Catalogue no. 82-003-X
ISSN 1209-1367

Health Reports

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Release date: October 16, 2024

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From BpTRU to OMRON: The impact of changing automated blood pressure measurement devices on adult population estimates of blood pressure and hypertension

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DOI: https://www.doi.org/10.25318/82-003-x202401000001-eng

ABSTRACT

Background

In Cycle 7 (2022), the Canadian Health Measures Survey (CHMS) introduced the OMRON (OM) IntelliSense HEM-907XL blood pressure (BP) monitor after using the BpTRU (BT) BPM-300 BP monitor for six cycles. This study assessed differences between adult BP values measured by both devices and whether equations could be developed to compare BP measurements taken using the two devices.

Data and methods

In Cycle 6 (2018 to 2019) of the CHMS, BP was measured using BT and OM devices. Between-device estimates of systolic BP (SBP), diastolic BP (DBP), and hypertension prevalence were compared for 1,072 adults aged 18 to 79 years. Sex, age, body mass index (BMI), and the use of antihypertensive medication were examined in linear regression models to predict SBP and DBP values measured with OM based on those measured with BT.

Results

Average SBP measured with OM was 6 millimetres of mercury (mmHg) higher than average SBP measured with BT, and average DBP measured with OM was 2 mmHg lower than DBP measured with BT. Hypertension prevalence based on OM readings was 35.4%, compared with 34.0% based on BT readings. Between-device BP differences varied in magnitude by sex, age group, and BMI category. Average model-predicted estimates of BP were comparable to measured estimates, but predicted values were lower at higher levels of BP.

Interpretation

Switching BP monitors will substantively affect population estimates of adult SBP and DBP but may have less impact on estimates of adult hypertension prevalence. The prediction equations proposed in this study can be applied to adult BP data from cycles 1 to 6 of the CHMS for comparison with BP measurements taken in Cycle 7, with some caveats. The impact of changing to the OM monitor in Cycle 7 should be acknowledged when reporting estimates of adult BP based on the CHMS.

Keywords

Blood pressure measurement, crossover study, automated sphygmomanometers, hypertension, prevalence.

AUTHORS

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What is already known on this subject?

- Hypertension affects close to one in four adult Canadians and is a risk factor for chronic disease such as cardiovascular, cerebrovascular, and renovascular diseases.
- Blood pressure (BP) measurement can vary across methods and devices. Thus, ongoing surveillance via population health surveys may be hampered when the measurement device is changed.
- In Cycle 7, the Canadian Health Measures Survey (CHMS) introduced the OMRON (OM) IntelliSense HEM-907XL BP monitor after six cycles of using the BpTRU (BT) BPM-300 BP monitor.

What does this study add?

- This study compares BP measurements taken by the OM and BT devices on a sample of adult individuals aged 18 to 79 years during a single visit to the mobile examination centre in Cycle 6 of the CHMS.
- Average systolic BP (SBP) measured with OM was 6 millimetres of mercury (mmHg) higher than average SBP measured with BT, and average diastolic BP (DBP) measured with OM was 2 mmHg lower than DBP with BT in the study sample.
- Average hypertension prevalence based on BP measured with OM was 1.4 percentage points higher than hypertension prevalence based on BP measured with BT.
- The prediction equations proposed in this study can be applied to adult BP data from cycles 1 to 6 for comparison with BP measurements in Cycle 7, with some caveats.
- The change in BP monitor will substantively affect population estimates of adult SBP and DBP but may have less impact on estimates of adult hypertension prevalence. The impact of changing to OM in Cycle 7 should be acknowledged when reporting estimates of adult BP based on the CHMS.

Hypertension is common in Canada, affecting almost one-quarter of the adult population aged 20 to 79 years.[1] It is an important modifiable risk factor for chronic disease and associated with increased risk of morbidity and mortality.[2] Ongoing surveillance via population health surveys is necessary to monitor and assess the population burden of hypertension in Canada.

Approximately one in five Canadian adults with hypertension is unaware of their condition,[1] and self-reported blood pressure (BP) tends to underestimate the prevalence of hypertension.[3] Since 2007, the Canadian Health Measures Survey (CHMS) has used validated, standardized automated BP measurement[4] to monitor systolic BP (SBP), diastolic BP (DBP), and the prevalence of hypertension in the population.

The BpTRU (BT) BPM-300 BP monitor was used for cycles 1 to 6 (2007 to 2019) of the CHMS for BP measurement. However, a replacement device was needed after BT ceased operations in 2017. After consultation with experts and other national health surveys, the validated OMRON (OM) IntelliSense HEM-907XL BP monitor[5] was chosen for BP measurement starting in Cycle 7. Because BP measurement can vary across methods and devices,[6-8] a crossover study was implemented in Cycle 6 to compare measurements taken by the two devices on the same individuals aged 6 to 79 years.

This analysis estimates SBP, DBP, and hypertension prevalence based on measurements from BT and OM devices and compares differences across selected characteristics for adults aged 18 to 79 years. It also assesses the feasibility of developing prediction equations so BP data from earlier CHMS cycles can be compared with BP estimates from Cycle 7 onward. The crossover study data for children and youth aged 6 to 17 years were analyzed with the same objectives, and the results have been published separately.[9]

Data and methods

Data

Data are from Cycle 6 of the CHMS, a nationally representative cross-sectional survey that collects questionnaire and directly measured health information from community-dwelling individuals aged 3 to 79 years living in the 10 provinces. People living in the three territories or on reserves or Indigenous 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 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 information on health, nutrition, medication

use, and lifestyle. At the MEC, direct physical measurements are taken, including BP, height, and weight. More information about the CHMS is available online.[10]

Crossover study protocol

Cycle 6 of the CHMS (January 2018 to December 2019) collected automated digital BP measurements from all respondents using the BT BPM-300 BP monitor (BpTRU Medical Devices Limited, Coquitlam, British Columbia). The BT monitor takes six readings, with a one-minute interval between the beginning of each consecutive measurement, and averages the last five to determine SBP and DBP levels.[11] Crossover study respondents also had their BP measured using the OM IntelliSense HEM-907XL BP monitor (OMRON Healthcare Incorporated, Vernon Hills, Illinois). Average mode was used, in which the OM monitor takes three readings, each one minute apart, and averages all three to determine SBP and DBP levels.[12]

The last eight sites in Cycle 6 were available for the crossover study. The number of sites and the target sample sizes were selected to ensure that differences in the devices could be measured for each age group independently: ages 6 to 19 years, two sites (n=154); ages 20 to 39 years, four sites (n=210); ages 40 to 59 years, six sites (n=338); and ages 60 to 79 years, eight sites (n=491). Respondents in the crossover study were randomly assigned to have their measurements taken with BT or OM first, based on whether their randomly generated identification number was even or odd.

A health measures specialist (HMS) or a medical radiation technologist (MRT) trained in BP measurement explained the protocol of the crossover study to the respondent at the MEC. The HMS or MRT measured the respondent's mid-arm circumference for cuff placement and selected the appropriate cuff size for each BP monitor. The cuff for the monitor to be used first was then placed on the respondent's arm. If the BT monitor was used first, the respondent was left alone for a five-minute rest period, after which the HMS or MRT returned to the room. The HMS or MRT then pressed start, remained for the first reading, then left the room for approximately five minutes while the BT monitor took the remaining five readings. If the OM monitor was used first, the HMS or MRT pressed start to activate the five-minute timer on the machine then left and returned to the room after approximately nine minutes. During this time, the OM monitor automatically took three readings following the five-minute rest period. No additional five-minute rest period was used after the first BP monitor, and the HMS or MRT did not speak to the respondent or move the respondent's position while changing the cuff and starting the protocol for the second BP monitor.

Age group targets were surpassed during collection, resulting in 1,341 crossover study respondents with valid BP measurements from OM and BT devices. Those aged 18 to 79 years were eligible for this analysis, a total of 1,104 respondents. Less than 3% of eligible respondents were excluded from the analysis for the following reasons: having a difference between their average BP reading from BT and OM devices over three standard deviations from the overall mean difference (SBP and DBP, n=1; SBP only, n=6; and DBP only, n=13), being pregnant (n=4), or having insufficient data to derive body mass index (BMI) (n=8). The final analytical sample was 1,072.

Measures and definitions

BP: For the BT device, mean SBP and DBP were estimated from at least one and up to five valid measurements; less than 3% of mean SBP and DBP values were based on fewer than five measurements. For the OM device, mean SBP and DBP were estimated from at least one and up to three valid measurements; less than 1% of mean values were based on fewer than three measurements.

Antihypertensive medication use: Current medications were recorded during the household and MEC interviews, and these were assigned to codes from the Anatomical Therapeutic Chemical (ATC) classification system, 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), and other antihypertensive agents (ATC codes in category C02, excluding C02KX01).

Hypertension: Individuals were classified as hypertensive if they had a mean SBP of 135 millimetres of mercury (mmHg) or higher, had a mean DBP of 85 mmHg or higher, or reported using antihypertensive medication in the past month. These SBP and DBP thresholds are consistent with those recommended for defining hypertension using automated BP measurements in clinical settings.[13]

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

Weight: Individuals' 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: Individuals' BMI was calculated as their measured weight in kg divided by the square of their measured height in m. Three categories of BMI were examined: neither overweight nor obese (BMI less than 25 kg/m^2), overweight (BMI of 25 kg/m^2 to less than 30 kg/m^2), or obese (BMI of 30 kg/m^2 or higher).

Covariates

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

Table 1
Estimates and differences in systolic and diastolic blood pressure and hypertension prevalence as measured by OMRON and BpTRU, by selected characteristics, crossover study sample aged 18 to 79 years, Canada, excluding territories, 2018 to 2019

		Mean SBP (mmHg)			Mean DBP (mmHg)			Hypertension prevalence		
	n	OM	BT	Difference (OM - BT)	OM	BT	Difference (OM - BT)	OM	BT	Difference (OM - BT)
Total	**1,072**	120	115	6	70	72	-2	35.4	34.0	1.4 †
Sex										
Male	496	123	116	7	71	74	-3	40.5	39.3	1.2
Female	576	118	114	4	69	71	-2	30.9	29.3	1.6
Age group										
18 to 39 years	233	112	105	8	67	69	-2	4.3	4.3	0.0
40 to 59 years	377	118	112	5	71	74	-2	26.0	26.8	-0.8
60 to 64 years	171	125	120	5	73	75	-2	52.6	50.3	2.3
65 to 69 years	105	126	120	6	71	73	-2	48.6	41.9	6.7 †
70 to 74 years	114	129	123	6	68	71	-2	64.9	60.5	4.4 †
75 to 79 years	72	129	126	3	67	70	-3	77.8	75.0	2.8
Men										
18 to 39 years	93	118	107	11	66	69	-3	5.4	F	…
40 to 59 years	177	122	116	7	74	76	-3	32.8	33.9	-1.1
60 to 64 years	92	125	118	7	72	75	-3	56.5	54.3	2.2
65 to 69 years	56	126	119	7	71	75	-3	51.8	50.0	1.8
70 to 74 years	54	126	119	8	67	71	-3	68.5	64.8	3.7
75 to 79 years	24	126	123	3 ‡	66	71	-4	83.3	79.2	4.2
Women										
18 to 39 years	140	109	103	6	67	68	-2	3.6	5.0	-1.4
40 to 59 years	200	113	109	4	69	71	-2	20.0	20.5	-0.5
60 to 64 years	79	126	122	4	74	75	-1	48.1	45.6	2.5
65 to 69 years	49	126	122	4	70	72	-2	44.9	32.7	12.2 †
70 to 74 years	60	132	127	5	69	71	-1	61.7	56.7	5.0
75 to 79 years	48	130	127	3	67	69	-2	75.0	72.9	2.1
Body mass index category										
Neither overweight nor obese	363	116	108	7	65	69	-3	21.2	19.3	1.9
Overweight	406	122	117	6	71	73	-2	38.4	36.2	2.2
Obese	303	124	120	4	74	75	-1	48.2	48.5	-0.3
Men										
Neither overweight nor obese	122	120	110	10	66	69	-4	26.2	24.6	1.6
Overweight	212	123	116	7	71	74	-3	39.6	38.2	1.4
Obese	162	125	119	6	74	76	-2	52.5	51.9	0.6
Women										
Neither overweight nor obese	241	114	108	6	65	68	-3	18.7	16.6	2.1
Overweight	194	121	117	4	71	73	-1	37.1	34.0	3.1
Obese	141	122	121	2	73	74	0 ‡	43.3	44.7	-1.4
Antihypertensive medication use										
Yes	260	128	122	6	71	73	-2	100.0	100.0	0.0
No	812	118	112	6	70	72	-2	14.7	12.8	1.8 †
Men										
Yes	143	126	119	8	71	73	-3	100.0	100.0	0.0
No	353	122	114	7	71	74	-3	16.4	14.7	1.7
Women										
Yes	117	129	125	4	71	72	-1	100.0	100.0	0.0
No	459	116	111	4	69	71	-2	13.3	11.3	2.0

… not applicable

F too unreliable to be published

† Indicates the difference between OM-measured hypertension prevalence and BT-measured hypertension prevalence was statistically different from zero at $p < 0.05$ (McNemar's test).

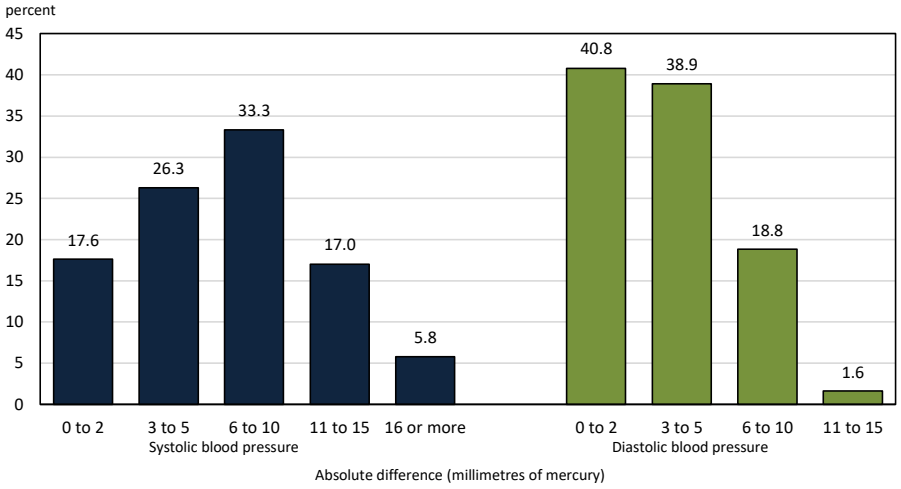
‡ All blood pressure differences between BT and OM measurements were statistically different from zero at $p < 0.05$ (paired t-test), with the exception of those marked with this symbol

Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, OM = OMRON, BT = BpTRU, mmHg = millimetres of mercury, and n = sample size.
Differences were calculated on unrounded means, then all SBP and DBP estimates were rounded to the nearest integer. Hypertension is defined as an SBP of 135 mmHg or higher, a DBP of 85 mmHg or higher, or the use of any antihypertensive medication in the past month.
Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

Analytical techniques

Mean SBP and DBP, mean differences, hypertension prevalence, and prevalence differences were estimated from BT and OM measurements across selected characteristics, stratified by sex. Mean SBP and DBP estimates were rounded to the nearest integer. The frequency distribution of absolute between-device differences in SBP and DBP was estimated by sex. Sex-specific Bland–Altman plots illustrated device differences in measured SBP and DBP, stratified by hypertension status. Intraclass correlation coefficients (ICCs) quantified the degree of correlation and agreement between the

Chart 1
Frequency distribution of absolute difference between OMRON and BpTRU for systolic and diastolic blood pressure, crossover study sample aged 18 to 79 years, Canada, excluding territories, 2018 to 2019



Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

two sets of measurements for each stratum. ICC estimates and their 95% confidence intervals (CIs) were calculated based on a *k*=1, consistency, two-way mixed-effects model.[14]

The feasibility of developing prediction equations to compare BP measurements based on BT readings with those based on OM readings was assessed. Overall and sex-specific scatterplots and histograms were used to examine the correlation between and the distribution of SBP and DBP from both devices according to age group, BMI category, and antihypertensive medication use. The REG procedure in SAS was used to estimate separate SBP and DBP base models with SBP (or DBP) measured with OM as the outcome and SBP (or DBP) measured with BT as the sole independent variable. Sex and an interaction between sex and the BT value were then tested in each model to assess the need for sex-specific models. Age in years and BMI in kg/m^2 and their polynomials (quadratic, cubic) and antihypertensive medication use were added sequentially to each base model. Model fit statistics, including likelihood ratio tests of nested models, residual plots, and predicted R-squared values, were evaluated. Sex-specific SBP and one overall DBP equation—base and with covariates (full)—were generated from the final selected models. The HPREG procedure with forward selection and the Schwarz Bayesian information criterion specified for model fit were then used to confirm the model selection. Regression coefficients were truncated to five decimal places, and the predicted R-squared was rounded to two decimal places. Sex-specific probability density plots of predicted versus measured SBP and DBP stratified by hypertension status were generated.

Differences between predicted and measured mean SBP and DBP (paired t-tests with statistical significance set at $p < 0.05$) and hypertension prevalence (McNemar's tests with statistical significance set at $p < 0.05$) were also assessed by sex, age group, BMI category, and antihypertensive medication use.

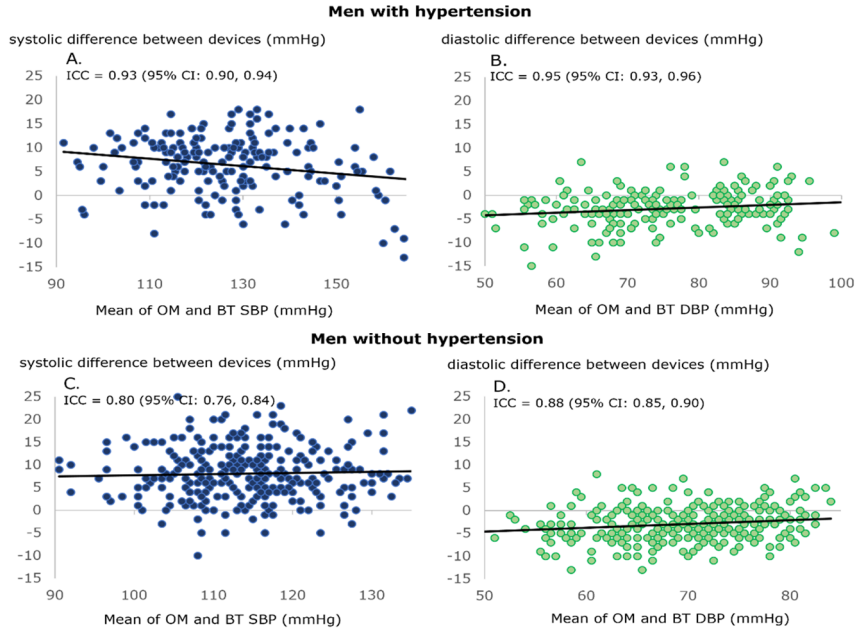
BP is highly variable,[15] and consecutive BP measurements tend to regress to the mean[16] (e.g., low initial BP values tend to rise, while higher values tend to fall). In a sensitivity analysis, device order—whether the BT device was used first or not—was added as a covariate in each final model, and the model fit statistics and predicted values produced by these adjusted models were assessed.

To evaluate whether crossover sample differences translated into population-level differences, weighted estimates of SBP, DBP, and hypertension prevalence based on BT measurements, OM measurements, and OM predictions were calculated. These weighted estimates were generated using survey weights and bootstrap weights of respondents in the crossover sample that were calibrated on the full Cycle 6 population by age group (18 to 19 years, 20 to 39 years, 40 to 59 years, and 60 to 79 years) and sex.

All analyses were conducted in SAS Enterprise Guide 9.4 and SAS-callable SUDAAN 11.0.3 except for the ICCs and the probability density plots. The psych package[17] was used to generate the ICCs and the ggplot2, ggpubr, and scales packages[18-20] were used to generate the density plots in RStudio 4.1.3.

Figure 1

Bland-Altman plots of blood pressure differences between devices among men, by hypertension status, adults aged 18 to 79 years, Canada, excluding territories, 2018 to 2019

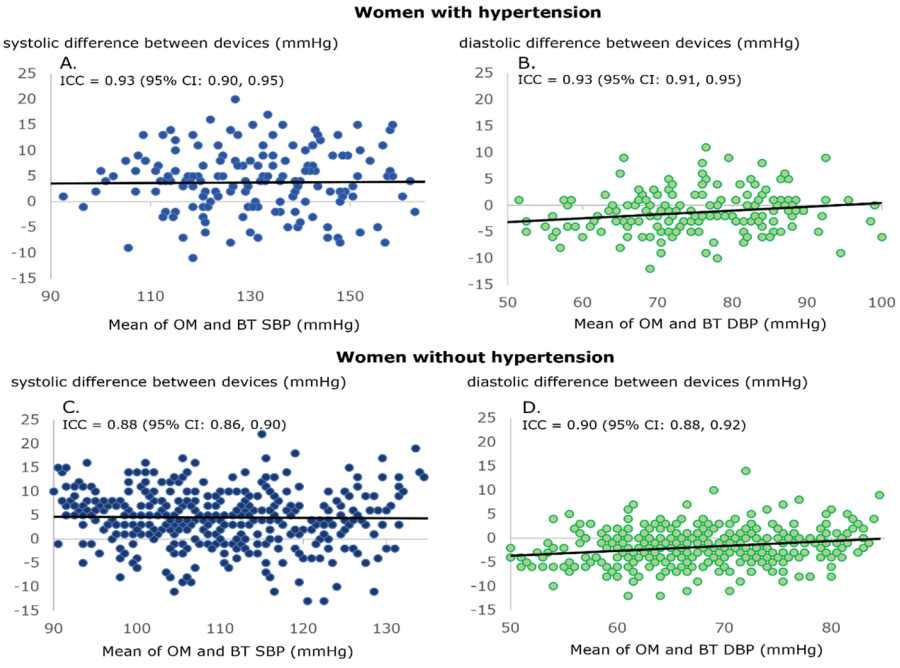


Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, OM = OMRON, BT= BpTRU, ICC = intraclass correlation coefficient (A. ICC= 0.93 (95% CI: 0.90, 0.94); B. ICC = 0.95 (95% CI: 0.93, 0.96); C. ICC = 0.80 (95% CI: 0.76, 0.84); D. ICC = 0.88 (95% CI: 0.85, 0.90)), CI = confidence interval, and mmHg = millimetres of mercury.

Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

Figure 2

Bland-Altman plots of blood pressure differences between devices among women, by hypertension status, adults aged 18 to 79 years, Canada, excluding territories, 2018 to 2019



Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, OM = OMRON, BT= BpTRU, ICC = intraclass correlation coefficient (A. ICC= 0.93 (95% CI: 0.90, 0.95); B. ICC = 0.93 (95% CI: 0.91, 0.95); C. ICC = 0.88 (95% CI: 0.86, 0.90); D. ICC = 0.90 (95% CI: 0.88, 0.92)), CI = confidence interval, and mmHg = millimetres of mercury.

Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

Results

OMRON versus BpTRU

The average age of the study sample was 53 years. Slightly over half were women (n=576) or under the age of 60 (n=610), two-thirds were overweight or obese (n=709), and about one in four (n=260) were taking antihypertensive medication (Table 1). Overall mean SBP measured with OM was 6 mmHg higher than that measured with BT. Mean DBP measured with OM was 2 mmHg lower than that measured with BT. The average between-device differences across characteristics ranged from +2 to +11 mmHg for SBP and from -4 to 0 mmHg for DBP. The mean difference in SBP between the two devices was larger for men (7 mmHg) than for women (4 mmHg). It decreased for both sexes with increasing age and increasing BMI but varied little according to antihypertensive medication use. The difference in DBP between the devices was similar across sexes, varied somewhat by age group, and decreased with increasing body mass, mainly for women.

About 44% of participants had a between-device absolute difference in SBP of 5 mmHg or less, and 80% had an absolute difference in DBP of 5 mmHg or less (Chart 1). Absolute between-device agreement differences in SBP were within 5 mmHg for 52% of women versus 34% of men (data not shown). Differences in DBP were within 5 mmHg for 83% of women versus 76% of men (data not shown).

For men with hypertension, the difference between the BT and OM measurements decreased with increasing SBP (Figure 1-A). For men without hypertension (Figure 1-C) and women with or without hypertension (figures 2-A and 2-C), the difference between BT and OM remained relatively stable regardless of SBP level. For both sexes, the difference between BT and OM decreased with increasing DBP regardless of hypertension status (figures 1-B, 1-D, 2-B, and 2-D). The ICCs for those with hypertension ranged from 0.93 (95% CI: 0.90, 0.94) to 0.95 (95% CI: 0.93, 0.96), indicating excellent agreement and correlation between the two devices,[14] and from 0.80 (95% CI: 0.76, 0.84) to 0.90 (95% CI: 0.88, 0.92) for those without hypertension (good to excellent agreement and correlation).

Overall OM-based hypertension prevalence was 35.4%, an estimated 1.4 percentage points higher than BT-based prevalence (34.0%) (Table 1). The difference in the prevalence of hypertension between the two devices was not consistent across sexes, age groups, or BMI categories.

Predicted versus measured blood pressure

The prediction equations are presented in Table 2. The predicted R-squared for the base models ranged from 0.82 to 0.87 and for the full models from 0.84 to 0.88. The full SBP and DBP models performed better than the base models for both sexes across age groups, BMI categories, and antihypertensive medication use categories (Table 3). The full SBP and DBP models produced predicted mean values that were no different than measured mean values, apart from the predicted SBP among individuals aged 75 to 79 years (difference of +2 mmHg).

Some differences were observed between predicted BP and measured BP across the BP distribution (figures 3 and 4). For example, among men with hypertension, predicted SBP was less likely to fall within 135 to 165 mmHg (Figure 3-A) and predicted DBP was less likely to fall within 85 to 100 mmHg (Figure 3-B) than measured BP. For women with hypertension, predicted SBP was less likely to fall within 135 to 150 mmHg (Figure 4-A), while predicted DBP was less likely to fall within 85 to 95 mmHg (Figure 4-B), compared with measured BP. For men without hypertension, there was a difference between predicted and measured BP along the entire distribution for SBP (Figure 3-C) but minimal difference between the two curves for DBP (Figure 3-D). For women without hypertension, predicted SBP was less likely to fall within 95 to 100 mmHg than measured SBP (Figure 4-C), and there was minimal difference between the two curves for DBP (Figure 4-D).

Table 2
Equations to convert systolic and diastolic blood pressure measured by BpTRU to systolic and diastolic blood pressure measured by OMRON for adults aged 18 to 79 years, by sex

	Equations	Predicted R-squared
Men 18 to 79 years		
SBP		
Base model	OM^P-SBP = 24.35235 + 0.85321×(BT-SBP)	0.82
Full model	OM^P-SBP = 37.39698 + 0.90131×(BT-SBP) - 0.42297×(age) + 0.00313×(age^2) - 0.22358×(bmi) + 2.58234×(Bpmed)	0.84
Women 18 to 79 years		
SBP		
Base model	OM^P-SBP = 13.25715 + 0.92145×(BT-SBP)	0.87
Full model	OM^P-SBP = 23.13778 + 0.93959×(BT-SBP) - 0.23370×(age) + 0.00238×(age^2) - 0.25365×(bmi)	0.88
Men and women 18 to 79 years		
DBP		
Base model	OM^P-DBP = -1.57930 + 0.99070×(BT-DBP)	0.86
Full model	OM^P-DBP = -8.88739 + 0.97550×(BT-DBP) - 1.51526×(male) - 0.02247×(age) + 0.53322×(bmi) - 0.00559×(bmi^2)	0.88

Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, BT = BpTRU, OM = OMRON, age = age in years (continuous), bmi = body mass index (continuous), Bpmed = taking antihypertensive medication (1 = yes, 0 = no), and male (1 = yes, 0 = no). OM^P indicates OM-predicted SBP and DBP.
Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

Table 3

Estimates and differences in measured and predicted mean systolic and diastolic blood pressure using OMRON, base and full models, by selected characteristics, crossover study sample aged 18 to 79 years, Canada, excluding territories, 2018 to 2019

	Mean SBP (mmHg)					Mean DBP (mmHg)				
		Base model		Full model			Base model		Full model	
	OM measured	OM predicted	Difference (OM predicted - OM measured)	OM predicted	Difference (OM predicted - OM measured)	OM measured	OM predicted	Difference (OM predicted - OM measured)	OM predicted	Difference (OM predicted - OM measured)
Total	120	120	0	120	0	70	70	0	70	0
Sex										
Male	123	123	0	123	0	71	71	1 †	71	0
Female	118	118	0	118	0	69	69	-1 †	69	0
Age group										
18 to 39 years	112	111	-1 †	112	0	67	66	0	67	0
40 to 59 years	118	118	1 †	118	0	71	71	0	71	0
60 to 64 years	125	125	0	125	0	73	73	0	73	0
65 to 69 years	126	126	0	125	-1	71	71	0	71	0
70 to 74 years	129	128	-1	128	-1	68	69	0	68	0
75 to 79 years	129	130	1	131	2 †	67	67	1	67	1
Men										
18 to 39 years	118	116	-2 †	118	0	66	67	0	66	0
40 to 59 years	122	123	1	123	0	74	74	0	73	0
60 to 64 years	125	125	0	124	0	72	73	1 †	72	0
65 to 69 years	126	126	0	125	-1	71	72	1	71	0
70 to 74 years	126	126	-1	125	-1	67	69	1 †	68	0
75 to 79 years	126	130	3	130	3	66	68	2	68	1
Women										
18 to 39 years	109	108	-1	109	0	67	66	-1	67	0
40 to 59 years	113	114	1 †	113	0	69	69	0	70	0
60 to 64 years	126	126	0	125	-1	74	73	-1 †	74	-1
65 to 69 years	126	126	0	126	0	70	70	-1	70	0
70 to 74 years	132	130	-2	131	-1	69	68	-1	69	-1
75 to 79 years	130	131	0	132	1	67	67	0	67	0
Body mass index category										
Neither overweight nor obese	116	114	-1 †	116	0	65	66	1 †	65	0
Overweight	122	122	0	122	0	71	71	0	71	0
Obese	124	125	2 †	124	0	74	73	-1 †	74	0
Men										
Neither overweight nor obese	120	118	-2 †	120	0	66	67	2 †	65	0
Overweight	123	123	0	124	0	71	72	1 †	71	0
Obese	125	126	1 †	125	0	74	74	0	74	0
Women										
Neither overweight nor obese	114	113	-1 †	114	0	65	66	1 †	65	0
Overweight	121	121	0	121	0	71	70	-1 †	71	0
Obese	122	124	2 †	122	0	73	71	-2 †	73	0
Antihypertensive medication use										
Yes	128	127	-1	127	0	71	71	0	71	0
No	118	118	0	118	0	70	70	0	70	0
Men										
Yes	126	126	-1	126	0	71	71	0	71	0
No	122	122	0	122	0	71	71	1 †	71	0
Women										
Yes	129	128	-1	128	-1	71	70	-1 †	71	0
No	116	116	0	116	0	69	68	-1 †	69	0

† Indicates the difference between the OM-predicted and OM-measured values was statistically different from zero at $p < 0.05$ (paired t-test).

Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, OM = OMRON, and mmHg = millimetres of mercury. Differences were calculated and tested on unrounded means, then all estimates were rounded to the nearest integer.

Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

The underprediction at higher levels of SBP resulted in predicted hypertension prevalence estimates from the full model being slightly lower than measured estimates across characteristics, with an average difference of -2.7 percentage points (Table 4). The exceptions were for both sexes in the oldest age group and for women with obesity where the average difference ranged from 0.0 to +2.1 percentage points.

Adjusting for device order in each model had little effect on predicted mean BP values or predicted hypertension prevalence, nor did it alter the underestimation of predicted values at higher levels of BP (data not shown).

Population-level differences

When weighted to represent the population of adults aged 18 to 79 years, differences between the devices were comparable in magnitude and direction to the unweighted estimates. At the population level, average SBP measured with OM was 7 mmHg higher (95% CI: 5, 8) than that measured with BT, and average DBP measured with OM was 2 mmHg lower (95% CI: -3, -2) than that measured with BT (Table 5). Weighted differences in SBP and DBP between predicted and measured values were also comparable to the unweighted estimates (data not shown).

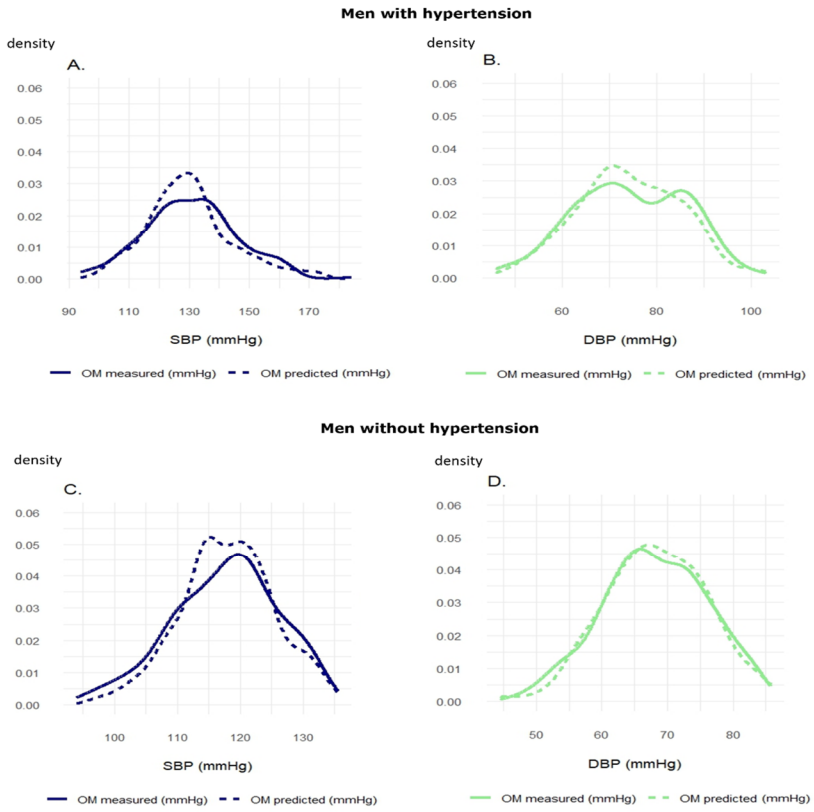
Between-device differences in population-level hypertension prevalence were also comparable to the unweighted estimates, with an average +1.6 percentage point difference (95% CI: -1.3%, +4.6%) (Table 6). Between-device differences fluctuated across the characteristics but with considerable variability, as shown by their wide confidence intervals.

Weighted differences between predicted and measured values were comparable in magnitude and direction to the unweighted estimates. The overall difference between predicted and measured BP in population prevalence was -2.8 percentage points (95% CI: -5.5%, -0.1%) (Table 6). Prevalence differences between predicted and measured BP fluctuated—with wide confidence intervals—across characteristics.

Discussion

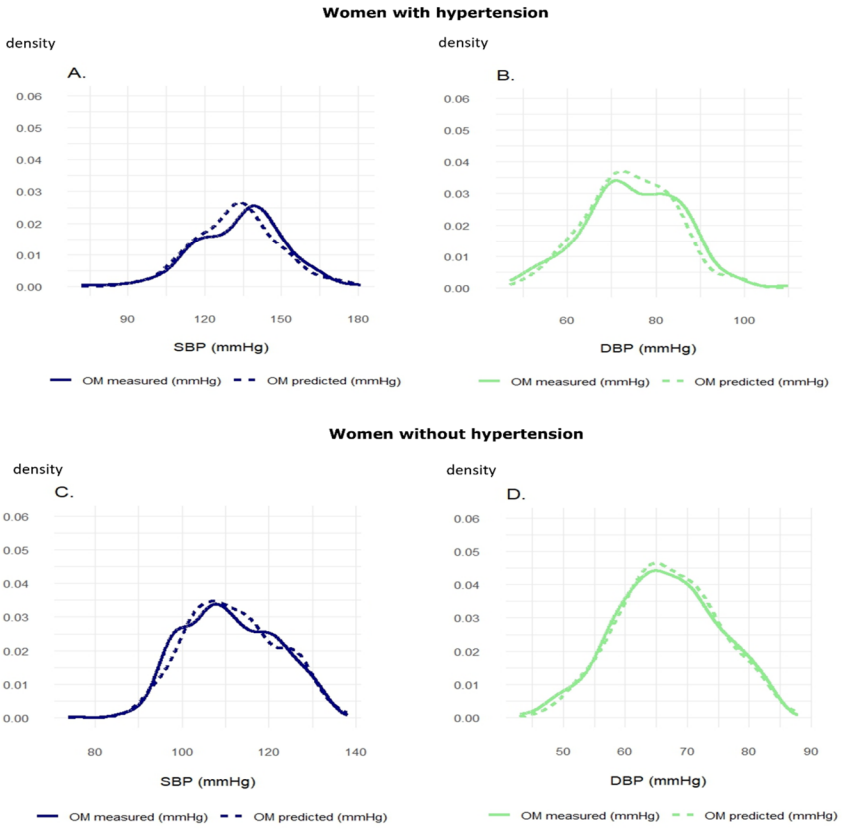
The present analysis found systematic between-device differences in measured SBP and DBP but fewer between-device differences in hypertension prevalence in a sample of adults aged 18 to 79 years. Prediction equations to compare BT-based BP data with OM-based BP data were developed and assessed. The results suggest that these equations can be used as intended, but with some caveats.

Figure 3
Probability density plots of the full model's predicted versus measured blood pressure among men using OMRON, by hypertension status, adults aged 18 to 79 years, Canada, excluding territories, 2018 to 2019



Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, OM = OMRON, and mmHg = millimetres of mercury.
Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

Figure 4
Probability density plots of the full model's predicted versus measured blood pressure among women using OMRON, by hypertension status, adults aged 18 to 79 years, Canada, excluding territories, 2018 to 2019



Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, OM = OMRON, and mmHg = millimetres of mercury.
Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

In the study sample, mean SBP measured with OM was 6 mmHg higher than mean SBP measured with BT, and mean DBP measured with OM was 2 mmHg lower than mean DBP with BT. Between-device differences across characteristics ranged from an average of +2 to +11 mmHg for SBP and an average of -4 to -1 mmHg for DBP. Overall, these between-device differences are substantively higher than reported cycle-over-cycle absolute differences at the population level in average adult SBP and DBP. To date, published estimates for cycles 1 to 6 show these differences ranging from 2 to 3 mmHg for SBP and 0 to 2 mmHg for DBP.[21] In their study comparing BT with OM in 260 cardiovascular clinic patients—average age 66 years—Rinfret et al. reported no between-device difference in DBP but found that OM-measured SBP exceeded BT-measured SBP by almost 5 mmHg.[7] Conversely, Myers et al. reported similar values for SBP and DBP between the BT and OM devices.[22] However, their sample of 100 individuals—average age 63 years—consisted of patients admitted to an ambulatory BP monitoring unit with an average SBP of 132 to 141 mmHg, depending on the device used. The present study also found that average between-device differences were lower at higher values of BP.

Average hypertension prevalence based on OM-measured BP was 1.4 percentage points higher (+1.2 for men and +1.6 for women) than BT-based prevalence in the study sample. When weighted to represent the population, the overall difference between OM and BT prevalence was +1.6 percentage points (95% CI: -1.3, +4.6). These percentage point differences fall within the range of variability of existing cycle-over-cycle differences in reported population estimates of adult hypertension prevalence.[23] There are two main reasons why the substantive between-device differences in measured SBP did not produce correspondingly large between-device differences in hypertension prevalence in this study. First, the observed between-device differences in SBP were smaller at higher values. Second, people were classified as hypertensive if their measured BP met the BP criteria for hypertension or if they reported taking antihypertensive medication, regardless of their measured BP. Among those classified as hypertensive in the current study, about 80% were taking antihypertensive medication, compared with 77% of the adult population in 2018 to 2019 (data not shown). Thus, only a relatively small proportion of hypertensive individuals are classified as such based solely on their measured BP.

Table 4

Estimates and differences in predicted and measured hypertension prevalence using OMRON, base and full models, by selected characteristics and sex, crossover study sample aged 18 to 79 years, Canada, excluding territories, 2018 to 2019

	Hypertension prevalence (%)				
		Base model		Full model	
	OM measured	OM predicted	Difference (OM predicted - OM measured)	OM predicted	Difference (OM predicted - OM measured)
Total	35.4	32.6	-2.7 †	32.6	-2.7 †
Sex					
Male	40.5	37.9	-2.6 †	37.1	-3.4 †
Female	30.9	28.1	-2.8 †	28.8	-2.1 †
Age group					
18 to 39 years	4.3	2.6	-1.7 †	3.0	-1.3
40 to 59 years	26.0	22.8	-3.2 †	23.3	-2.7 †
60 to 64 years	52.6	50.9	-1.8	49.7	-2.9
65 to 69 years	48.6	41.9	-6.7 †	41.9	-6.7 †
70 to 74 years	64.9	62.3	-2.6	60.5	-4.4 †
75 to 79 years	77.8	77.8	0.0	79.2	1.4
Men					
18 to 39 years	5.4	F	…	F	…
40 to 59 years	32.8	29.4	-3.4	29.9	-2.8
60 to 64 years	56.5	54.3	-2.2	51.1	-5.4
65 to 69 years	51.8	48.2	-3.6	48.2	-3.6
70 to 74 years	68.5	68.5	0.0	64.8	-3.7
75 to 79 years	83.3	83.3	0.0	83.3	0.0
Women					
18 to 39 years	3.6	F	…	3.6	0.0
40 to 59 years	20.0	17.0	-3.0 †	17.5	-2.5
60 to 64 years	48.1	46.8	-1.3	48.1	0.0
65 to 69 years	44.9	34.7	-10.2	34.7	-10.2
70 to 74 years	61.7	56.7	-5.0	56.7	-5.0
75 to 79 years	75.0	75.0	0.0	77.1	2.1
Body mass index category					
Neither overweight nor obese	21.2	18.5	-2.8 †	18.7	-2.5 †
Overweight	38.4	34.7	-3.7 †	34.5	-3.9 †
Obese	48.2	46.9	-1.3	46.9	-1.3
Men					
Neither overweight nor obese	26.2	24.6	-1.6	23.8	-2.5
Overweight	39.6	36.8	-2.8	35.8	-3.8 †
Obese	52.5	49.4	-3.1	48.8	-3.7
Women					
Neither overweight nor obese	18.7	15.4	-3.3 †	16.2	-2.5
Overweight	37.1	32.5	-4.6 †	33.0	-4.1 †
Obese	43.3	44.0	0.7	44.7	1.4
Antihypertensive medication use					
Yes	100.0	100.0	0.0	100.0	0.0
No	14.7	11.1	-3.6 †	11.1	-3.6 †
Men					
Yes	100.0	100.0	0.0	100.0	0.0
No	16.4	12.7	-3.7 †	11.6	-4.8 †
Women					
Yes	100.0	100.0	0.0	100.0	0.0
No	13.3	9.8	-3.5 †	10.7	-2.6 †

… not applicable

F too unreliable to be published

† Indicates the difference between the predicted and measured hypertension prevalence estimates was statistically different from zero at $p < 0.05$ (McNemar's test).

Notes: OM = OMRON. Differences in prevalence between predicted and measured values were calculated on unrounded estimates, then all estimates were rounded to the nearest decimal. Hypertension is defined as a systolic blood pressure of 135 millimetres of mercury (mmHg) or higher, a diastolic blood pressure of 85 mmHg or higher, or the use of any antihypertensive medication in the past month.

Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

Separate SBP and DBP prediction equations were developed to compare BT-based BP data with OM-based BP data. The models that contained additional covariates performed better than the base models. These full models produced sex-specific average predicted BP estimates that were comparable to measured BP across age groups, BMI categories, and antihypertensive medication use categories. The predicted BP values followed the distribution of measured BP, except at the

Table 5
Estimates of mean systolic and diastolic blood pressure measured by OMRON and BpTRU, weighted crossover study sample aged 18 to 79 years, Canada, excluding territories, 2018 to 2019

	Measured mean SBP (mmHg)					Measured mean DBP (mmHg)				
			Difference	95% CI				Difference	95% CI	
	OM	BT	(OM - BT)	from	to	OM	BT	(OM - BT)	from	to
Total	118	112	7	5	8	69	71	-2	-3	-2
Sex										
Male	122	113	8	6	10	70	73	-3	-4	-2
Female	115	110	5	3	7	68	70	-2	-3	-1
Age group										
18 to 39 years	113	104	9	7	11	66	67	-2	-3	-1
40 to 59 years	118	113	5	4	7	72	74	-3	-4	-2
60 to 64 years	122	117	5	3	7	73	75	-2	-3	-2
65 to 69 years	127	122	5	2	7	70	73	-2	-4	-1
70 to 74 years	130	125	5	2	8	70	73	-3	-5	-2
75 to 79 years	124	121	3	1	6	63	66	-3	-5	-2
Men										
18 to 39 years	116	105	11	8	13	65	67	-2	-3	-1
40 to 59 years	124	117	7	5	9	74	77	-3	-5	-1
60 to 64 years	123	117	6	4	8	73	76	-3	-4	-3
65 to 69 years	129	122	7	5	9	74	77	-3	-5	-1
70 to 74 years	131	125	5	-1	11	71	76	-5	-7	-2
75 to 79 years	127	124	3	0	6	62	66	-4	-5	-3
Women										
18 to 39 years	110	103	8	4	11	66	68	-1	-3	1 ‡
40 to 59 years	113	109	4	2	5	69	71	-2	-3	-1
60 to 64 years	121	117	4	1	7	73	74	-1	-2	0
65 to 69 years	125	123	2	-1	5 ‡	67	68	-1	-4	1 ‡
70 to 74 years	130	125	5	4	7	68	70	-2	-3	-1
75 to 79 years	122	119	3	-1	7 ‡	63	66	-3	-5	-1
Body mass index category										
Neither overweight nor obese	112	104	9	7	11	63	66	-3	-4	-3
Overweight	121	115	6	5	7	71	73	-2	-3	-1
Obese	123	119	5	3	7	75	76	-1	-2	0
Men										
Neither overweight nor obese	117	105	12	8	16	62	66	-4	-5	-2
Overweight	122	115	7	4	10	70	73	-3	-5	-1
Obese	125	118	7	5	8	76	78	-2	-3	-1
Women										
Neither overweight nor obese	110	103	7	4	10	63	66	-3	-4	-2
Overweight	120	115	5	3	6	72	73	-1	-3	0 ‡
Obese	120	119	1	-3	5 ‡	72	73	0	-3	2 ‡
Antihypertensive medication use										
Yes	124	120	5	3	7	70	72	-2	-4	0
No	117	110	7	5	9	69	71	-2	-3	-2
Men										
Yes	125	118	7	6	9	71	72	-2	-4	1 ‡
No	121	112	9	6	11	70	73	-3	-4	-2
Women										
Yes	123	121	2	-2	5 ‡	69	71	-2	-3	-1
No	113	108	6	4	8	68	69	-2	-3	0

‡ All blood pressure differences between BT and OM measurements were statistically different from zero at $p < 0.05$ (paired t-test), with the exception of those marked with this symbol

Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, OM = OMRON, BT = BpTRU, CI = confidence interval, and mmHg = millimetres of mercury. Differences were calculated on unrounded means, then all SBP and DBP estimates were rounded to the nearest integer.

Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

upper levels of the BP distribution, where the predicted values were lower than measured ones. This resulted in slightly lower predicted hypertension prevalence estimates compared with those based on measured values. When weighted to represent the population, average overall predicted hypertension prevalence remained slightly lower than average measured prevalence.

The magnitude of the overall differences in predicted versus measured prevalence—unweighted and weighted—was within the range of variability of previously published population estimates of adult hypertension prevalence.[23] However, there were larger differences between predicted and measured prevalence for certain groups—e.g., women who were overweight. While not statistically outside the typical range of variability—owing to wide CIs—they were outside this range in terms of the magnitude of the point estimate difference. It is unclear whether a full cycle of CHMS BP data, with an increased sample size, would have produced equally large prevalence differences but with narrower CIs for certain groups—differences that would be considered substantive and statistically significant. Given this uncertainty, differences

Table 6
Measured and predicted hypertension prevalence, by selected characteristics, weighted crossover study sample aged 18 to 79 years, Canada, excluding territories, 2018 to 2019

	Measured					Predicted versus measured			
				95% CI			Difference	95% CI	
	OM	BT	Difference (OM - BT)	from	to	OM predicted (full model)	(OM predicted - OM measured)	from	to
Total	28.3	26.7	1.6	-1.3	4.6	25.5	-2.8	-5.5	-0.1 †
Sex									
Male	33.2	33.4	-0.3	-4.8	4.2	31.1	-2.1	-5.7	1.5
Female	23.5	20.0	3.5	-0.3	7.4	20.0	-3.6	-7.4	0.3
Age group									
18 to 39 years	5.1	5.4	-0.3	-1.4	0.9	4.8	-0.3	-0.9	0.4
40 to 59 years	31.1	27.8	3.4	-4.5	11.3	25.9	-5.3	-11.7	1.1
60 to 64 years	45.4	47.4	-2.0	-13.2	9.3	43.0	-2.4	-6.1	1.3
65 to 69 years	56.3	50.2	6.1	-1.9	14.2	50.5	-5.9	-12.5	0.8
70 to 74 years	65.1	61.4	3.7	-0.7	8.0	61.4	-3.7	-8.0	0.7
75 to 79 years	87.3	84.8	2.6	-3.8	8.9	87.7	0.4	-0.7	1.4
Men									
18 to 39 years	8.5	F	…	…	…	F	…	…	…
40 to 59 years	37.5	37.6	-0.1	-9.6	9.4	35.5	-2.0	-8.6	4.5
60 to 64 years	52.1	57.6	-5.6	-29.1	18.0	44.8	-7.3	-20.4	5.8
65 to 69 years	60.6	60.4	0.3	-0.9	1.4	58.0	-2.6	-11.5	6.2
70 to 74 years	78.2	73.0	5.1	-5.7	15.9	73.0	-5.1	-15.9	5.7
75 to 79 years	90.7	87.3	3.4	-10.1	16.9	90.7	0.0	…	…
Women									
18 to 39 years	1.7	1.9	-0.2	-0.8	0.4	1.7	0.0	…	…
40 to 59 years	24.8	18.0	6.8	-3.3	17.0	16.2	-8.5	-18.7	1.7
60 to 64 years	39.3	38.0	1.3	-1.8	4.4	41.4	2.1	-3.3	7.5
65 to 69 years	51.8	39.5	12.3	-1.9	26.6	42.5	-9.3	-21.4	2.7
70 to 74 years	52.3	50.1	2.2	-1.4	5.8	50.1	-2.2	-5.8	1.4
75 to 79 years	84.9	82.9	2.0	-3.5	7.4	85.5	0.6	-0.9	2.2
Body mass index category									
Neither overweight nor obese	11.6	11.4	0.2	-3.9	4.3	10.4	-1.2	-3.9	1.6
Overweight	32.9	27.8	5.1	-0.7	10.9	26.9	-6.0	-11.9	-0.1 †
Obese	45.8	46.6	-0.9	-6.5	4.8	44.9	-0.9	-5.0	3.3
Men									
Neither overweight nor obese	13.8	16.1	-2.3	-9.7	5.0	12.9	-0.9	-3.8	2.0
Overweight	36.5	34.5	2.0	-3.1	7.2	33.3	-3.3	-7.7	1.2
Obese	45.4	46.5	-1.1	-9.9	7.8	43.7	-1.7	-8.4	4.9
Women									
Neither overweight nor obese	10.3	8.6	1.7	-1.4	4.8	8.9	-1.4	-6.0	3.3
Overweight	28.9	20.4	8.5	-3.6	20.7	19.8	-9.1	-21.0	2.8
Obese	46.3	46.9	-0.6	-1.7	0.5	46.9	0.6	-0.5	1.7
Antihypertensive medication use									
Yes	100.0	100.0	0.0	…	…	100.0	0.0	…	…
No	13.7	11.7	2.0	-2.1	6.1	10.3	-3.4	-7.0	0.3
Men									
Yes	100.0	100.0	0.0	…	…	100.0	0.0	…	…
No	17.0	17.3	-0.3	-7.0	6.3	14.4	-2.6	-8.2	3.1
Women									
Yes	100.0	100.0	0.0	…	…	100.0	0.0	…	…
No	10.6	6.5	4.1	-0.7	9.0	6.5	-4.2	-9.0	0.7

… not applicable

F too unreliable to be published

† Indicates the difference between OM-predicted and OM-measured hypertension prevalence was statistically different from zero at $p < 0.05$ (McNemar's test).

Notes: SBP = systolic blood pressure, DBP = diastolic blood pressure, OM = OMRON, BT = BpTRU, and CI = confidence interval. Differences in prevalence were calculated on unrounded estimates, then all estimates were rounded to the nearest decimal. Hypertension is defined as an SBP of 135 millimetres of mercury (mmHg) or higher, a DBP of 85 mmHg, or the use of any antihypertensive medication in the past month.

Source: Statistics Canada, Canadian Health Measures Survey crossover study, 2018 to 2019.

between predicted hypertension prevalence estimates from BP data in previous cycles and measured hypertension prevalence estimates in Cycle 7 onward should be interpreted with caution.

At the population-level, Emberson et al. predicted that an absolute reduction of 7 mmHg in SBP would result in a 16% reduction in first occurrences of major cardiovascular disease over 10 years.[24] At the individual level, a margin of 5 mmHg in SBP can affect the intensity of treatment of patients with hypertension.[7] It follows that the magnitude of the difference in population estimates of SBP—and to a lesser extent DBP—resulting from the introduction of the OM device in Cycle 7 will be interpreted as a substantive change in the BP of Canadian adults. Thus, the impact of changing to the OM device should be acknowledged when estimates of adult BP from Cycle 7 onward are reported.

Strengths and limitations

This study has several strengths. BP, height, and weight were measured objectively using systematic methodologies. All respondents had their BP measured by trained staff following strict protocols during a single visit to the MEC, and device order was randomly assigned. The recommended set of prediction equations had predicted R-squared values ranging from 0.84 to 0.88, indicating good predictive power. Nevertheless, results of this study should be interpreted considering certain limitations. The results pertain to adults aged 18 to 79 years, and the equations are not generalizable to younger or older age groups. Cuff sizes were not concordant between the two devices, and different cuff sizes used on the same person may have affected the results.[7,25] Limited study sample size reduced statistical power when examining and interpreting between-device differences in hypertension prevalence across multiple characteristics. The equations produced predicted BP values that were comparable to measured BP values on average, but with some underestimation at the upper end of the BP distribution. This should be noted when using the equations. Moreover, there was some uncertainty regarding the ability of the predicted BP values to produce adequate predicted hypertension prevalence estimates for certain groups. This too should be noted when using the equations. The crossover sample survey weight and bootstrap weights were generated by a simple calibration on the existing full population of Cycle 6 by age group and sex to show the potential impact of the device change on population estimates. The results may have been slightly different had the crossover sample weights been generated independently following all the standard steps in the CHMS weighting process.

Conclusion

This study of Canadian adults found systematic between-device differences in SBP and DBP measurements between the OM and the BT monitors for people aged 18 to 79 years. Consequently, adult BP data in Cycle 7 of the CHMS will be substantively different from adult BP data in previous cycles. The switch in BP devices and the resulting impact on BP data in Cycle 7 should be noted when reporting estimates of adult BP based on the CHMS. The prediction equations developed in this study can be applied to adult BP data from cycles 1 to 6 for comparison with BP measurements in Cycle 7, with the following caveats. First, the predicted values slightly underestimate the BP values at the upper end of the BP distribution. Second, hypertension prevalence estimates based on predicted BP values should be interpreted with caution.

Acknowledgments

The authors gratefully acknowledge the help of Joel Barnes, who provided the syntax to produce the probability density plots in RStudio.

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