2	1.2	0.7	2.0	8.6	7.2	10.3	17.6	14.8	20.7
Female	37.1 *	33.4	40.9	22.6 *	19.1	26.6	14.3	11.8	17.1	1.3	0.8	2.1	8.4	6.2	11.4	16.3	13.8	19.1
<b>Age group</b>																		
20 to 39	44.3	39.0	49.8	24.3	19.5	29.9	18.7	14.3	23.6	F	...	...	F	...	...	10.2	7.6	13.5
40 to 59	27.4	23.3	31.9	30.0	24.5	36.1	14.2	11.1	17.9	1.3	0.7	2.2	9.0	6.8	11.8	18.1	14.2	22.9
60 to 79	23.5 <sup>§§</sup>	20.2	27.2	24.2	21.0	27.7	8.7 <sup>§§</sup>	6.7	11.2	2.5 <sup>§§</sup>	1.5	3.9	16.7 <sup>§§</sup>	13.8	19.9	24.5 <sup>§§</sup>	20.8	28.7
<b>Postsecondary graduate</b>																		
No (ref.)	30.2	25.8	34.9	25.9	21.1	31.3	12.5	9.2	16.9	0.8	0.4	1.4	10.2	7.7	13.3	20.4	16.8	24.7
Yes	33.3	30.0	36.8	26.9	23.6	30.5	15.2	12.6	18.2	1.2	0.9	1.8	7.9	6.3	9.9	15.4 *	12.9	18.3
<b>Smoker</b>																		
Yes (ref.)	33.0	26.6	40.0	22.6	16.3	30.4	15.0	8.1	26.1	1.7	0.7	3.8	11.4	7.3	17.4	16.4	12.3	21.5
No	32.4	28.9	36.0	27.2	24.2	30.3	14.3	12.7	16.1	1.2	0.8	1.7	8.1	6.6	9.8	16.9	14.7	19.4
<b>Met physical activity guidelines</b>																		
No (ref.)	29.8	25.1	35.0	24.2	19.9	29.2	14.0	11.6	16.8	1.3	0.8	2.1	9.0	6.7	12.0	21.6	18.5	25.1
Yes	34.7	31.7	37.8	28.4	24.4	32.7	14.3	11.6	17.4	1.2	0.7	1.8	8.0	6.4	10.1	13.5 *	10.8	16.8

F too unreliable to be published

... not applicable

\* significantly different from reference category (p < 0.05)

<sup>§§</sup> linear test for trend across age group statistically significant (p < 0.01)

**Notes:** Sample sizes (n) in each phenotype: metabolically healthy with normal weight, n=1,402; metabolically healthy with overweight, n=1,254; metabolically healthy with obesity, n=665; metabolically unhealthy with normal weight, n=63; metabolically unhealthy with overweight, n=367; and metabolically unhealthy with obesity, n=837. Phenotypes are based on measured data. All other data are self-reported.

**Source:** Statistics Canada, Canadian Health Measures Survey, 2014 to 2015, 2016 to 2017, and 2018 to 2019, combined.

### Covariates

Sex at birth (male or female) and age in years were reported at the visit to the MEC.

Age groups were 20 to 39 years, 40 to 59 years, and 60 to 79 years. The highest level of education of the respondent was categorized into postsecondary graduate or not (yes or no). Smoking status was categorized into current daily smoker or not (yes or no). Self-reported total minutes per week of PA were categorized into meeting the PA guidelines of 150 minutes of activity per week or not (yes or no).

### Health status and morbidity indicators

Self-rated general and mental health were each dichotomized by combining fair and poor into one category and good, very good, and excellent into the other. CVD conditions included self-reported heart disease, history of heart attack, and history of stroke and were dichotomized into none and one or more. Non-CV chronic conditions that have been linked to impaired metabolic health, obesity, or both were selected from self-reported, diagnosed long-term conditions expected to last (or that had already lasted) six months or more, including asthma,<sup>28,29</sup> arthritis,<sup>30</sup> osteoporosis,<sup>31,32</sup> cancer,<sup>7,33</sup> liver or gallbladder disease,<sup>34</sup> inflammatory bowel disease (cycles 5 and 6 only),<sup>35,36</sup> glaucoma<sup>8</sup> (cycles 5 and 6 only), and cataracts

(cycles 5 and 6 only).<sup>9</sup> These were summed and categorized into none, one, or two or more. For the regression analysis, this variable was dichotomized into at least one non-CV chronic condition or none (yes or no). High sensitivity C-reactive protein (hs-CRP) (measured in serum) was selected as a biomarker of systemic inflammation and classified into three categories: low (less than 1 mg/L, which is the desirable level), moderate (1 mg/L to 3 mg/L), or high (greater than 3 mg/L).<sup>37</sup> Respondents who had hs-CRP values below the limit of detection (n=139) were assigned to the low category. Respondents who had hs-CRP values above the analytical range (n=61) were treated as missing. For the regression analysis, inflammation was dichotomized into moderate to high (1 mg/L or greater) or not (yes or no).

### Statistical analysis

All analyses were done using cycles 4, 5, and 6 combined. Proportions, means, and 95% confidence intervals (CIs) were estimated to examine the prevalence of components of impaired metabolic health, BMI categories, highest level of education, health behaviours (smoking status, meeting PA guidelines), and health status and morbidity indicators by sex. The proportion distribution of phenotypes was estimated across sexes, age groups, highest levels of education, and health behaviours. The prevalence of health status (general health, mental health) and morbidity indicators (CVD conditions, non-CV chronic

conditions, inflammation) was estimated across the phenotypes. Separate multivariable logistic regression models were used to estimate the association between the phenotypes and the health status and morbidity indicators except CVD conditions—underlying sample sizes were too small for this indicator—while adjusting for sex, age group, education, smoking status, meeting PA guidelines, and CHMS cycle. In each model, listwise deletion exclusions were n=64 (general health), n=75 (mental health), n=64 (non-CV chronic conditions), and n=145 (inflammation), respectively. Adjusted health status and morbidity prevalence estimates, prevalence differences, prevalence ratios, and their 95% CIs across phenotypes were estimated from each model by calculating mean marginal effects, adjusted for covariates.

All estimates were weighted by using the combined survey weights for cycles 4, 5, and 6, and the sampling variance was calculated by using the combined bootstrap weights for these cycles. Statistical significance of t-tests, linear tests for trend, and model parameters were assessed at p < 0.05, with n multiple comparisons assessed at p < (0.05/n). All analyses were conducted in SAS 9.4 and SAS-callable SUDAAN 11.0.3.

## Results

While 27% of adults aged 20 to 79 were classified as MU, 35% of adults were classified with overweight, and 31% with obesity (Table 1). Elevated WC was the most prevalent component of impaired metabolic health (47%), followed by elevated BP (31%), elevated fasting glucose (29%), reduced HDL-C (26%), and elevated triglycerides (25%). A higher proportion of males than females were classified with overweight, had elevated triglycerides, had elevated BP, had elevated fasting glucose, were a daily smoker, reported poor or fair general health, or reported one or more CVD conditions. Conversely, a higher proportion of females than males were classified with normal weight, had an elevated WC or reduced HDL-C, reported they had not met PA guidelines, had two or more non-CV chronic conditions, or had high levels of inflammation.

### Metabolic health by body mass index category

Just under 4% of adults with normal weight were MU, 24% of adults with overweight were MU, and 54% of adults with obesity were MU, with minimal differences between males and females (Chart 1). The prevalence of being MU in all BMI categories was higher in older age groups (Chart 2). For example, among adults with obesity, 35% of those aged 20 to 39 years were MU versus 74% of those aged 60 to 79 years (linear test for trend p<0.01).

**Table 3**  
Prevalence of health status and morbidity indicators, by phenotype, adults aged 20 to 79, Canada, excluding territories, 2014 to 2019

	Metabolically healthy						Metabolically unhealthy											
	with normal weight		with overweight		with obesity		with normal weight		with overweight		with obesity							
	95% confidence interval		95% confidence interval		95% confidence interval		95% confidence interval		95% confidence interval		95% confidence interval							
	%	from	to	%	from	to	%	from	to	%	from	to	%	from	to			
<b>Health status</b>																		
<b>General health</b>																		
Poor or fair	4.8	3.4	6.6	8.1	5.5	11.8	10.8	6.8	16.5 <sup>§</sup>	17.5	6.1	41.1	16.6 <sup>†</sup>	11.9	22.6	22.2 <sup>†</sup>	17.5	27.8
Good, very good, or excellent	95.2	93.4	96.6	91.9	88.2	94.5	89.2	83.5	93.2 <sup>§</sup>	82.5	58.9	93.9	83.4 <sup>†</sup>	77.4	88.1	77.8 <sup>†</sup>	72.2	82.5
<b>Mental health</b>																		
Poor or fair	8.5	6.3	11.2	6.0	3.9	9.3	8.1	5.2	12.5	9.7	2.8	28.4	7.2	3.5	14.3	10.4	7.3	14.7
Good, very good, or excellent	91.5	88.8	93.7	94.0	90.7	96.1	91.9	87.5	94.8	90.3	71.6	97.2	92.8	85.7	96.5	89.6	85.3	92.7
<b>Morbidity</b>																		
<b>Cardiovascular disease conditions</b>																		
None	97.3	96.1	98.2	95.6	93.7	97.0	96.4	92.5	98.4	F	...	...	84.8 <sup>†</sup>	79.7	88.9	91.3 <sup>†</sup>	89.1	93.1
One or more	2.7	1.8	3.9	4.4	3.0	6.3	3.6	1.6	7.5	F	...	...	15.2 <sup>†</sup>	11.1	20.3	8.7 <sup>†</sup>	6.9	10.9
<b>Non-cardiovascular chronic conditions</b>																		
None	70.8	66.1	75.1	66.4	59.7	72.4	73.7	64.7	81.1	60.6	45.9	73.6	55.4 <sup>†</sup>	47.2	63.4	52.8 <sup>†</sup>	46.1	59.3
One	20.2	15.3	26.1	23.9	18.0	31.0	17.3	12.0	24.3	22.9	11.9	39.5	30.6 <sup>†</sup>	24.9	37.0	32.1 <sup>†</sup>	27.5	37.1
Two or more	9.0	6.9	11.6	9.7	7.5	12.5	9.0	5.7	14.0	16.5	8.1	30.5	13.9	9.6	19.7	15.1 <sup>†</sup>	11.7	19.3
<b>Inflammation</b>																		
Low	62.1	57.2	66.7	42.5	37.5	47.8	27.7	21.2	35.3 <sup>§§</sup>	33.3 <sup>†</sup>	16.5	55.6	26.2 <sup>†</sup>	17.6	37.2	11.5 <sup>†</sup>	8.3	15.8 <sup>§</sup>
Moderate	28.5	24.5	32.8	40.6	35.6	45.9	33.4	23.7	44.6	54.8 <sup>†</sup>	33.5	74.5	55.6 <sup>†</sup>	45.3	65.5	40.9	34.1	48.1
High	9.5	7.2	12.4	16.8	13.1	21.4	38.9	30.1	48.5 <sup>§§</sup>	11.9	4.3	29.3	18.2	12.8	25.2	47.6	41.0	54.2 <sup>§§</sup>

F too unreliable to be published

... not applicable

<sup>§</sup> linear test for trend across body mass index categories within metabolically healthy phenotypes or within metabolically unhealthy phenotypes statistically significant (p < 0.05)

<sup>§§</sup> linear test for trend across body mass index categories within metabolically healthy phenotypes or within metabolically unhealthy phenotypes statistically significant (p < 0.01)

<sup>†</sup> significantly different from metabolically healthy adults in the same body mass index category (p < 0.05)

**Notes:** Phenotypes and inflammation are based on measured data. All other data are self-reported.

**Source:** Statistics Canada, Canadian Health Measures Survey, 2014 to 2015, 2016 to 2017, and 2018 to 2019, combined.

**Table 4**  
**Model-adjusted prevalence of health status and morbidity indicators across phenotypes, adults 20 to 79 years, Canada, excluding territories, 2014 to 2019**

	Adjusted prevalence								
	%	95% confidence interval		Difference (%)	95% confidence interval		Ratio	95% confidence interval	
		from	to		from	to		from	to
<b>Poor or fair general health</b>									
MH with normal weight (ref.)	5.0	3.7	6.8	...	...	...	1.0	...	...
MH with overweight	8.2	5.7	11.5	3.1 *	0.6	5.7	1.6	1.1	2.4
MH with obesity	11.4 <sup>§§</sup>	7.3	17.4	6.4 *	1.4	11.4	2.3	1.4	3.8
MU with normal weight	11.6	3.5	32.4	6.6	-4.9	18.1	2.3	0.9	6.3
MU with overweight	14.3	9.4	21.2	9.3 †	3.4	15.3	2.9	1.7	4.9
MU with obesity	20.5	15.4	26.8	15.5 †	9.7	21.2	4.1	2.7	6.3
<b>Poor or fair mental health</b>									
MH with normal weight (ref.)	8.2	6.1	10.9	...	...	...	1.0	...	...
MH with overweight	6.0	4.0	9.1	-2.1	-5.9	1.7	0.7	0.4	1.5
MH with obesity	7.8	4.7	12.7	-0.4	-4.6	3.8	1.0	0.5	1.8
MU with normal weight	11.7	2.3	43.4	3.6	-10.5	17.7	1.4	0.4	5.6
MU with overweight	7.5	3.5	15.5	-0.6	-6.3	5.0	0.9	0.4	2.2
MU with obesity	10.1	6.9	14.6	1.9	-2.6	6.4	1.2	0.7	2.2
<b>At least one non-cardiovascular chronic condition</b>									
MH with normal weight (ref.)	33.1	28.2	38.3	...	...	...	1.0	...	...
MH with overweight	34.3	28.9	40.1	1.2	-6.4	8.8	1.0	0.8	1.3
MH with obesity	31.4	23.1	41.1	-1.7	-11.1	7.8	1.0	0.7	1.3
MU with normal weight	31.2	21.3	43.3	-1.8	-13.7	10.1	0.9	0.6	1.4
MU with overweight	31.4	25.6	37.9	-1.6	-9.2	5.9	1.0	0.7	1.2
MU with obesity	41.2	35.0	47.5	8.1	-0.1	16.3	1.2	1.0	1.6
<b>Moderate-to-high inflammation</b>									
MH with normal weight (ref.)	37.7	32.9	42.9	...	...	...	1.0	...	...
MH with overweight	58.6	53.4	63.7	20.9 †	14.7	27.1	1.6	1.4	1.8
MH with obesity	73.7 <sup>§§</sup>	65.5	80.4	35.9 †	27.9	43.9	2.0	1.7	2.3
MU with normal weight	61.5	33.2	83.7	23.8	-0.3	47.8	1.6	1.1	2.5
MU with overweight	71.8	59.4	81.6	34.0 †	21.6	46.5	1.9	1.5	2.4
MU with obesity	87.8 <sup>§§</sup>	82.9	91.5	50.1 †	44.8	55.3	2.3	2.1	2.6

...not applicable

\* significantly different from reference category (p < 0.05)

† significantly different from reference category when adjusted for multiple comparisons (p < 0.01)

§§ linear test for trend across body mass index categories within metabolically healthy phenotypes or within metabolically unhealthy phenotypes statistically significant (p < 0.01)

**Notes:** MH =metabolically healthy, MU = metabolically unhealthy. Sex, age group, education, smoking status, meeting physical activity guidelines, and Canadian Health Measures Survey cycle were included in each model. At least one cardiovascular disease condition was not modelled as underlying sample sizes were too small for this indicator. Phenotypes and inflammation are based on measured data. All other data are self-reported.

**Source:** Statistics Canada, Canadian Health Measures Survey, 2014 to 2015, 2016 to 2017, and 2018 to 2019, combined.

### Prevalence of phenotypes

About 73% of adults were categorized as MH, distributed across BMI groups as MH with normal weight (33%), with overweight (26%), and with obesity (14%) (Table 2). The 27% of adults categorized as MU were distributed across BMI groups as MU with normal weight (1%), with overweight (9%), and with obesity (17%). The prevalence of being MH with normal weight was higher among females (37%) than males (28%), and the prevalence of being MH with overweight was lower (23% among females versus 30% among males). Among older age groups, the prevalence of being MH with normal weight and being MH with obesity was lower, whereas the prevalence of all MU phenotypes was higher (linear test for trend p<0.01). Among postsecondary graduates, the prevalence of being MU with obesity was lower compared with those who were not postsecondary graduates. The prevalence of being MU with obesity was also lower among those who reported meeting PA guidelines versus those who reported not meeting them.

### Health status across phenotypes

Poor or fair general health prevalence was greater with higher BMI among MH adults (Table 3). It was higher among MU adults with overweight (17% [95% CI: 12%, 23%]) compared with MH adults with overweight (8% [95% CI: 6%, 12%]), and also higher among MU adults with obesity (22% [95% CI: 18%, 28%]) compared with MH adults with obesity (11% [95% CI: 7%, 17%]).

### Morbidity across phenotypes

The prevalence of one or more CVD conditions was higher among MU adults with overweight (15% [95% CI: 11%, 20%]) than among MH adults with overweight (4% [95% CI: 3%, 6%]) and higher among MU adults with obesity (9% [95% CI: 7%, 11%]) compared with MH adults with obesity (4% [95% CI: 2%, 8%]) (Table 3). There was also a higher prevalence of at least one non-CV condition among MU adults with obesity

than among MH adults with obesity. The prevalence of low inflammation was lower for each MU phenotype compared with its MH counterpart. High inflammation was more prevalent among both MH and MU adults with higher BMI (linear test for trend  $p < 0.01$ ).

### Model-adjusted prevalence of negative health indicators across phenotypes

After adjusting for sex, age group, education, smoking status, meeting PA guidelines, and CHMS cycle, model-adjusted prevalence of poor or fair general health was greater at higher BMI categories for MH adults (Table 4). The model-adjusted prevalence of moderate-to-high inflammation was greater at higher BMI categories for both MH and MU adults, reaching 74% (95% CI: 66%, 80%) for MH adults with obesity and 88% (95% CI: 83%, 92%) for MU adults with obesity. There was minimal difference across the phenotypes in model-adjusted poor or fair mental health. Excluding smoking status and meeting PA guidelines from the models—given their potential causal association with both the phenotypes and the health status and morbidity indicators—did not affect the results (data not shown).

Compared with MH adults with normal weight, MU adults with overweight were 2.9 times (95% CI: 1.7, 4.9) more likely and MU adults with obesity were 4.1 times (95% CI: 2.7, 6.3) more likely to report poor or fair general health (Table 4). Except for MU adults with normal weight, adults in all other phenotypes were 1.6 times (95% CI: 1.4, 1.8) to 2.3 times (95% CI: 2.1, 2.6) more likely to have moderate-to-high inflammation than MH adults with normal weight.

When the model-adjusted prevalence of negative health outcomes for MU versus MH adults was examined within BMI categories, MU adults with obesity were 1.8 times more likely (95% CI: 1.1, 3.0) to report poor or fair general health compared with MH adults with obesity (Figure 1). MU adults with normal weight were 1.6 times (95% CI: 1.1, 2.5) more likely, MU adults with overweight were 1.2 times (95% CI: 1.0, 1.5) more likely, and MU adults with obesity were 1.2 times (95% CI: 1.1, 1.3) more likely than each of their MH counterparts to have moderate-to-high inflammation.

## Discussion

This study examined the association between metabolic health status and BMI categories, estimated the population prevalence of the joint phenotypes, and examined the prevalence of selected negative health indicators according to these phenotypes among adults in Canada. Having defined MU as the presence of at least three out of five of elevated WC, elevated triglycerides, reduced HDL-C, elevated BP, and elevated fasting glucose, this study found that MU was associated with higher BMI and with older age, and that about one in four adults were categorized as MU. The prevalence of the phenotypes

differed significantly by age, and the prevalence of poor or fair general health and systemic inflammation varied by phenotype.

Results showed that the prevalence of being MU was higher among adults in higher BMI categories, with just over half of all adults classified with obesity also defined as MU. The proportion of MU adults was higher with age, for all BMI categories, resulting in almost three out of four adults aged 60 to 79 with obesity being MU. These findings are consistent with those of others who have reported a positive association between the components of impaired metabolic health and obesity<sup>12,38,39</sup> and found that these components, regardless of obesity, become more prevalent with age.<sup>40</sup>

The adults categorized as MU were distributed across BMI groups as MU with normal weight (1%), with overweight (9%), and with obesity (17%). A study using National Health and Nutrition Examination Survey (NHANES) data from 2017/2018 with the same adult phenotype criteria reported similar proportions of MU adults with normal weight (2%) and with overweight (11%) but a higher proportion of MU adults with obesity (26%).<sup>12</sup> This latter result likely reflects the higher overall obesity prevalence reported in that study (41%) compared with the present study (31%); this is consistent with adult obesity rates being historically higher in the United States than in Canada.<sup>41</sup> The proportions of MH adults with normal weight and with overweight in the present study were higher than in the NHANES study—33% of MH adults with normal weight in this study versus 25% in the NHANES study and 26% of MH adults with overweight in this study versus 20% in the NHANES study. However, the proportion of MH adults with obesity was the same (14%), and both studies showed a similar trend, with higher prevalence of MU phenotypes at older age groups.

Compared with MH adults with normal weight—the suggested reference phenotype<sup>15</sup>—this study found that MU adults with overweight and with obesity were more likely to report poor or fair general health—three times more likely for those with overweight and four times more likely for those with obesity. Poor self-rated health increases the risk of mortality. In longitudinal studies, it predicted not only all-cause mortality but mortality from ischaemic heart diseases and cerebrovascular diseases.<sup>42</sup>

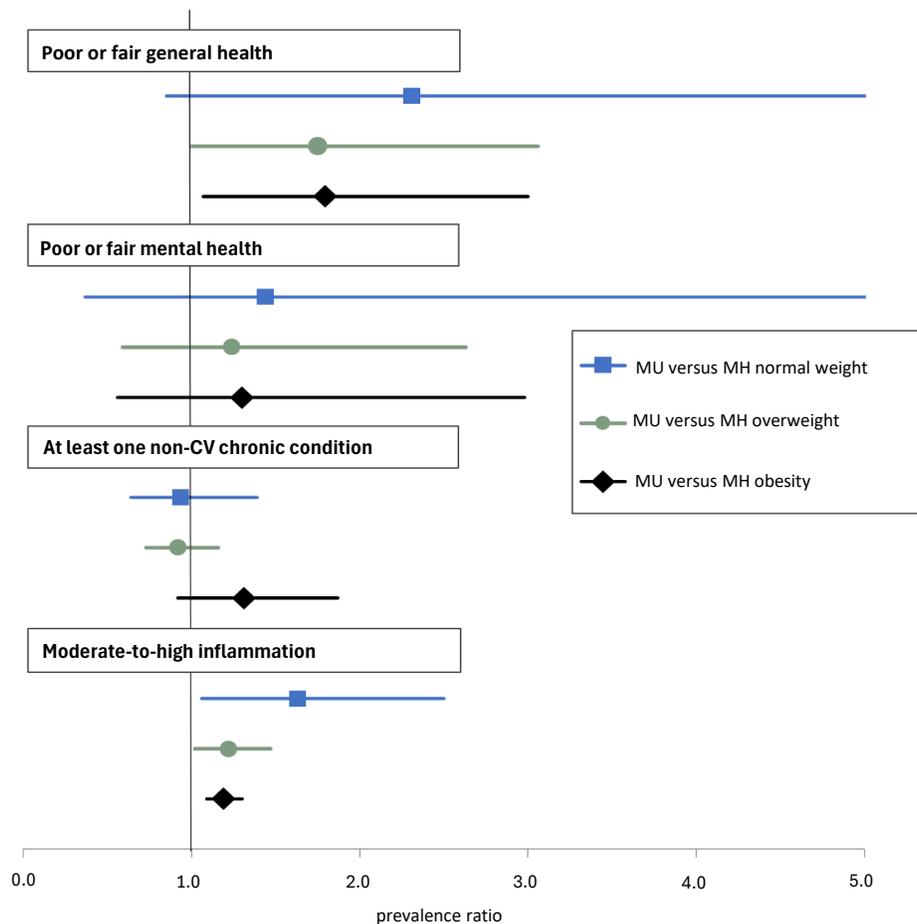
Systemic inflammation is a key mechanism driving atherosclerotic CVD.<sup>43</sup> By categorizing hs-CRP—a blood biomarker of systemic inflammation<sup>43</sup>—into categories of inflammation, the current study found that adults with higher BMI were more likely to have moderate-to-high inflammation regardless of metabolic health status. Moreover, MU adults with overweight or obesity had an even higher likelihood of moderate-to-high inflammation compared with their MH counterparts. These results align with previous observations that higher BMI and metabolic ill health are associated with higher inflammatory activity.<sup>43,44</sup> While it is not surprising that the combination of obesity and MU had the highest model-adjusted prevalence of moderate-to-high inflammation—9 out of 10 MU adults with obesity—almost 4 in 10 MH adults with normal

weight did as well. Given that elevated levels of inflammatory markers are associated with increased risk of CVD,<sup>44,45</sup> these results suggest that regardless of BMI, metabolic health and biomarkers of inflammation should also be examined when assessing health status.

This study has several strengths. The results are based on a representative sample of adults, which produced robust population estimates of the phenotypes. Height, weight, and the components of metabolic health were measured objectively using systematic methodologies. Because the CHMS data are cross-sectional, duration in a particular phenotype was unknown. Studies suggest phenotype membership is not static and that, in particular, MH people at higher BMIs are at increased risk of becoming MU over time.<sup>4,39</sup> However, others have suggested that current BMI—as used in this study—better reflects CV and metabolic risk than time spent in a BMI category.<sup>46</sup>

Certain limitations of this study should be considered. Systemic inflammation is on the causal pathway of developing metabolic abnormalities<sup>44</sup> and is associated with excess visceral fat.<sup>43</sup> Thus, the observed association between the phenotypes and moderate-to-high inflammation in the current study is likely bidirectional. Fat mass distribution—which is associated with metabolic health<sup>4</sup>—was not measured in the CHMS. Additional behaviours on the pathway between obesity, metabolic health, and health status and morbidity, such as diet quality or alcohol consumption, were not examined in this study. Small sample sizes prevented comparisons of sex and age group associations between the phenotypes and the health indicators, examination of model-adjusted prevalence of CVD, or analysis of specific population groups. Finally, the findings of this study should be considered in the context of the chosen definition of metabolic health.

**Figure 1**  
**Model-adjusted prevalence ratios for health status and morbidity indicators, metabolically unhealthy versus metabolically healthy individuals in each body mass index category, adults aged 20 to 79 years, Canada, excluding territories, 2014 to 2019**



**Notes:** MU = metabolically unhealthy, MH = metabolically healthy, non-CV = non-cardiovascular. Errors bars indicate the 95% confidence interval for the prevalence ratio. Phenotypes and inflammation are based on measured data.  
**Source:** Statistics Canada, Canadian Health Measures Survey, 2014 to 2015, 2016 to 2017 and 2018 to 2019, combined.

**Conclusion**

By examining the interplay between BMI and metabolic health, this study produced the first population-level estimates of these joint phenotypes among adults in Canada. MU adults with obesity had the highest prevalence of systemic inflammation and were more likely to report poor or fair general health than MH adults with normal weight. Adults in all BMI categories who were MU had a higher prevalence of systemic inflammation than their MH counterparts. With poor self-reported health and inflammation shown to increase the

likelihood of CVD morbidity and mortality, the results of this study provide a better understanding of phenotype prevalence and the related health risks. In turn, this can enhance awareness and inform health promotion strategies. National longitudinal data, which include metabolic health and BMI linked to health service use and death data, would help provide further insight into the association between obesity, metabolic health status, morbidity, and mortality risk in Canada.

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