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Authors & Title

Trends in systematic recording errors of blood pressure and associations with outcomes in Canadian and UK Primary Care: a retrospective observational study

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Abstract

Objectives: to study systematic errors in recording blood pressure (BP) as measured by end digit preference (EDP); to determine associations between EDP, uptake of Automated Office BP (AOBP) machines and cardiovascular outcomes.

Design: Retrospective observational study using routinely collected electronic medical record data from 2006 to 2015 and a survey on year of AOBP acquisition in Toronto, Canada in 2017.

Setting: Primary care practices in Canada and the UK

Participants: Adults aged 18 years or more.

Main outcome measures: Mean rates of EDP and change in rates. Rates of EDP following acquisition of an AOBP machine. Associations between site EDP levels and mean BP. Associations between site EDP levels and frequency of cardiovascular outcomes.

Results: 707,227 patients in Canada and 1,558,471 patients in the UK were included. From 2006 to 2015, the mean rate of BP readings with both systolic and diastolic pressure ending in zero decreased from 26.6% to 15.4% in Canada and from 24.2% to 17.3% in the U.K. Systolic BP readings ending in zero decreased from 41.8% to 32.5% in the three years following the purchase of an AOBP machine. Sites with high EDP had a mean systolic BP of 2.0 mmHg in Canada, and 1.7 mmHg in the UK, lower than sites with no or low EDP. Patients in sites with high levels of EDP had a higher frequency of stroke (standardized morbidity ratio SMR 1.15, 95% CI 1.12-1.17), myocardial infarcts (SMR 1.16, 95% CI 1.14-1.19), and angina (SMR 1.25, 95% CI 1.22-1.28) than patients in sites with no or low EDP.

Conclusions: Acquisition of an AOBP was associated with a decrease in EDP levels. Sites with higher rates of EDP rounded BP readings down and had a higher frequency of adverse cardiovascular outcomes. The routine use of manual office-based BP measurement should be reconsidered.

Strengths and limitations of this study

- The study found that the purchase of AOBP machines by primary care offices was followed by more accurate BP measurement
- Offices with less accurate BP measurement (more end digit preference) rounded BP readings down
- These offices also had higher frequencies of adverse cardiovascular outcomes
- The survey of AOBP machine purchase was done only in Ontario; we infer that the purchase of an AOBP machine was associated with less end digit preference elsewhere

Introduction:

High blood pressure (BP) is a leading cause of increased morbidity and early mortality in adults.[1] BP should be routinely measured as part of clinical encounters.[2] However, there are long standing concerns about the precision and accuracy of BP measurement in practice.[3,4] There is evidence that measuring BP manually, using an aneroid or mercury column sphygmomanometer, is associated with systematic recording errors including end digit preference (EDP) and observer bias.[5] EDP means that the observer rounds off the last digit;[6] for example, BPs end in zero for up to 60% of records instead of the expected 10%.[7,8] Observer bias means that BP is adjusted towards a preferred level (rounding up or rounding down).[8] These issues may lead to errors in the diagnosis and treatment of hypertension.[9]

Automated Office BP (AOBP) measurement uses a machine to record and report the numerical values of systolic and diastolic BPs on a digital display.[10] Three to six recordings are done; the initial reading is discarded and the remaining readings are averaged.[11] Research suggests that EDP is reduced as a result of this method. [9,11] AOBP is comparable to the gold standard of 24-hour automated home BP monitoring.[12] Canadian and European hypertension guidelines now recommend AOBP as the preferred method for office-based measurement of BP,[2,13] but have not made a recommendation to discontinue the routine use of manual BP measurement.

There is evidence that AOBP machines are increasingly used in primary care; it has been reported that more than 10,000 AOBP machines are currently in use in Canada.[11] In a recent Canadian survey, 43% of family physicians reported using AOBP to screen for hypertension.[14] However, the proportion of office BP measurements done using AOBP when machines are available in an office is not known. Changes in the proportion of BPs with EDP could serve as a marker of increasing use of AOBP in primary care practice, though this requires validation.

Accurate measurement is essential for BP control. There is a need to quantify systematic BP measurement errors in primary care, consider these in the context of changing AOBP use and estimate the effects of errors on cardiovascular outcomes affected by BP control.

The objectives of this study were therefore to (1) report the EDP levels with respect to patient and provider-level characteristics, (2) examine the changes in EDP with AOBP uptake in offices, (3) quantify prevalence and trends in systematic recording errors in BP recording and (4) determine associations between EDP and cardiovascular outcomes.

Methods:

We used a repeated cross-sectional observational design. We applied the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) checklist for reporting observational studies.[15]

Settings and Data sources

Canada

The Canadian Primary Care Sentinel Surveillance Network (CPCSSN) database was used for this study.[16] CPCSSN is Canada's largest EMR-based chronic disease surveillance system[16] and includes data collected from eleven primary care practice based research networks in 8 of Canada's 13 provinces and territories. Consenting family physicians and other primary care providers participating in CPCSSN contribute de-identified EMR data to regional network repositories; patients can opt-out if they choose to do so. Data from all participating networks are collected every six months and aggregated in a single central database.[16] The distribution of the CPCSSN patient population is reasonably similar to that of Canadian census.[17]

We used EMR data extracted and processed using procedures previously described.[16] CPCSSN case definition algorithms have been validated against chart audits for eight chronic conditions (diabetes, hypertension, chronic obstructive pulmonary disease, depression, osteoarthritis, dementia, parkinsonism and epilepsy) in multiple sites across Canada.[18]

U.K.

We repeated the analyses using the Royal College of General Practitioners Research and Surveillance Centre (RCGP RSC) database for the UK. This is one of Europe's oldest primary care sentinel networks.[6] It has been reported that the RCGP RSC has data of high quality for chronic disease, including diabetes[6] and cardiovascular outcomes.[19]
The RCGP RSC data are extracted weekly from the EMRs of >150 representative general practices (groups of physicians practicing in the same location) in England, covering a population of over 1.5 million patients and 3% of the population. A comparison of RCGP RSC practices with national pay-for-performance data, prescribing data, and the quality and outcomes framework suggests that data are representative of the national population in terms of age and gender of the population, ethnicity and deprivation.[6]

Study population

We used routinely collected clinical electronic medical record (EMR) data from primary care clinics across Canada and the UK. These data were extracted in Canada as of June 30th, 2016 and in the UK as of December 31st 2016. We examined BP measurements taken between January 1st, 2006 and December 31st, 2015 in the CPCSSN database and in the RCGP RSC database. We included all patients who were at least 18 years of age as of BP measurement date. We identified patient characteristics that may influence BP and its measurement. Patient variables included: age; sex; presence of hypertension and/or diabetes; body mass index; use of hypertensive medications. We recorded the total number of patients included for each site; a site was a group of physicians practicing in the same location.

Statistical Analysis

We examined the proportions of BPs ending in each digit in Canada and UK. We used the entire collection of BP records in both databases to estimate the unadjusted frequency of last digit zero for both systolic and diastolic BPs with respect to patient, site and temporal characteristics.

Since each patient may have BP recorded multiple times with irregular visit to primary care between Jan 2006 to Dec 2015, we chose to discard excess information using a sampling mechanism.[20] We used stratified sampling without replacement to randomly choose one BP measurement for each patient. The estimates and the confidence intervals of odds ratios were computed using bootstrap where one thousand independently sampled replicates of the CPCSSN and RCGP RSC database were generated.[21] All covariates in the regression model were held constant for each patient with respect to the study follow-up. For example, the most recent information on BMI or the diagnosis of diabetes or hypertension medication was used for each patient.

To correlate rates of EDP with AOBP uptake, we conducted a subgroup analysis using data from UTOPIAN, the University of Toronto Practice Based Research Network. UTOPIAN is the largest network in CPCSSN, with about 25% of data in the national database; it includes providers and patients from Toronto and surrounding areas in southern Ontario, Canada. We collected data on AOBP use from UTOPIAN practices using a survey, shown in supplementary materials. We contacted office representatives through email/phone and asked them whether there was an AOBP in the office and when it was purchased. Office representatives were also asked to estimate how often BPs were done with the machine in the past year.

Responses were linked with EMR based blood pressure measurements for each site and the linked data were used for the subgroup analysis. We examined the association between length of time the machine was present in the office and the rate of EDP, as well as association between EDP for 2015 and the self-reported level of use in the past year.

We implemented unsupervised cluster analysis to categorize primary care sites into three groups for each year.[22] The three groups were labeled as: (1) high EDP; (2) medium EDP; and (3) low or no EDP. Practices were clustered by presence of less commonly recorded end digits (1,3,7,9) for both sBP and dBP; 40% of BPs would be expected to end in one of those digits. To control for excessive noise in the data, we chose to exclude the sites with less than 1000 BP measurements within a year.

Since the changes in uncommon end digits (1,3,7,9) may be confounded by the recruitment of new sites over time or changes in patient populations within sites, the proportion of recording uncommon digits was reported for each measurement year, giving a rate of EDP per site per year. The similarity between all pairs belonging to the same cluster was computed using the Ward score.[23] We examined the mean sBP among patients with and without hypertension and diabetes using the classification obtained from the cluster analysis.

We estimated the annual frequency of three cardiovascular events (myocardial infarct, angina, stroke) using UK data; these conditions have not yet been validated in the Canadian data in CPCSSN. We compared sites with high EDP in each year against sites with low or no EDP for the same year. The denominator was defined as the total number of patients who had at least one blood pressure recorded within each year of interest for each group. The numerator was defined as the total number of patients included in the denominator with a cardiovascular event within the same year. Patients with a cardiovascular event were censored in subsequent years. We estimated the standardized morbidity ratio for each condition in groups with high EDP compared to groups with low or no EDP.

This study was reviewed and approved by the Research Ethics Board (REB) at the University of Toronto; the survey was reviewed and approved by REBs at each participating site. REB approval was not deemed to be necessary for the UK, as no patients were identified; this was classified as a service evaluation. The study received a favorable opinion from the RCGP RSC study review panel. CPCSSN has received REB approval from Health Canada, and each host university for all participating practice-based research networks. All participating primary care providers have provided written informed consent for the collection and analysis of their EMR data. All statistical analyses were conducted using SAS software, version 9.4 M4 (SAS Institute).

No patients were involved in setting the research question or the outcome measures, nor were they involved in developing plans for design or implementation of the study. We received input into the study from Patient and Public representatives who commented on the relevance of the question and the potential impact of the research on outcomes.

Results:

Data from 181 sites and 707,227 patients in CPCSSN were included; there were 5.5 million BP records. Data from 164 sites and 1,558,471 patients in the RCGP RSC database were included; there were 13.4 million BP records. Each patient was counted once, regardless of the number of BPs and number of years in which they had a BP recorded. The most frequently recorded end digit was zero while the least frequent end digits were one, three, seven and nine (Table 1, Figure 1).

Patient and site characteristics and trends in levels of EDP are shown in table 2. The frequency of last digit zero for both systolic and diastolic BP decreased by 11.2% in Canada and by 6.9% in the UK from 2006 to 2015. Table 3 describes the adjusted odds ratios (ORs) of recording zero as the last digit of systolic BP. The ORs of last digit zero were greater among female patients (CPCSSN: OR=1.10, 95% CI 1.09-1.11; RCGP: OR=1.16, 95% CI 1.15-1.16). Patients with hypertension were less likely to have EDP than patients without hypertension (CPCSSN: OR=0.89, 95% CI 0.88-0.91; RCGP RSC: OR=0.79, 95% CI 0.78-0.80). Patients with diabetes were less likely to have EDP in Canada (OR=0.98 95% CI: 0.96-0.99) but were more likely to have this in the UK (OR=1.025 95% CI:1.01-1.04). ORs of EDP decreased as BMI levels increased in Canada but not in the UK.

65 UTOPIAN sites were surveyed; 55 (85%) responded. 93% of the UTOPIAN sites reported having at least one AOBP machine in the practice; most were bought between 2007 and 2014. Even when AOBP machines were present, most offices reported still using manual measurement. There was a reduction of 9.3% (from 41.7% to 32.5%) in the proportion of systolic BPs ending in zero within three years of adopting the AOBP machines (95% CI: -8.9% to -9.8%). Family practices who reported rarely or never using AOBP machines had higher end digit preference than those reporting at least some use of AOBP (Figure 2).

As illustrated in Figure 3, cluster analyses were used to find the optimal decision boundaries to classify sites into high EDP, medium EDP, low or no EDP for Canada and UK. Table 4 provides the number and percentage of sites in each group. In 2006 there was only one Canadian site (3.6%) with low or no EDP while in the UK, 61 sites (38.4%) were in this group. Sites exhibiting high EDP decreased by 47.7% in Canada and by 15.1% in the UK from 2006 to 2015. In contrast, the proportion of sites classified as having low or no EDP increased by 22.9% in Canada and 12.8% in the UK.

The mean systolic BP by EDP group is shown on Table 5. Sites with low or no EDP had a higher mean systolic BP than sites with high EDP (1.97mmHg in Canada; 1.76mmHg in UK). When stratified by presence or absence of hypertension or diabetes, the direction was similar with differences ranging from 0.9 to 2.4 mm Hg.

As shown in figure 4, we observed a higher mean frequency of myocardial infarct (0.40%, 95% CI 0.39 to 0.41), stroke (0.64%, 95% CI 0.63 to 0.65) and angina (0.42%, 95% CI 0.41 to 0.43) in sites with high EDP as compared to sites with low or no EDP: 0.34% (95% CI 0.33 to 0.35), 0.56% (95% CI 0.55 to 0.57) and 0.33% (95% CI 0.32 to 0.34)respectively. Table 6 provides the standardized morbidity ratio; this was higher for all three conditions for sites with high EDP compared to sites with low or no EDP.

Discussion:

We found significant levels of systematic recording errors in BP measurement in the UK and Canada; these decreased over time. There was an association between the length of time an AOBP machine was present in an office and a decrease in EDP. Higher rates of EDP, and presumably more use of manual BP recording in those sites, appeared to be associated with rounding down of BPs and a higher frequency of adverse cardiovascular outcomes.

Our study found decreasing rates of in EDP; there have been increasingly strong guideline recommendations to switch to AOBP.[2,24] While a recent survey found that almost half of Canadian physicians reported using AOBP to screen for hypertension,[14] most offices in this study reported continued use of manual BP measurement for some patients even when an AOBP machine was present in the office. We found a gradual decrease in EDP associated with the length of time that AOBP has been present in the office, indicating that physicians and sites may be increasingly accustomed to its routine use for measurement.

European Guidelines recommending adoption of AOBP were associated with a large decrease in recorded blood pressures ending in zero in the U.K., from 71.2% in 1996-1997 to 36.7% in 2005-2006.[25] UK studies based on the Quality Improvement in Chronic Kidney Disease (QICKD) trial[26] have shown reductions over time, presumably related to the progressive introduction of AOBP – though this assumption was not validated.[27] In addition, there were changes in the patterns of recording odd vs. even terminal digits. Another study in China also noted decreases in EDP over time.[28] Implementation of AOBP in offices thus appears to be correlated with decreases in EDP.[3,7,25]

The use of AOBP measurement resulted in lower readings than manual BP measurement (by 5 to 10 mmg Hg) in a randomized controlled trial (RCT); AOBP readings agreed more closely with the gold standard of 24 hour BP measurement than manual BP readings.[11] The introduction of AOBP should therefore be associated with a combination of lower rates of EDP (greater precision) and lower BP readings that are more consistent with the gold standard (greater accuracy).

We found that sites with low or no EDP (those presumably using AOBP more consistently) had a mean BP that was close to 2 mm Hg higher than those with greater rates of EDP (and presumably more use of manual BP in the practice); RCT data had led to an expectation that this would be about 5 mm Hg lower. Therefore, observer errors associated with manual BP may have resulted in both rounding towards zero and systematically rounding down. Rounding down was observed for patients with diabetes and hypertension as well as for those without these conditions. This could potentially lead to under-diagnosis of hypertension and under-treatment of diagnosed hypertension.

Another observational study had found that higher rates of EDP (and presumably more manual BPs) were associated with lower mean systolic BP, by 2 to 3 mm Hg.[25] A study in the UK found that the change from manual to AOBP in primary care practices resulted in lower rates of EDP but no changes in mean BP.[3]

A large cluster RCT (CHAP) documented improved management of hypertension in communities randomized to the intervention. This consisted of more accurate AOBP-based measurement in pharmacies with forwarding of abnormal BP results to family physicians.[29] The CHAP intervention resulted in a significant decrease in hospitalizations due to cardiovascular disease (myocardial infarction, stroke, heart failure).[29] In that trial, there was an improvement in BP from a mean of 142 mm Hg to 123 mm Hg when the initial pharmacy-based reading was elevated.[30] Systematically more accurate measurement of BP through the use of AOBP in the community, followed by notification of the primary care provider when BP was elevated, may have resulted in more treatment of elevated BP in primary care and decreased adverse cardiovascular outcomes.

The results in this real world observational study in two countries are plausibly consistent with those of the CHAP RCT. We found that practices with greater precision for BP measurement (less EDP) also had a lower prevalence of adverse cardiovascular outcomes for their patients. It is possible that these practices were using AOBP more often and were thus measuring BP with greater accuracy. Systematic rounding down associated with

higher rates of EDP and presumably greater use of manual BP measurement by practices in this study appeared to be associated with an elevated frequency of adverse cardiovascular outcomes.

A switch to routine use of AOBP for most office-based BP measurements would require the purchase of enough machines to support the number of physicians and patients in each office, training of staff and health care providers, and changes in offices processes to support more consistent us of AOBP. We are not aware of financial or other practice level incentives in either country promoting this change.

Limitations

The study has several strengths. We used data from routine community-based primary care. We also included a large sample of both patients and primary care providers from multiple settings across Canada and the UK, observed over a decade or more. Therefore, this study reasonably reflects current clinical practices for individuals receiving primary care in both countries.

This study has several shortcomings. This was a convenience sample of primary care practices that contributed EMR data to CPCSSN and the RCGP RSC. We surveyed practices for their use of AOBP in one network only (UTOPIAN); the survey was done at the office level rather than by physician. There may be recall bias and the actual proportion of patients whose BP was measured using an AOBP is unknown.

There may be unmeasured confounders associated with both higher incidence of cardiovascular outcomes and greater rates of EDP. Nonetheless, the differences between groups persisted as practices switched to lower rates of EDP over time and there is no a priori reason to expect a change in unmeasured confounders in practices switching to AOBP and lower rates of EDP.

We did not examine whether there was any repeated measurement bias or recording bias in AOBP practices.

Conclusions

In conclusion, systematic measurement errors including rounding down are associated with higher rates of EDP. It is likely that this is associated with more manual BP measurement in these primary care practices and in turn is correlated with a higher risk of adverse cardiovascular outcomes at a population level. Our findings suggest that the continued routine use of manual measurement of BP in primary care offices may be problematic. We recommend the use of AOBP as the standard of care for measuring and monitoring BP in medical offices.

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The authors have no competing interests to declare.

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MG, FS, SK SdeL contributed to conception and design. BA was responsible for acquisition of Canadian, and SdeL for UK data. SK, RM and WH contributed substantially to the analysis of data. MG and SK with input from SdeL drafted the initial version of the article. All authors contributed to the interpretation of data. All authors reviewed and revised the article for important intellectual content and gave final approval of the version to be published. MG is the guarantor of this work, with SdeL for the RCGP RSC data, and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. MG had final responsibility for the decision to submit for publication.

Data are from a nationally representative Canadian repository of primary care EMR data, the Canadian Primary Care Sentinel Surveillance Network (http://cpcssn.ca). CPCSSN data are available to researchers as outlined in the process available on the website, cpcssn.ca . Similarly, the Royal College of General Practitioners (RCGP) Research and Surveillance Centre (RSC) network database can be accessed by researchers following the process set out at: www.rcgp.org.uk/rsc. Extra data is available by emailing michelle.greiver@nygh.on.ca.

Table 1: Frequency of end-digits for systolic and diastolic blood pressures

End-digits	Canada		UK	
	Systolic BP	Diastolic BP	Systolic BP	Diastolic BP
0	32.4%	35.9%	33.8%	34.0%
1	3.6%	3.7%	4.5%	4.5%
2	13.1%	10.9%	10.3%	9.6%
3	3.8%	3.8%	4.8%	4.7%
4	10.4%	10.0%	9.1%	9.3%
5	7.2%	6.8%	8.3%	8.2%
6	9.3%	8.9%	8.5%	8.4%
7	3.9%	3.8%	4.9%	4.8%
8	12.6%	12.4%	11.2%	11.6%
9	3.8%	3.4%	4.8%	4.9%

Table 2: Patient/site characteristics and blood pressure measurements ending in zero for both systolic BP and diastolic BP in Canada (CPCSSN) and the UK (RCGP RSC database)

	Canada			UK		
Characteristics	**Number of Patients (% of patients)**	**Number of Blood Pressures (% of BPs)**	**Number of BPs with both systolic and diastolic BP ending in zero (% with both ending in zero)**	**Number of Patients (% of patients)**	**Number of Blood Pressures (% of BPs)**	**Number of BPs with both systolic and diastolic BP ending in zero (% with both ending in zero)**
Total	707,227	5,503,663	1,044,031 (19.0%)	1,558,471	13,424,678	2,674,497 (19.9%)
Age in years						
18 to 39	189,254 (26.8%)	816,136 (14.8%)	165,025 (20.2%)	531,632 (34.1%)	2,330,344 (17.4%)	538,786(23.1%)
40 to 59	247,771 (35%)	1,534,126 (27.9%)	292,435 (19.1%)	498,272 (32.0%)	3,298,174 (24.6%)	631,260(19.1%)
60 to 79	201,364 (28.5%)	2,115,655 (38.4%)	377,724 (17.9%)	352,483 (22.6%)	4,879,583 (36.3%)	868,894(17.8%)
80+	68,838 (9.7%)	1,037,716 (18.9%)	208,847 (20.1%)	176,084 (11.3%)	2,916,577 (21.7%)	635,557(21.8%)
Sex						
Female	414,644 (58.6%)	3,325,256 (60.4%)	648,357 (19.5%)	901,866 (57.9%)	8,133,678 (60.6%)	1,708,742(21.0%)
Male	292,583 (41.4%)	2,178,377 (39.6%)	395,674 (18.2%)	656,605 (42.13%)	5,291,000 (39.4%)	965,755(18.3%)
BMI range						
Underweight (BMI <18.5)	10,233 (1.4%)	70,776 (1.3%)	14,649 (20.7%)	44,654 (2.9%)	308,481 (2.3%)	71,234(23.1%)
Normal weight (18.5 to 24.9)	170,684 (24.1%)	1,177,970 (21.4%)	236,883 (20.1%)	560,214 (36.0%)	4,071,114 (30.3%)	852,192(20.9%)
Overweight (25 to 29.9)	182,141 (25.8%)	1,545,777 (28.1%)	283,163 (18.3%)	446,850(28.7%)	4,412,326 (32.9%)	842,338(19.1%)
Obesity class I (30 to 34.9)	101,980 (14.4%)	1,013,286 (18.4%)	175,781 (17.3%)	200,761 (12.9%)	2,421,241 (18.0%)	455,572(18.8%)
Obesity class II (35 to 39.9)	42,235 (6.0%)	468,239 (8.5%)	77,408 (16.5%)	71,450 (4.6%)	928,259 (6.9%)	176,969(19.1%)
Obesity class III (≥40)	27,451 (3.9%)	320,682 (5.8%)	52,327 (16.3%)	37,370 (2.4%)	491,533 (3.7%)	96,589(19.7%)
Not available	172,503 (24.4%)	906,903 (16.5%)	203,820 (22.5%)	197,172 (12.7%)	791,724 (5.9%)	179,603(22.7%)
Diabetes						
Yes	86,103 (12.2%)	1,299,693 (23.6%)	233,944 (18%)	65,335(4.2%)	1,909,804 (14.2%)	359,324(18.8%)

No	621,124 (87.8%)	4,203,940 (76.4%)	810,087 (19.3%)	1,493,136 (95.1%)	11,514,874 (85.8%)	2,315,173(20.1%)
Hypertension						
Yes	185,508 (26.2%)	2,704,921 (49.1%)	486,787 (18%)	235,716 (15.1%)	6,359,131 (47.4%)	1,141,665(18.0%)
No	521,719 (73.8%)	2,798,712 (50.9%)	557,244 (19.9%)	1,322,755 (84.9%)	7,065,547 (52.6%)	1,532,832(21.7%)
Hypertension medications						
Yes	125,484 (17.7%)	2,704,947 (49.1%)	395,371 (17.7%)	466,800 (30.0%)	8,327,009 (62.0%)	1,571,464(18.9%)
No	581,743 (82.3%)	2,798,686 (50.9%)	648,660 (19.8%)	1,091,671 (70.1%)	5,097,669 (38.0%)	1,103,033(21.6%)
Practice site size						
1st quartile (smallest site)	36,363 (5.1%)	249,957 (4.5%)	63,781 (25.5%)	173610(11.1%)	1,671,387 (12.5%)	303,084(18.1%)
2nd quartile	77,776 (11%)	584,575 (10.6%)	110,411 (18.9%)	305460(19.6%)	2836288 (21.1%)	480,604(16.9%)
3rd quartile	156,601 (22.1%)	1,156,892 (21.0%)	228,521 (19.8%)	416580(26.7%)	3,774,278	846,481(22.4%)
4th quartile (largest site)	436,487 (61.7%)	3,512,209 (63.8%)	641,318 (18.3%)	662821(42.5%)	5,142,725	1,044,328(20.3%)
Measurement year*						
2006	52,168 (7.4%)	121,355 (2.2%)	32,335 (26.6%)	542,695(34.8%)	1,347,400 (10.0%)	325,843(24.2%)
2007	81,699 (11.6%)	183,591 (3.3%)	49,030 (26.7%)	553,033(35.5%)	1,342,979 (10.1%)	303,477(22.6%)
2008	125,781(17.8%)	277,858 (5.0%)	72,772 (26.2%)	563,222(36.1%)	1,353,092 (10.1%)	288,418(21.3%)
2009	167,345(23.7%)	368,245 (6.7%)	94,871 (25.8%)	572,940(36.8%)	1,358,664 (10.1%)	278,829(20.5%)
2010	213,250(30.2%)	531,316 (9.7%)	117,612 (22.1%)	580,069(37.2%)	1,340,279 (10.0%)	266,242(19.9%)
2011	263,691(37.3%)	615,364 (11.2%)	125,282 (20.4%)	590,921(37.9%)	1,354,956 (10.1%)	257,309(19.0%)
2012	299,590(42.4%)	700,903 (12.7%)	128,192 (18.3%)	602,642(38.7%)	1,347,042 (10.0%)	249,344(18.5%)
2013	332,809(47.1%)	813,009 (14.8%)	133,434 (16.4%)	617,073(39.6%)	1,366,085 (10.2%)	246,754(18.1%)
2014	360,180(50.9%)	894,350 (16.3%)	137,181 (15.3%)	612,382(39.3%)	1,325,141 (9.9%)	235,377(17.8%)
2015	386,541(54.7%)	997,642 (18.1%)	153,322 (15.4%)	594,589(38.2%)	1,289,040 (9.6%)	222,904(17.3%)

*considering repeated measurements of blood pressure for each patient with respect to measurement year.

BMI - body mass index (weight in kg / height in meters^2)

Table 3: Adjusted odds ratios of recording zero as the last digit of systolic blood pressure by patient and site characteristics

			Canada				UK			
Effect	**Index Group**	**Reference group**	**Odds ratio**	**95% confidence interval**		**P-value**	**Odds ratio**	**95% confidence interval**		**P-value**
Age	18 to 39	80+	1.088	1.063	1.112	<0.001	0.784	0.773	0.795	<0.001
	40 to 59	80+	1.012	0.990	1.034	0.294	0.788	0.777	0.798	<0.001
	60 to 79	80+	0.942	0.923	0.963	<0.001	0.783	0.772	0.794	<0.001
Sex	Female	Male	1.100	1.089	1.112	<0.001	1.156	1.148	1.163	<0.001
BMI	Underweight (BMI <18.5)	Obesity class III (BMI ≥40)	1.316	1.267	1.366	<0.001	1.047	1.019	1.074	0.001
	Normal (BMI 18.5 to 24.9)	Obesity class III	1.226	1.192	1.258	<0.001	0.960	0.939	0.980	<0.001
	Overweight (BMI 25 to 29.9)	Obesity class III	1.135	1.104	1.166	<0.001	0.947	0.926	0.966	<0.001
	Obesity class I (BMI 30 to 34.9)	Obesity class III	1.065	1.036	1.096	<0.001	0.953	0.932	0.973	<0.001
	Obesity class II (BMI 35 to 39.9)	Obesity class III	1.008	0.978	1.040	0.618	0.967	0.943	0.992	0.007
Diabetes	Yes	No	0.982	0.964	0.999	0.047	1.025	1.008	1.042	0.004
Hypertension	Yes	No	0.892	0.877	0.908	<0.001	0.790	0.780	0.799	<0.001
Hypertension medications	Yes	No	0.967	0.947	0.986	0.001	1.057	1.047	1.068	<0.001
Practice Site size	1st quartile (smallest site)	4th quartile (largest site)	1.950	1.908	1.990	<0.001	0.816	0.809	0.823	<0.001
	2nd quartile	4th quartile (largest site)	1.075	1.058	1.094	<0.001	0.893	0.885	0.900	<0.001
	3rd quartile	4th quartile (largest site)	1.087	1.074	1.100	<0.001	0.891	0.883	0.899	<0.001
Measurement year	2006	2015	1.910	1.833	1.990	<0.001	1.647	1.625	1.668	<0.001
	2007	2015	1.923	1.857	1.989	<0.001	1.473	1.451	1.494	<0.001
	2008	2015	1.840	1.790	1.895	<0.001	1.376	1.357	1.396	<0.001
	2009	2015	1.858	1.815	1.903	<0.001	1.321	1.300	1.341	<0.001
	2010	2015	1.582	1.548	1.617	<0.001	1.257	1.238	1.275	<0.001
	2011	2015	1.379	1.352	1.407	<0.001	1.178	1.161	1.196	<0.001
	2012	2015	1.239	1.216	1.262	<0.001	1.112	1.094	1.129	<0.001
	2013	2015	1.096	1.077	1.116	<0.001	1.052	1.038	1.067	<0.001
	2014	2015	1.037	1.021	1.052	<0.001	1.016	1.000	1.030	0.041

BMI - body mass index (weight in kg / height in meters^2)

Table 4: Number and percentage of sites in each EDP group from 2006 to 2015

Year	Canada						UK					
	Low or no EDP		Medium EDP		High EDP		Low or no EDP		Medium EDP		High EDP	
	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)
2006	1	3.6%	1	3.6%	26	92.9%	61	38.4%	39	24.5%	59	37.1%
2007	3	7.3%	3	7.3%	35	85.4%	69	42.9%	41	25.5%	51	31.7%
2008	8	13.8%	3	5.2%	47	81.0%	71	44.1%	45	28.0%	45	28.0%
2009	8	11.1%	7	9.7%	57	79.2%	74	46.0%	45	28.0%	42	26.1%
2010	15	15.3%	11	11.2%	72	73.5%	76	46.6%	45	27.6%	42	25.8%
2011	17	15.5%	16	14.5%	77	70.0%	78	47.9%	45	27.6%	40	24.5%
2012	27	21.8%	25	20.2%	72	58.1%	82	50.3%	40	24.5%	41	25.2%
2013	33	22.8%	33	22.8%	79	54.5%	79	48.5%	48	29.4%	36	22.1%
2014	30	20.0%	41	27.3%	79	52.7%	85	52.1%	42	25.8%	36	22.1%
2015	41	26.5%	44	28.4%	70	45.2%	84	51.2%	44	26.8%	36	22.0%

EDP – End digit preference

Table 5: Mean systolic blood pressure by EDP group

		CPCSSN database (Canada)			RCGP RSC database (UK)		
		No. of BP measurements	Mean sBP in mm Hg	Std. Dev.	No. of BP measurements	Mean sBP in mm Hg	Std. Dev.
All patients	**Low or no EDP**	1,151,795	128.21	18.92	5,618,800	135.05	20.09
	High EDP	2,925,279	126.24	18.52	3,624,391	133.29	19.63
	Difference		1.97			1.76	
Hypertensive	**Low or no EDP**	584,082	134.59	19.29	2,687,218	142.63	19.03
	High EDP	1,436,251	133.51	18.36	1,715,006	141.23	18.19
	Difference		1.08			1.40	
Non-hypertensive	**Low or no EDP**	567,713	121.65	16.09	2,931,582	128.10	18.44
	High EDP	1,489,028	119.23	15.77	1,909,385	126.15	18.07
	Difference		2.42			1.95	
Diabetic	**Low or no EDP**	300,630	131.42	18.81	823,959	138.89	18.75
	High EDP	675,920	130.52	18.09	515,843	136.76	17.79
	Difference		0.9			2.13	
Non-Diabetic	**Low or no EDP**	851,165	127.08	18.83	4,794,841	134.39	20.23
	High EDP	2,249,359	124.96	18.46	3,108,548	132.71	19.86
	Difference		2.12			1.68	

EDP – End digit preference
sBP – systolic blood pressure
Std. Dev – standard deviation
Std. Dev – standard deviation

Table 6: Standardized morbidity ratio for groups with high EDP group when compared to groups with low or no EDP

Angina			
Parameter	**Estimate**	**95% Confidence Limits**	
Standardized morbidity ratio	1.25	1.22	1.28
Acute Myocardial infraction			
Standardized morbidity ratio	1.16	1.14	1.19
Stroke			
Standardized morbidity ratio	1.15	1.12	1.17

EDP – End digit preference

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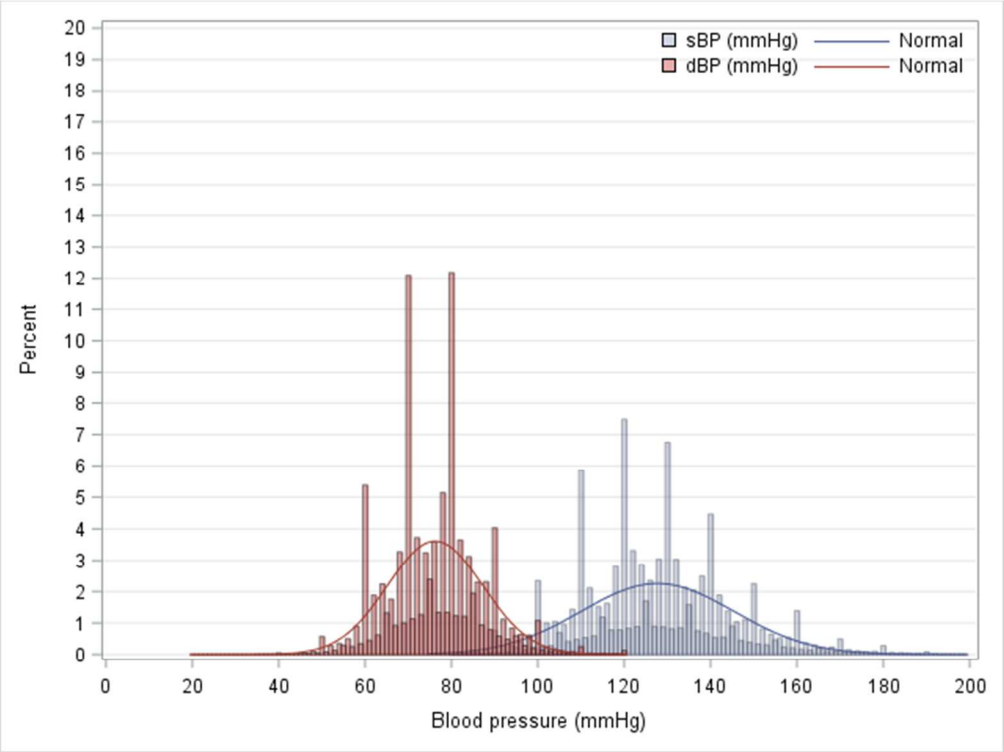
Figure 1: Histogram of systolic and diastolic blood pressure in Canada and the UK

a) Canada: CPCSSN database (2006-2015)



b) UK: RCGP RSC database (2006-2015)

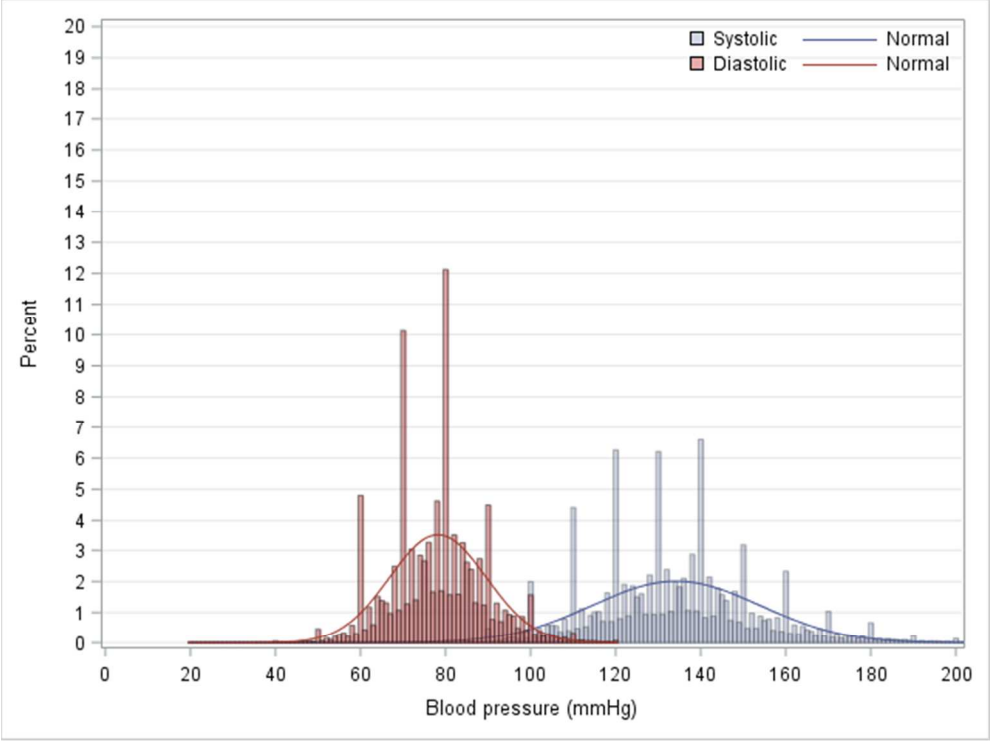
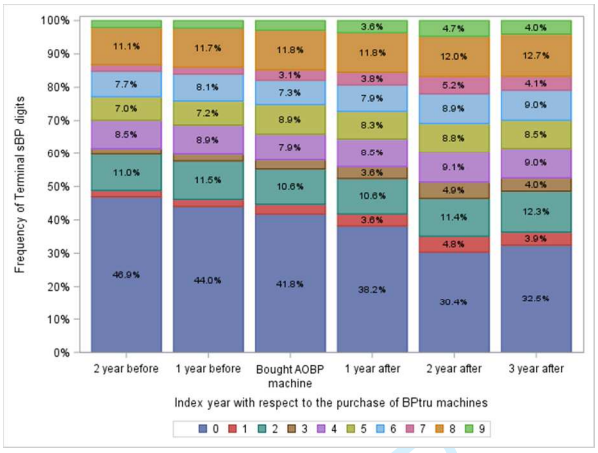


Figure 2: Impact of adopting automated office blood pressure machines on end digit preference for systolic blood pressure

a) Impact with respect to year of purchase of office automated blood pressure machine



b) Impact with respect to reported estimate on frequency of use of office automated blood pressure machine

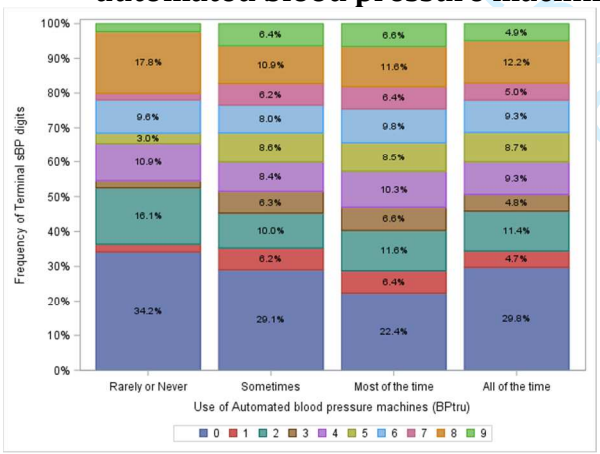


Figure 3: Proportions of systolic and diastolic BPs ending in 1, 3, 7 or 9 per practice site for each year of interest in Canada and UK from 2006 to 2015

a) Canada **b) UK**

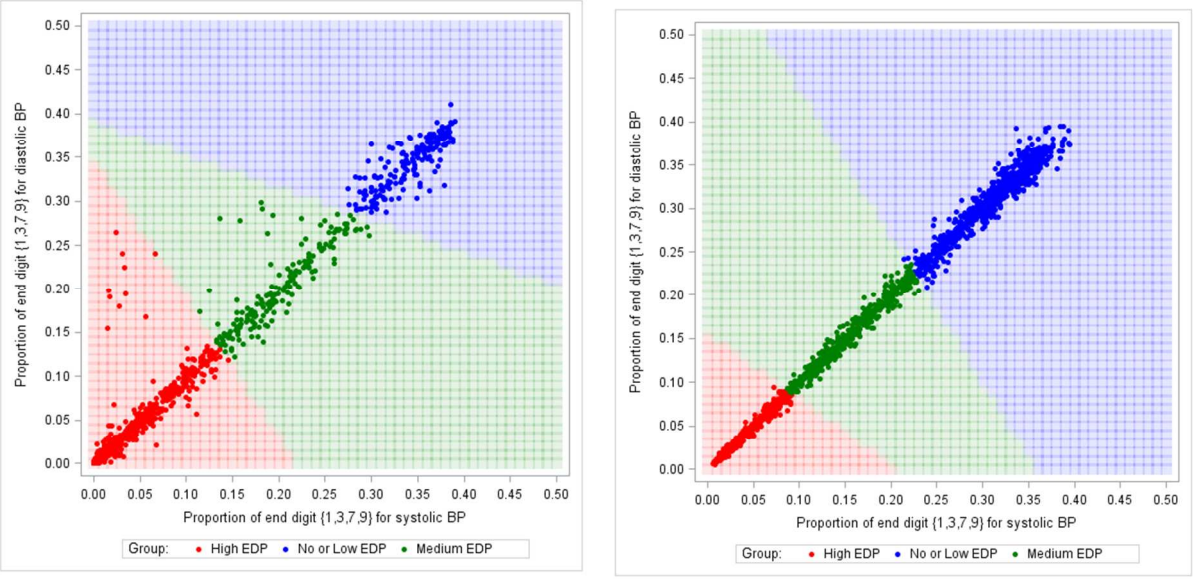
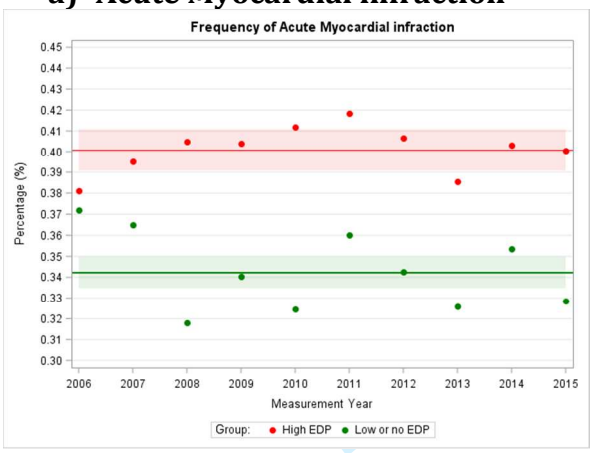
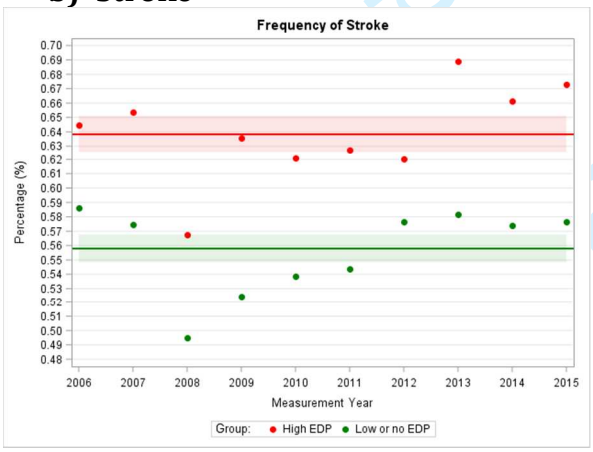


Figure 4: Frequency of cardiovascular events in high EDP and no or low EDP group

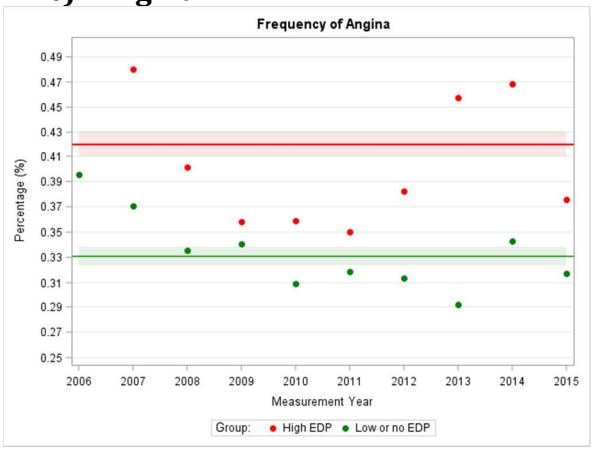
a) Acute Myocardial infraction



b) Stroke



c) Angina



STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract: **Page 1**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found: **Page 2**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **Page 3-4**
Objectives	3	State specific objectives, including any prespecified hypotheses **Page 3**
Methods		
Study design	4	Present key elements of study design early in the paper **Page 3**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **Page 4-5**
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants **Page 4**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **Page 4**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **Page 5-6**
Bias	9	Describe any efforts to address potential sources of bias **N/A**
Study size	10	Explain how the study size was arrived at **N/A**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **Page 5-6**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **Page 5-6**
		(*b*) Describe any methods used to examine subgroups and interactions **Page 5-6**
		(*c*) Explain how missing data were addressed **N/A**
		(*d*) If applicable, describe analytical methods taking account of sampling strategy **N/A**
		(*e*) Describe any sensitivity analyses **N/A**
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **Page 6**
		(b) Give reasons for non-participation at each stage **N/A**
		(c) Consider use of a flow diagram **N/A**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **Page 6**
		(b) Indicate number of participants with missing data for each variable of interest **Page 7**
Outcome data	15*	Report numbers of outcome events or summary measures **Page 7**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **Page 7**

		(*b*) Report category boundaries when continuous variables were categorized **Page 7**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **N/A**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **Page 7**
Discussion		
Key results	18	Summarise key results with reference to study objectives **Page 7**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **Page 8-9**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **Page 7-9**
Generalisability	21	Discuss the generalisability (external validity) of the study results **Page 9**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **Page 10**

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Trends in end digit preference for blood pressure and associations with cardiovascular outcomes in Canadian and UK Primary Care: a retrospective observational study

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Authors & Title

Trends in end digit preference for blood pressure and associations with cardiovascular outcomes in Canadian and UK Primary Care: a retrospective observational study

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Abstract

Objectives: to study systematic errors in recording blood pressure (BP) as measured by end digit preference (EDP); to determine associations between EDP, uptake of Automated Office BP (AOBP) machines and cardiovascular outcomes.

Design: Retrospective observational study using routinely collected electronic medical record data from 2006 to 2015 and a survey on year of AOBP acquisition in Toronto, Canada in 2017.

Setting: Primary care practices in Canada and the UK

Participants: Adults aged 18 years or more.

Main outcome measures: Mean rates of EDP and change in rates. Rates of EDP following acquisition of an AOBP machine. Associations between site EDP levels and mean BP. Associations between site EDP levels and frequency of cardiovascular outcomes.

Results: 707,227 patients in Canada and 1,558,471 patients in the UK were included. From 2006 to 2015, the mean rate of BP readings with both systolic and diastolic pressure ending in zero decreased from 26.6% to 15.4% in Canada and from 24.2% to 17.3% in the U.K. Systolic BP readings ending in zero decreased from 41.8% to 32.5% in the three years following the purchase of an AOBP machine. Sites with high EDP had a mean systolic BP of 2.0 mmHg in Canada, and 1.7 mmHg in the UK, lower than sites with no or low EDP. Patients in sites with high levels of EDP had a higher frequency of stroke (standardized morbidity ratio SMR 1.15, 95% CI 1.12-1.17), myocardial infarcts (SMR 1.16, 95% CI 1.14-1.19), and angina (SMR 1.25, 95% CI 1.22-1.28) than patients in sites with no or low EDP.

Conclusions: Acquisition of an AOBP was associated with a decrease in EDP levels. Sites with higher rates of EDP rounded BP readings down and had a higher frequency of adverse cardiovascular outcomes. The routine use of manual office-based BP measurement should be reconsidered.

Strengths and limitations of this study

- The study found that the purchase of AOBP machines by primary care offices was followed by more accurate BP measurement
- Offices with less accurate BP measurement (more end digit preference) rounded BP readings down
- These offices also had higher frequencies of adverse cardiovascular outcomes
- The survey of AOBP machine purchase was done only in Ontario; we infer that the purchase of an AOBP machine was associated with less end digit preference elsewhere

Introduction:

High blood pressure (BP) is a leading cause of increased morbidity and early mortality in adults.[1] BP should be routinely measured as part of clinical encounters.[2] However, there are long standing concerns about the precision and accuracy of BP measurement in practice.[3,4] There is evidence that measuring BP manually, using an aneroid or mercury column sphygmomanometer, is associated with systematic recording errors including end digit preference (EDP) and observer bias.[5] EDP means that the observer rounds off the last digit;[6] for example, BPs end in zero for up to 60% of records instead of the expected 10%.[7,8] Observer bias means that BP is adjusted towards a preferred level (rounding up or rounding down).[8] These issues may lead to errors in the diagnosis and treatment of hypertension.[9]

Automated Office BP (AOBP) measurement uses a machine to record and report the numerical values of systolic and diastolic BPs on a digital display.[10] Three to six recordings are done; the initial reading is discarded and the remaining readings are averaged.[11] Research suggests that EDP is reduced as a result of this method. [9,11] AOBP is comparable to the gold standard of 24-hour automated home BP monitoring.[12] Canadian and European hypertension guidelines now recommend AOBP as the preferred method for office-based measurement of BP,[2,13] but have not made a recommendation to discontinue the routine use of manual BP measurement.

There is evidence that AOBP machines are increasingly used in primary care; it has been reported that more than 10,000 AOBP machines are currently in use in Canada.[11] In a recent Canadian survey, 43% of family physicians reported using AOBP to screen for hypertension.[14] However, the proportion of office BP measurements done using AOBP when machines are available in an office is not known. Changes in the proportion of BPs with EDP could serve as a marker of increasing use of AOBP in primary care practice, though this requires validation.

Accurate measurement is essential for BP control. There is a need to quantify systematic BP measurement errors in primary care, consider these in the context of changing AOBP use and estimate the effects of errors on cardiovascular outcomes affected by BP control.

The objectives of this study were therefore to (1) report the EDP levels with respect to patient and provider-level characteristics, (2) examine the changes in EDP with AOBP uptake in offices, (3) quantify prevalence and trends in systematic recording errors in BP recording and (4) determine associations between EDP and cardiovascular outcomes.

Methods:

We used a repeated cross-sectional observational design. We applied the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) checklist for reporting observational studies.[15]

Settings and Data sources

Canada

The Canadian Primary Care Sentinel Surveillance Network (CPCSSN) database was used for this study.[16] CPCSSN is Canada's largest electronic medical record (EMR)-based chronic disease surveillance system[16] and includes data collected from eleven primary care practice based research networks in 8 of Canada's 13 provinces and territories. Consenting family physicians and other primary care providers participating in CPCSSN contribute de-identified EMR data to regional network repositories; patients can opt-out if they choose to do so. Data from all participating networks are collected every six months and aggregated in a single central database.[16] The distribution of the CPCSSN patient population is reasonably similar to that of Canadian census.[17]

We used EMR data extracted and processed using procedures previously described.[16] CPCSSN case definition algorithms have been validated against chart audits for eight chronic conditions (diabetes, hypertension, chronic obstructive pulmonary disease, depression, osteoarthritis, dementia, parkinsonism and epilepsy) in multiple sites across Canada.[18]

U.K.

We repeated the analyses using the Royal College of General Practitioners Research and Surveillance Centre (RCGP RSC) database for the UK. This is one of Europe's oldest primary care sentinel networks.[6] It has been reported that the RCGP RSC has data of high quality for chronic disease, including diabetes[6] and cardiovascular outcomes.[19]
The RCGP RSC data are extracted weekly from the EMRs of >150 representative general practices (groups of physicians practicing in the same location) in England, covering a population of over 1.5 million patients and 3% of the population. A comparison of RCGP RSC practices with national pay-for-performance data, prescribing data, and the quality and outcomes framework suggests that data are representative of the national population in terms of age and gender of the population, ethnicity and deprivation.[6]

Study population

We used routinely collected clinical electronic medical record (EMR) data from primary care clinics across Canada and the UK. These data were extracted in Canada as of June 30th, 2016 and in the UK as of December 31st 2016. We examined BP measurements taken between January 1st, 2006 and December 31st, 2015 in the CPCSSN database and in the RCGP RSC database. We included all patients who were at least 18 years of age as of BP measurement date. We identified patient characteristics that may influence BP and its measurement. Patient variables included: age; sex; presence of hypertension and/or diabetes; body mass index; use of hypertensive medications. We recorded the total number of patients included for each site; a site was a group of physicians practicing in the same location.

Statistical Analysis

We examined the proportions of BPs ending in each digit in Canada and UK. We used the entire collection of BP records in both databases to estimate the unadjusted frequency of last digit zero for both systolic and diastolic BPs with respect to patient, site and temporal characteristics.

Since many patients had BP recorded multiple times with irregular visit to primary care between Jan 2006 to Dec 2015, we chose to discard excess information using a sampling mechanism.[20] In particular, we generated 1000 independent replicates using the stratified sampling without replacement where one BP measurement was randomly chosen for a given patient. Logistic regression was performed on 1000 independently sampled replicates of the CPCSSN and RCGP RSC database. The odds ratios were estimated using the mean and 95% confidence intervals were estimated using the 2.5% and 97.5% percentiles of one thousand bootstrap estimates.[21] All covariates in the regression model were held constant to their latest value for each patient with respect to the study follow-up. For example, the most recent information on BMI or the diagnosis of diabetes or hypertension medication was used for each patient.

To correlate rates of EDP with AOBP uptake, we conducted a subgroup analysis using data from UTOPIAN, the University of Toronto Practice Based Research Network. UTOPIAN is the largest network in CPCSSN, with about 25% of data in the national database; it includes providers and patients from Toronto and surrounding areas in southern Ontario, Canada. We collected data on AOBP use from UTOPIAN practices using a survey, shown in supplementary materials. We contacted office representatives through email/phone and asked them whether there was an AOBP in the office and when it was purchased. Office representatives were also asked to estimate how often BPs were done with the machine in the past year.

Responses were linked with EMR based blood pressure measurements for each site and the linked data were used for the subgroup analysis. We examined the association between length of time the machine was present in the office and the rate of EDP, as well as association between EDP for 2015 and the self-reported level of use in the past year.

We implemented unsupervised cluster analysis to categorize primary care sites into three groups for each year.[22] The three groups were labeled as: (1) high EDP; (2) medium EDP; and (3) low or no EDP. Practices were clustered by presence of less commonly recorded end digits (1,3,7,9) for both sBP and dBP; 40% of BPs would be expected to end in one of those digits. To control for excessive noise in the data, we chose to exclude the sites with less than 1000 BP measurements within a year.

Since the changes in uncommon end digits (1,3,7,9) may be confounded by the recruitment of new sites over time or changes in patient populations within sites, the proportion of recording uncommon digits was reported for each measurement year, giving a rate of EDP per site per year. The similarity between all pairs belonging to the same cluster was computed using the Ward score.[23] We examined the mean sBP among patients with and

without hypertension and diabetes using the classification obtained from the cluster analysis.

We estimated the annual frequency of three cardiovascular events (myocardial infarct, angina, stroke) using UK data; these conditions have not yet been validated in the Canadian data in CPCSSN. We compared sites with high EDP in each year against sites with low or no EDP for the same year. The denominator was defined as the total number of patients who had at least one blood pressure recorded within each year of interest for each group. The numerator was defined as the total number of patients included in the denominator with a cardiovascular event within the same year. Patients with a cardiovascular event were censored in subsequent years. We estimated the standardized morbidity ratio for each condition in groups with high EDP compared to groups with low or no EDP.

This study was reviewed and approved by the Research Ethics Board (REB) at the University of Toronto; the survey was reviewed and approved by REBs at each participating site. REB approval was not deemed to be necessary for the UK, as no patients were identified; this was classified as a service evaluation. The study received a favorable opinion from the RCGP RSC study review panel. CPCSSN has received REB approval from Health Canada, and each host university for all participating practice-based research networks. All participating primary care providers have provided written informed consent for the collection and analysis of their EMR data. All statistical analyses were conducted using SAS software, version 9.4 M4 (SAS Institute).

Patient and public involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in developing plans for design or implementation of the study. We received input into the study from Patient and Public representatives who commented on the relevance of the question and the potential impact of the research on outcomes.

Results:

Data from 181 sites and 707,227 patients in CPCSSN were included; there were 5.5 million BP records. Data from 164 sites and 1,558,471 patients in the RCGP RSC database were included; there were 13.4 million BP records. Each patient was counted once, regardless of the number of BPs and number of years in which they had a BP recorded. The most frequently recorded end digit was zero while the least frequent end digits were one, three, seven and nine (Table 1, Figure 1).

Patient and site characteristics and trends in levels of EDP are shown in table 2. The frequency of last digit zero for both systolic and diastolic BP decreased by 11.2% in Canada and by 6.9% in the UK from 2006 to 2015. Table 3 describes the adjusted odds ratios (ORs) of recording zero as the last digit of systolic BP. The ORs of last digit zero were greater among female patients (CPCSSN: OR=1.10, 95% CI 1.09-1.11; RCGP: OR=1.16, 95% CI 1.15-1.16). Patients with hypertension were less likely to have EDP than patients without

hypertension (CPCSSN: OR=0.89, 95% CI 0.88-0.91; RCGP RSC: OR=0.79, 95% CI 0.78-0.80). Patients with diabetes were less likely to have EDP in Canada (OR=0.98 95% CI: 0.96-0.99) but were more likely to have this in the UK (OR=1.025 95% CI:1.01-1.04). ORs of EDP decreased as BMI levels increased in Canada but not in the UK.

65 UTOPIAN sites were surveyed; 55 (85%) responded. 93% of the UTOPIAN sites reported having at least one AOBP machine in the practice; most were bought between 2007 and 2014. Even when AOBP machines were present, most offices reported still using manual measurement. There was a reduction of 9.3% (from 41.7% to 32.5%) in the proportion of systolic BPs ending in zero within three years of adopting the AOBP machines (95% CI: -8.9% to -9.8%). Family practices who reported rarely or never using AOBP machines had higher end digit preference than those reporting at least some use of AOBP (Figure 2).

As illustrated in Figure 3, cluster analyses were used to find the optimal decision boundaries to classify sites into high EDP, medium EDP, low or no EDP for Canada and UK. Table 4 provides the number and percentage of sites in each group. In 2006 there was only one Canadian site (3.6%) with low or no EDP while in the UK, 61 sites (38.4%) were in this group. Sites exhibiting high EDP decreased by 47.7% in Canada and by 15.1% in the UK from 2006 to 2015. In contrast, the proportion of sites classified as having low or no EDP increased by 22.9% in Canada and 12.8% in the UK.

The mean systolic BP by EDP group is shown on Table 5. Sites with low or no EDP had a higher mean systolic BP than sites with high EDP (1.97mmHg in Canada; 1.76mmHg in UK). When stratified by presence or absence of hypertension or diabetes, the direction was similar with differences ranging from 0.9 to 2.4 mm Hg.

As shown in figure 4, we observed a higher mean frequency of myocardial infarct (0.40%, 95% CI 0.39 to 0.41), stroke (0.64%, 95% CI 0.63 to 0.65) and angina (0.42%, 95% CI 0.41 to 0.43) in sites with high EDP as compared to sites with low or no EDP: 0.34% (95% CI 0.33 to 0.35), 0.56% (95% CI 0.55 to 0.57) and 0.33% (95% CI 0.32 to 0.34)respectively. Table 6 provides the standardized morbidity ratio; this was higher for all three conditions for sites with high EDP compared to sites with low or no EDP.

Discussion:

We found significant levels of systematic recording errors in BP measurement in the UK and Canada; these decreased over time. There was an association between the length of time an AOBP machine was present in an office and a decrease in EDP. Higher rates of EDP, and presumably more use of manual BP recording in those sites, appeared to be associated with rounding down of BPs and a higher frequency of adverse cardiovascular outcomes.

Our study found decreasing rates of in EDP; there have been increasingly strong guideline recommendations to switch to AOBP.[2,24] While a recent survey found that almost half of Canadian physicians reported using AOBP to screen for hypertension,[14] most offices in this study reported continued use of manual BP measurement for some patients even when an

AOBP machine was present in the office. We found a gradual decrease in EDP associated with the length of time that AOBP has been present in the office, indicating that physicians and sites may be increasingly accustomed to its routine use for measurement.

European Guidelines recommending adoption of AOBP were associated with a large decrease in recorded blood pressures ending in zero in the U.K., from 71.2% in 1996-1997 to 36.7% in 2005-2006.[25] UK studies based on the Quality Improvement in Chronic Kidney Disease (QICKD) trial[26] have shown reductions over time, presumably related to the progressive introduction of AOBP – though this assumption was not validated.[27] In addition, there were changes in the patterns of recording odd vs. even terminal digits. Another study in China also noted decreases in EDP over time.[28] Implementation of AOBP in offices thus appears to be correlated with decreases in EDP.[3,7,25]

The use of AOBP measurement resulted in lower readings than manual BP measurement (by 5 to 10 mmg Hg) in a randomized controlled trial (RCT); AOBP readings agreed more closely with the gold standard of 24 hour BP measurement than manual BP readings.[11] The introduction of AOBP should therefore be associated with a combination of lower rates of EDP (greater precision) and lower BP readings that are more consistent with the gold standard (greater accuracy). An observational study, however, found an association between higher rates of EDP and lower mean systolic BP, by 2 to 3 mm Hg.[25] A study in the UK found that the change from manual to AOBP in primary care practices resulted in lower rates of EDP but no changes in mean BP.[3]

We found that sites with low or no EDP (those presumably using AOBP more consistently) had a mean BP that was close to 2 mm Hg higher than those with greater rates of EDP (and presumably more use of manual BP in the practice) rather than the expected 5 mm Hg lower. Therefore, observer errors associated with manual BP may have resulted in both rounding towards zero and systematically rounding down. Rounding down was observed for patients with diabetes and hypertension as well as for those without these conditions. This could potentially lead to under-diagnosis of hypertension and under-treatment of diagnosed hypertension.

A possible explanation for the observation of rounding down is provided by Prospect Theory, used in Behavioral Economics, which describes decisions made under conditions of uncertainty. Negative perceptions about possible risks (or risk aversion) outweigh positive perceptions about possible gains.[29] There may be a behavioral bias towards rounding down; this may avoid perceived risks associated with adding more medications with less emphasis on gains from cardiovascular outcome prevention.

A large cluster RCT (CHAP) documented improved management of hypertension in communities randomized to the intervention. This consisted of more accurate AOBP-based measurement in pharmacies with forwarding of abnormal BP results to family physicians.[30] The CHAP intervention resulted in a significant decrease in hospitalizations due to cardiovascular disease (myocardial infarction, stroke, heart failure).[30] In that trial, there was an improvement in BP from a mean of 142 mm Hg to 123 mm Hg when the initial pharmacy-based reading was elevated.[31] Systematically more accurate measurement of BP

through the use of AOBP in the community, followed by notification of the primary care provider when BP was elevated, may have resulted in more treatment of elevated BP in primary care and decreased adverse cardiovascular outcomes.

The results in this real world observational study in two countries are plausibly consistent with those of the CHAP RCT. We found that practices with greater precision for BP measurement (less EDP) also had a lower prevalence of adverse cardiovascular outcomes for their patients. It is possible that these practices were using AOBP more often and were thus measuring BP with greater accuracy. Systematic rounding down associated with higher rates of EDP and presumably greater use of manual BP measurement by practices in this study appeared to be associated with an elevated frequency of adverse cardiovascular outcomes.

A switch to routine use of AOBP for most office-based BP measurements would require the purchase of enough machines to support the number of physicians and patients in each office, training of staff and health care providers, and changes in offices processes to support more consistent us of AOBP. We are not aware of financial or other practice level incentives in either country promoting this change.

Limitations

The study has several strengths. We used data from routine community-based primary care. We also included a large sample of both patients and primary care providers from multiple settings across Canada and the UK, observed over a decade or more. Therefore, this study reasonably reflects current clinical practices for individuals receiving primary care in both countries.

This study has several shortcomings. This was a convenience sample of primary care practices that contributed EMR data to CPCSSN and the RCGP RSC. We surveyed practices for their use of AOBP in one network only (UTOPIAN); the survey was done at the office level rather than by physician. There may be recall bias and the actual proportion of patients whose BP was measured using an AOBP is unknown.

The study was not randomized; therefore, there may be unmeasured confounders associated with both higher incidence of cardiovascular outcomes and greater rates of EDP. These could include incentives or programs that could lead to improved precision in BP measurement along with lower rates in cardiovascular outcomes, such as quality standards or funding. Our findings are associations rather than causation. Nonetheless, the differences between groups persisted as practices switched to lower rates of EDP over time and there is no a priori reason to expect a change in unmeasured confounders in practices switching to AOBP and lower rates of EDP.

Conclusions

In conclusion, systematic measurement errors including rounding down are associated with higher rates of EDP. It is likely that this is associated with more manual BP measurement in these primary care practices and in turn is correlated with a higher risk of adverse cardiovascular outcomes at a population level, although we cannot infer a causal relationship. Our findings suggest that the continued routine use of manual measurement of BP in primary care offices may be problematic. We recommend the use of AOBP as the standard of care for measuring and monitoring BP in medical offices.

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The authors have no competing interests to declare.

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Michelle Greiver (MG), Frank Sullivan (FS), Sumeet Kalia (SK) and Simon de Lusignan (SdeL) contributed to conception and design. Babak Aliarzadeh (BA) was responsible for acquisition of Canadian, and SdeL for UK data. Saddaf Syed (SS) was responsible for conducting the survey. SK, Rahim Moineddin (RM) and William Hinton (WH) contributed substantially to the analysis of data. MG and SK with input from SdeL drafted the initial version of the article. All authors, including Teja Voruganti, Martin Dawes and John Williams contributed to the interpretation of data. All authors reviewed and revised the article for important intellectual content and gave final approval of the version to be published. MG is the guarantor of this work, with SdeL for the RCGP RSC data, and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. MG had final responsibility for the decision to submit for publication.

Data are from a nationally representative Canadian repository of primary care EMR data, the Canadian Primary Care Sentinel Surveillance Network (http://cpcssn.ca). CPCSSN data are available to researchers as outlined in the process available on the website, cpcssn.ca . Similarly, the Royal College of General Practitioners (RCGP) Research and Surveillance Centre (RSC) network database can be accessed by researchers following the process set out at: www.rcgp.org.uk/rsc. Extra data is available by emailing michelle.greiver@nygh.on.ca.

Table 1: Frequency of end-digits for systolic and diastolic blood pressures

End-digits	Canada		UK	
	Systolic BP	Diastolic BP	Systolic BP	Diastolic BP
0	32.4%	35.9%	33.8%	34.0%
1	3.6%	3.7%	4.5%	4.5%
2	13.1%	10.9%	10.3%	9.6%
3	3.8%	3.8%	4.8%	4.7%
4	10.4%	10.0%	9.1%	9.3%
5	7.2%	6.8%	8.3%	8.2%
6	9.3%	8.9%	8.5%	8.4%
7	3.9%	3.8%	4.9%	4.8%
8	12.6%	12.4%	11.2%	11.6%
9	3.8%	3.4%	4.8%	4.9%

Table 2: Patient/site characteristics and blood pressure measurements ending in zero for both systolic BP and diastolic BP in Canada (CPCSSN) and the UK (RCGP RSC database)

	Canada			UK		
Characteristics	**Number of Patients (% of patients)**	**Number of Blood Pressures (% of BPs)**	**Number of BPs with both systolic and diastolic BP ending in zero (% with both ending in zero)**	**Number of Patients (% of patients)**	**Number of Blood Pressures (% of BPs)**	**Number of BPs with both systolic and diastolic BP ending in zero (% with both ending in zero)**
Total	707,227	5,503,663	1,044,031 (19.0%)	1,558,471	13,424,678	2,674,497 (19.9%)
Age in years						
18 to 39	189,254 (26.8%)	816,136 (14.8%)	165,025 (20.2%)	531,632 (34.1%)	2,330,344 (17.4%)	538,786(23.1%)
40 to 59	247,771 (35%)	1,534,126 (27.9%)	292,435 (19.1%)	498,272 (32.0%)	3,298,174 (24.6%)	631,260(19.1%)
60 to 79	201,364 (28.5%)	2,115,655 (38.4%)	377,724 (17.9%)	352,483 (22.6%)	4,879,583 (36.3%)	868,894(17.8%)
80+	68,838 (9.7%)	1,037,716 (18.9%)	208,847 (20.1%)	176,084 (11.3%)	2,916,577 (21.7%)	635,557(21.8%)
Sex						
Female	414,644 (58.6%)	3,325,256 (60.4%)	648,357 (19.5%)	901,866 (57.9%)	8,133,678 (60.6%)	1,708,742(21.0%)
Male	292,583 (41.4%)	2,178,377 (39.6%)	395,674 (18.2%)	656,605 (42.13%)	5,291,000 (39.4%)	965,755(18.3%)
BMI range						
Underweight (BMI <18.5)	10,233 (1.4%)	70,776 (1.3%)	14,649 (20.7%)	44,654 (2.9%)	308,481 (2.3%)	71,234(23.1%)
Normal weight (18.5 to 24.9)	170,684 (24.1%)	1,177,970 (21.4%)	236,883 (20.1%)	560,214 (36.0%)	4,071,114 (30.3%)	852,192(20.9%)
Overweight (25 to 29.9)	182,141 (25.8%)	1,545,777 (28.1%)	283,163 (18.3%)	446,850(28.7%)	4,412,326 (32.9%)	842,338(19.1%)
Obesity class I (30 to 34.9)	101,980 (14.4%)	1,013,286 (18.4%)	175,781 (17.3%)	200,761 (12.9%)	2,421,241 (18.0%)	455,572(18.8%)
Obesity class II (35 to 39.9)	42,235 (6.0%)	468,239 (8.5%)	77,408 (16.5%)	71,450 (4.6%)	928,259 (6.9%)	176,969(19.1%)
Obesity class III (≥40)	27,451 (3.9%)	320,682 (5.8%)	52,327 (16.3%)	37,370 (2.4%)	491,533 (3.7%)	96,589(19.7%)
Not available	172,503 (24.4%)	906,903 (16.5%)	203,820 (22.5%)	197,172 (12.7%)	791,724 (5.9%)	179,603(22.7%)
Diabetes						

Yes	86,103 (12.2%)	1,299,693 (23.6%)	233,944 (18%)	65,335(4.2%)	1,909,804 (14.2%)	359,324(18.8%)
No	621,124 (87.8%)	4,203,940 (76.4%)	810,087 (19.3%)	1,493,136 (95.1%)	11,514,874 (85.8%)	2,315,173(20.1%)
Hypertension						
Yes	185,508 (26.2%)	2,704,921 (49.1%)	486,787 (18%)	235,716 (15.1%)	6,359,131 (47.4%)	1,141,665(18.0%)
No	521,719 (73.8%)	2,798,712 (50.9%)	557,244 (19.9%)	1,322,755 (84.9%)	7,065,547 (52.6%)	1,532,832(21.7%)
Hypertension medications						
Yes	125,484 (17.7%)	2,704,947 (49.1%)	395,371 (17.7%)	466,800 (30.0%)	8,327,009 (62.0%)	1,571,464(18.9%)
No	581,743 (82.3%)	2,798,686 (50.9%)	648,660 (19.8%)	1,091,671 (70.1%)	5,097,669 (38.0%)	1,103,033(21.6%)
Practice site size						
1st quartile (smallest site)	36,363 (5.1%)	249,957 (4.5%)	63,781 (25.5%)	173610(11.1%)	1,671,387 (12.5%)	303,084(18.1%)
2nd quartile	77,776 (11%)	584,575 (10.6%)	110,411 (18.9%)	305460(19.6%)	2836288 (21.1%)	480,604(16.9%)
3rd quartile	156,601 (22.1%)	1,156,892 (21.0%)	228,521 (19.8%)	416580(26.7%)	3,774,278	846,481(22.4%)
4th quartile (largest site)	436,487 (61.7%)	3,512,209 (63.8%)	641,318 (18.3%)	662821(42.5%)	5,142,725	1,044,328(20.3%)
Measurement year*						
2006	52,168 (7.4%)	121,355 (2.2%)	32,335 (26.6%)	542,695(34.8%)	1,347,400 (10.0%)	325,843(24.2%)
2007	81,699 (11.6%)	183,591 (3.3%)	49,030 (26.7%)	553,033(35.5%)	1,342,979 (10.1%)	303,477(22.6%)
2008	125,781(17.8%)	277,858 (5.0%)	72,772 (26.2%)	563,222(36.1%)	1,353,092 (10.1%)	288,418(21.3%)
2009	167,345(23.7%)	368,245 (6.7%)	94,871 (25.8%)	572,940(36.8%)	1,358,664 (10.1%)	278,829(20.5%)
2010	213,250(30.2%)	531,316 (9.7%)	117,612 (22.1%)	580,069(37.2%)	1,340,279 (10.0%)	266,242(19.9%)
2011	263,691(37.3%)	615,364 (11.2%)	125,282 (20.4%)	590,921(37.9%)	1,354,956 (10.1%)	257,309(19.0%)
2012	299,590(42.4%)	700,903 (12.7%)	128,192 (18.3%)	602,642(38.7%)	1,347,042 (10.0%)	249,344(18.5%)
2013	332,809(47.1%)	813,009 (14.8%)	133,434 (16.4%)	617,073(39.6%)	1,366,085 (10.2%)	246,754(18.1%)
2014	360,180(50.9%)	894,350 (16.3%)	137,181 (15.3%)	612,382(39.3%)	1,325,141 (9.9%)	235,377(17.8%)
2015	386,541(54.7%)	997,642 (18.1%)	153,322 (15.4%)	594,589(38.2%)	1,289,040 (9.6%)	222,904(17.3%)

*considering repeated measurements of blood pressure for each patient with respect to measurement year.

BMI - body mass index (weight in kg / height in meters^2)

Table 3: Adjusted odds ratios of recording zero as the last digit of systolic blood pressure by patient and site characteristics

			Canada				UK			
Effect	**Index Group**	**Reference group**	**Odds ratio**	**95% confidence interval**		**P-value**	**Odds ratio**	**95% confidence interval**		**P-value**
Age	18 to 39	80+	1.088	1.063	1.112	<0.001	0.784	0.773	0.795	<0.001
	40 to 59	80+	1.012	0.990	1.034	0.294	0.788	0.777	0.798	<0.001
	60 to 79	80+	0.942	0.923	0.963	<0.001	0.783	0.772	0.794	<0.001
Sex	Female	Male	1.100	1.089	1.112	<0.001	1.156	1.148	1.163	<0.001
BMI	Underweight (BMI <18.5)	Obesity class III (BMI ≥40)	1.316	1.267	1.366	<0.001	1.047	1.019	1.074	0.001
	Normal (BMI 18.5 to 24.9)	Obesity class III	1.226	1.192	1.258	<0.001	0.960	0.939	0.980	<0.001
	Overweight (BMI 25 to 29.9)	Obesity class III	1.135	1.104	1.166	<0.001	0.947	0.926	0.966	<0.001
	Obesity class I (BMI 30 to 34.9)	Obesity class III	1.065	1.036	1.096	<0.001	0.953	0.932	0.973	<0.001
	Obesity class II (BMI 35 to 39.9)	Obesity class III	1.008	0.978	1.040	0.618	0.967	0.943	0.992	0.007
Diabetes	Yes	No	0.982	0.964	0.999	0.047	1.025	1.008	1.042	0.004
Hypertension	Yes	No	0.892	0.877	0.908	<0.001	0.790	0.780	0.799	<0.001
Hypertension medications	Yes	No	0.967	0.947	0.986	0.001	1.057	1.047	1.068	<0.001
Practice Site size	1st quartile (smallest site)	4th quartile (largest site)	1.950	1.908	1.990	<0.001	0.816	0.809	0.823	<0.001
	2nd quartile	4th quartile (largest site)	1.075	1.058	1.094	<0.001	0.893	0.885	0.900	<0.001
	3rd quartile	4th quartile (largest site)	1.087	1.074	1.100	<0.001	0.891	0.883	0.899	<0.001
Measurement year	2006	2015	1.910	1.833	1.990	<0.001	1.647	1.625	1.668	<0.001
	2007	2015	1.923	1.857	1.989	<0.001	1.473	1.451	1.494	<0.001
	2008	2015	1.840	1.790	1.895	<0.001	1.376	1.357	1.396	<0.001
	2009	2015	1.858	1.815	1.903	<0.001	1.321	1.300	1.341	<0.001
	2010	2015	1.582	1.548	1.617	<0.001	1.257	1.238	1.275	<0.001
	2011	2015	1.379	1.352	1.407	<0.001	1.178	1.161	1.196	<0.001
	2012	2015	1.239	1.216	1.262	<0.001	1.112	1.094	1.129	<0.001
	2013	2015	1.096	1.077	1.116	<0.001	1.052	1.038	1.067	<0.001
	2014	2015	1.037	1.021	1.052	<0.001	1.016	1.000	1.030	0.041

BMI - body mass index (weight in kg / height in meters^2)

Table 4: Number and percentage of sites in each EDP group from 2006 to 2015

Year	Canada						UK					
	Low or no EDP		Medium EDP		High EDP		Low or no EDP		Medium EDP		High EDP	
	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)
2006	1	3.6%	1	3.6%	26	92.9%	61	38.4%	39	24.5%	59	37.1%
2007	3	7.3%	3	7.3%	35	85.4%	69	42.9%	41	25.5%	51	31.7%
2008	8	13.8%	3	5.2%	47	81.0%	71	44.1%	45	28.0%	45	28.0%
2009	8	11.1%	7	9.7%	57	79.2%	74	46.0%	45	28.0%	42	26.1%
2010	15	15.3%	11	11.2%	72	73.5%	76	46.6%	45	27.6%	42	25.8%
2011	17	15.5%	16	14.5%	77	70.0%	78	47.9%	45	27.6%	40	24.5%
2012	27	21.8%	25	20.2%	72	58.1%	82	50.3%	40	24.5%	41	25.2%
2013	33	22.8%	33	22.8%	79	54.5%	79	48.5%	48	29.4%	36	22.1%
2014	30	20.0%	41	27.3%	79	52.7%	85	52.1%	42	25.8%	36	22.1%
2015	41	26.5%	44	28.4%	70	45.2%	84	51.2%	44	26.8%	36	22.0%

EDP – End digit preference

Table 5: Mean systolic blood pressure by EDP group

		CPCSSN database (Canada)			RCGP RSC database (UK)		
		No. of BP measurements	Mean sBP in mm Hg	Std. Dev.	No. of BP measurements	Mean sBP in mm Hg	Std. Dev.
All patients	**Low or no EDP**	1,151,795	128.21	18.92	5,618,800	135.05	20.09
	High EDP	2,925,279	126.24	18.52	3,624,391	133.29	19.63
	Difference		1.97			1.76	
Hypertensive	**Low or no EDP**	584,082	134.59	19.29	2,687,218	142.63	19.03
	High EDP	1,436,251	133.51	18.36	1,715,006	141.23	18.19
	Difference		1.08			1.40	
Non-hypertensive	**Low or no EDP**	567,713	121.65	16.09	2,931,582	128.10	18.44
	High EDP	1,489,028	119.23	15.77	1,909,385	126.15	18.07
	Difference		2.42			1.95	
Diabetic	**Low or no EDP**	300,630	131.42	18.81	823,959	138.89	18.75
	High EDP	675,920	130.52	18.09	515,843	136.76	17.79
	Difference		0.9			2.13	
Non-Diabetic	**Low or no EDP**	851,165	127.08	18.83	4,794,841	134.39	20.23
	High EDP	2,249,359	124.96	18.46	3,108,548	132.71	19.86
	Difference		2.12			1.68	

EDP – End digit preference
sBP – systolic blood pressure
Std. Dev – standard deviation
Std. Dev – standard deviation

Table 6: Standardized morbidity ratio for groups with high EDP group when compared to groups with low or no EDP

Angina			
Parameter	**Estimate**	**95% Confidence Limits**	
Standardized morbidity ratio	1.25	1.22	1.28
Acute Myocardial infraction			
Standardized morbidity ratio	1.16	1.14	1.19
Stroke			
Standardized morbidity ratio	1.15	1.12	1.17

EDP – End digit preference

Figure legends

Figure 1: Histogram of systolic and diastolic blood pressure in Canada and the UK

Figure 2: Impact of adopting automated office blood pressure machines on end digit preference for systolic blood pressure in Toronto

Figure 3: Proportions of systolic and diastolic BPs ending in 1, 3, 7 or 9 per practice site for each year of interest in Canada and UK from 2006 to 2015

Figure 4: Frequency of cardiovascular events in high EDP and no or low EDP group in the UK

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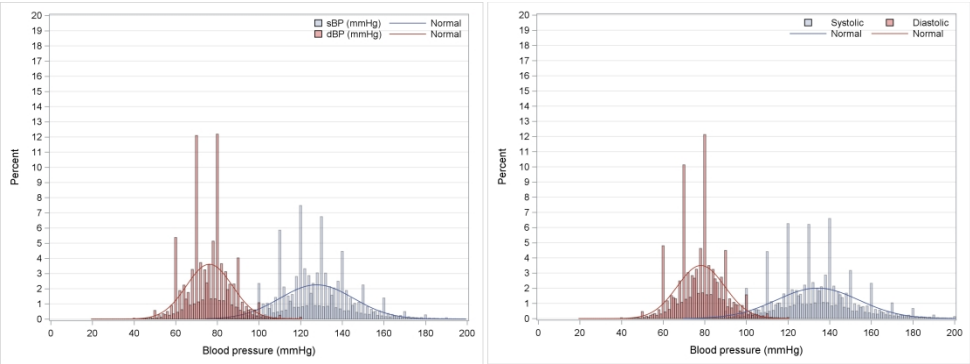

Figure 1: Histogram of systolic and diastolic blood pressure in Canada(left) and the UK (right)

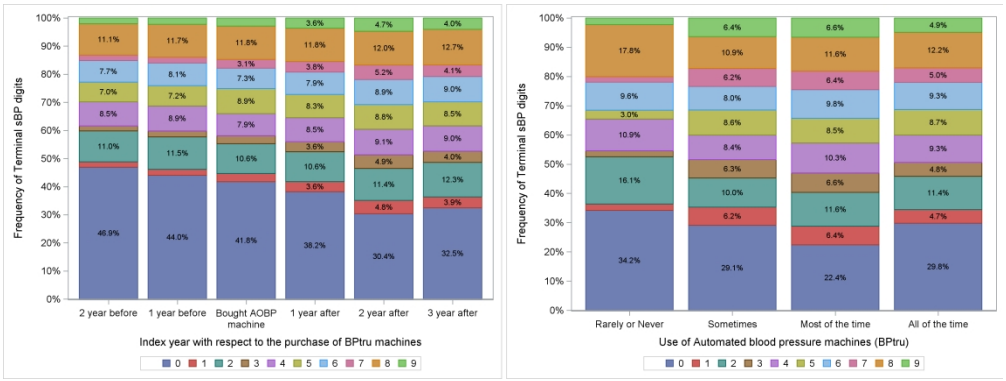

Figure 2: Impact of adopting automated office blood pressure machines on end digit preference for systolic blood pressure in Toronto

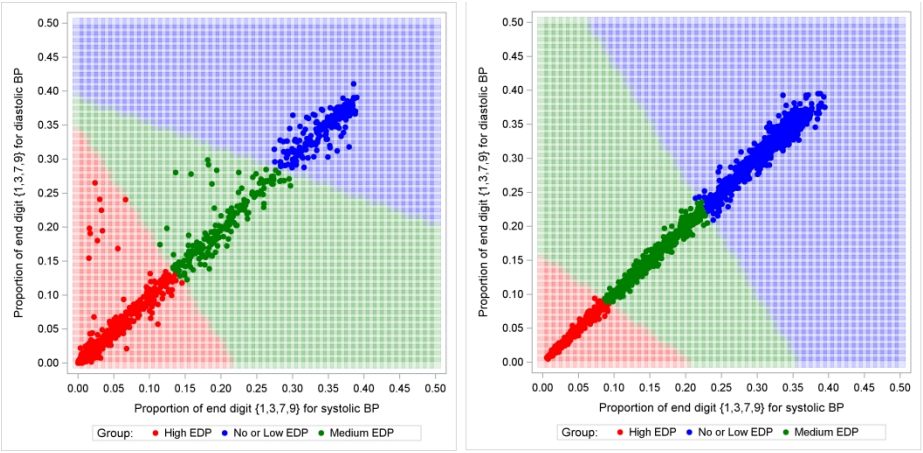

Figure 3: Proportions of systolic and diastolic BPs ending in 1, 3, 7 or 9 per practice site for each year of interest in Canada (left) and UK (right) from 2006 to 2015

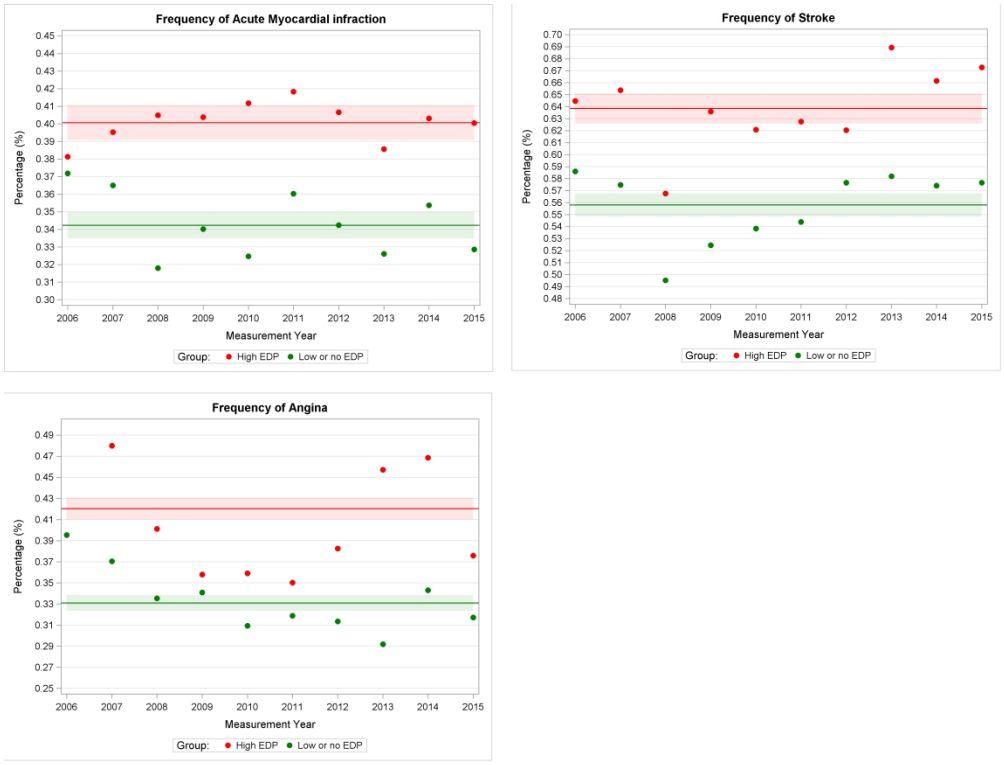

Figure 4: Frequency of cardiovascular events in high EDP and no or low EDP group in the UK

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract: **Page 1**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found: **Page 2**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **Page 3-4**
Objectives	3	State specific objectives, including any prespecified hypotheses **Page 3**
Methods		
Study design	4	Present key elements of study design early in the paper **Page 3**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **Page 4-5**
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants **Page 4**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **Page 4**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **Page 5-6**
Bias	9	Describe any efforts to address potential sources of bias **N/A**
Study size	10	Explain how the study size was arrived at **N/A**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **Page 5-6**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **Page 5-6**
		(*b*) Describe any methods used to examine subgroups and interactions **Page 5-6**
		(*c*) Explain how missing data were addressed **N/A**
		(*d*) If applicable, describe analytical methods taking account of sampling strategy **N/A**
		(*e*) Describe any sensitivity analyses **N/A**
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **Page 6**
		(b) Give reasons for non-participation at each stage **N/A**
		(c) Consider use of a flow diagram **N/A**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **Page 6**
		(b) Indicate number of participants with missing data for each variable of interest **Page 7**
Outcome data	15*	Report numbers of outcome events or summary measures **Page 7**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **Page 7**

		(*b*) Report category boundaries when continuous variables were categorized **Page 7**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **N/A**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **Page 7**
Discussion		
Key results	18	Summarise key results with reference to study objectives **Page 7**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **Page 8-9**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **Page 7-9**
Generalisability	21	Discuss the generalisability (external validity) of the study results **Page 9**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **Page 10**

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

1) Is there an automated machine (e.g. BPTru) in your office?

Yes [ ]
No [ ]

2) If Yes, when was the machine purchased?

Year [ ]
Month [ ]

3) If Yes, how many BP machines are there at your office?

Enter digit [ ]

4) How many exam rooms are there at your office?

Enter digit [ ]

5. Thinking of the past year, how often is the automated BP machine used to take blood pressures in your office?

-rarely or never

-some of the time

-most of the time

-almost all the time or all the time

BMJ Open

Trends in end digit preference for blood pressure and associations with cardiovascular outcomes in Canadian and UK Primary Care: a retrospective observational study

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Secondary Subject Heading:	General practice / Family practice, Health services research, Health informatics
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Authors & Title

Trends in end digit preference for blood pressure and associations with cardiovascular outcomes in Canadian and UK Primary Care: a retrospective observational study

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Abstract

Objectives: to study systematic errors in recording blood pressure (BP) as measured by end digit preference (EDP); to determine associations between EDP, uptake of Automated Office BP (AOBP) machines and cardiovascular outcomes.

Design: Retrospective observational study using routinely collected electronic medical record data from 2006 to 2015 and a survey on year of AOBP acquisition in Toronto, Canada in 2017.

Setting: Primary care practices in Canada and the UK

Participants: Adults aged 18 years or more.

Main outcome measures: Mean rates of EDP and change in rates. Rates of EDP following acquisition of an AOBP machine. Associations between site EDP levels and mean BP. Associations between site EDP levels and frequency of cardiovascular outcomes.

Results: 707,227 patients in Canada and 1,558,471 patients in the UK were included. From 2006 to 2015, the mean rate of BP readings with both systolic and diastolic pressure ending in zero decreased from 26.6% to 15.4% in Canada and from 24.2% to 17.3% in the U.K. Systolic BP readings ending in zero decreased from 41.8% to 32.5% in the three years following the purchase of an AOBP machine. Sites with high EDP had a mean systolic BP of 2.0 mmHg in Canada, and 1.7 mmHg in the UK, lower than sites with no or low EDP. Patients in sites with high levels of EDP had a higher frequency of stroke (standardized morbidity ratio SMR 1.15, 95% CI 1.12-1.17), myocardial infarcts (SMR 1.16, 95% CI 1.14-1.19), and angina (SMR 1.25, 95% CI 1.22-1.28) than patients in sites with no or low EDP.

Conclusions: Acquisition of an AOBP machine was associated with a decrease in EDP levels. Sites with higher rates of EDP had lower mean BPs and a higher frequency of adverse cardiovascular outcomes. The routine use of manual office-based BP measurement should be reconsidered.

Strengths and limitations of this study

- The study found that the purchase of AOBP machines by primary care offices was followed by more accurate BP measurement
- Offices with less accurate BP measurement (more end digit preference) rounded BP readings down
- These offices also had higher frequencies of adverse cardiovascular outcomes
- The survey of AOBP machine purchase was done only in Ontario; we infer that the purchase of an AOBP machine was associated with less end digit preference elsewhere

Introduction:

High blood pressure (BP) is a leading cause of increased morbidity and early mortality in adults.[1] BP should be routinely measured as part of clinical encounters.[2] However, there are long standing concerns about the precision and accuracy of BP measurement in practice.[3,4] There is evidence that measuring BP manually, using an aneroid or mercury column sphygmomanometer, is associated with systematic recording errors including end digit preference (EDP) and observer bias.[5] EDP means that the observer rounds off the last digit;[6] for example, BPs end in zero for up to 60% of records instead of the expected 10%.[7,8] Observer bias means that BP is adjusted towards a preferred level (rounding up or rounding down).[8] These issues may lead to errors in the diagnosis and treatment of hypertension.[9]

Automated Office BP (AOBP) measurement uses a machine to record and report the numerical values of systolic and diastolic BPs on a digital display.[10] Three to six recordings are done; the initial reading is discarded and the remaining readings are averaged.[11] Research suggests that EDP is reduced as a result of this method. [9,11] AOBP is comparable to the gold standard of 24-hour automated home BP monitoring.[12] Canadian and European hypertension guidelines now recommend AOBP as the preferred method for office-based measurement of BP,[2,13] but have not made a recommendation to discontinue the routine use of manual BP measurement.

There is evidence that AOBP machines are increasingly used in primary care; it has been reported that more than 10,000 AOBP machines are currently in use in Canada.[11] In a recent Canadian survey, 43% of family physicians reported using AOBP to screen for hypertension.[14] However, the proportion of office BP measurements done using AOBP when machines are available in an office is not known. Changes in the proportion of BPs with EDP could serve as a marker of increasing use of AOBP in primary care practice, though this requires validation.

Accurate measurement is essential for BP control. There is a need to quantify systematic BP measurement errors in primary care, consider these in the context of changing AOBP use and estimate the effects of errors on cardiovascular outcomes affected by BP control.

The objectives of this study were therefore to (1) report the EDP levels with respect to patient and provider-level characteristics, (2) examine the changes in EDP with AOBP uptake in offices, (3) quantify prevalence and trends in systematic recording errors in BP recording and (4) determine associations between EDP and cardiovascular outcomes.

Methods:

We used a repeated cross-sectional observational design. We applied the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) checklist for reporting observational studies.[15]

Settings and Data sources
Canada

The Canadian Primary Care Sentinel Surveillance Network (CPCSSN) database was used for this study.[16] CPCSSN is Canada's largest electronic medical record (EMR)-based chronic disease surveillance system[16] and includes data collected from eleven primary care practice based research networks in 8 of Canada's 13 provinces and territories. Consenting family physicians and other primary care providers participating in CPCSSN contribute de-identified EMR data to regional network repositories; patients can opt-out if they choose to do so. Data from all participating networks are collected every six months and aggregated in a single central database.[16] The distribution of the CPCSSN patient population is reasonably similar to that of Canadian census.[17]

We used EMR data extracted and processed using procedures previously described.[16] CPCSSN case definition algorithms have been validated against chart audits for eight chronic conditions (diabetes, hypertension, chronic obstructive pulmonary disease, depression, osteoarthritis, dementia, parkinsonism and epilepsy) in multiple sites across Canada.[18]

U.K.

We repeated the analyses using the Royal College of General Practitioners (RCGP) Research and Surveillance Centre (RSC) database for the UK. This is one of Europe's oldest primary care sentinel networks.[6] It has been reported that the RCGP RSC has data of high quality for chronic disease, including diabetes[6] and cardiovascular outcomes.[19]
The RCGP RSC data are extracted twice weekly from the EMRs of >150 representative general practices (groups of physicians practicing in the same location) in England, covering a population of over 1.5 million patients and 3% of the population. A comparison of RCGP RSC practices with national pay-for-performance data, prescribing data, and the quality and outcomes framework suggests that data are representative of the national population in terms of age and gender of the population, ethnicity and deprivation.[6] RCGP RSC includes comprehensive recording of cardiovascular risk factors and outcomes.[20]

Study population

We used routinely collected clinical electronic medical record (EMR) data from primary care clinics across Canada and the UK. These data were extracted in Canada as of June 30th, 2016 and in the UK as of December 31st 2016. We examined BP measurements taken between January 1st, 2006 and December 31st, 2015 in the CPCSSN database and in the RCGP RSC database. We included all patients who were at least 18 years of age as of BP measurement date. We identified patient characteristics that may influence BP and its measurement. Patient variables included: age; sex; presence of hypertension and/or diabetes; body mass index (BMI); use of hypertensive medications. We recorded the total number of patients included for each site; a site was a group of physicians practicing in the same location.

Statistical Analysis

We examined the proportions of BPs ending in each digit in Canada and UK. We used the entire collection of BP records in both databases to estimate the unadjusted frequency of last digit zero for both systolic and diastolic BPs with respect to patient, site and temporal characteristics.

Since many patients had BP recorded multiple times with irregular visit to primary care between Jan 2006 to Dec 2015, we chose to discard excess information using a sampling mechanism.[21] In particular, we generated 1000 independent replicates using the stratified sampling without replacement where one BP measurement was randomly chosen for a given patient. Logistic regression was performed on 1000 independently sampled replicates of the CPCSSN and RCGP RSC database. The odds ratios were estimated using the mean and 95% confidence intervals were estimated using the 2.5% and 97.5% percentiles of one thousand bootstrap estimates.[22] All covariates in the regression model were held constant to their latest value for each patient with respect to the study follow-up. For example, the most recent information on BMI or the diagnosis of diabetes or hypertension medication was used for each patient. We adjusted for patient variables that may influence BP or its measurement: age; sex; presence of hypertension and/or diabetes; BMI; use of hypertensive medications. We also adjusted for the size of the practice panels, as this may influence quality of care. Finally, we adjusted for year of measurement as EDP levels changed over time.

To correlate rates of EDP with AOBP uptake, we conducted a subgroup analysis using data from UTOPIAN, the University of Toronto Practice Based Research Network. UTOPIAN is the largest network in CPCSSN, with about 25% of data in the national database; it includes providers and patients from Toronto and surrounding areas in southern Ontario, Canada. We collected data on AOBP use from UTOPIAN practices using a survey, shown in supplementary materials. We contacted office representatives through email/phone and asked them whether there was an AOBP in the office and when it was purchased. Office representatives were also asked to estimate how often BPs were done with the machine in the past year.

Responses were linked with EMR based blood pressure measurements for each site and the linked data were used for the subgroup analysis. We examined the association between length of time the machine was present in the office and the rate of EDP, as well as association between EDP for 2015 and the self-reported level of use in the past year.

We implemented unsupervised cluster analysis to categorize primary care sites into three groups for each year.[23] The three groups were labeled as: (1) high EDP; (2) medium EDP; and (3) low or no EDP. Practices were clustered by presence of less commonly recorded end digits (1,3,7,9) for both sBP and dBP; 40% of BPs would be expected to end in one of those digits. To control for excessive noise in the data, we chose to exclude the sites with less than 1000 BP measurements within a year.

Since the changes in uncommon end digits (1,3,7,9) may be confounded by the recruitment of new sites over time or changes in patient populations within sites, the proportion of recording uncommon digits was reported for each measurement year, giving a rate of EDP per site per year. The similarity between all pairs belonging to the same cluster was computed using the Ward score.[24] We examined the mean sBP among patients with and without hypertension and diabetes using the classification obtained from the cluster analysis.

We estimated the annual frequency of three cardiovascular events (myocardial infarct, angina, stroke) using UK data; these conditions have not yet been validated in the Canadian data in CPCSSN. We compared sites with high EDP in each year against sites with low or no EDP for the same year. The denominator was defined as the total number of patients who had at least one blood pressure recorded within each year of interest for each group. The numerator was defined as the total number of patients included in the denominator with a cardiovascular event within the same year. Patients with a cardiovascular event were censored in subsequent years. We estimated the standardized morbidity ratio for each condition in groups with high EDP compared to groups with low or no EDP.

This study was reviewed and approved by the Research Ethics Board (REB) at the University of Toronto; the survey was reviewed and approved by REBs at each participating site. REB approval was not deemed to be necessary for the UK, as no patients were identified; this was classified as a service evaluation. The study received a favorable opinion from the RCGP RSC study review panel. CPCSSN has received REB approval from Health Canada, and each host university for all participating practice-based research networks. All participating primary care providers have provided written informed consent for the collection and analysis of their EMR data. All statistical analyses were conducted using SAS software, version 9.4 M4 (SAS Institute).

Patient and public involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in developing plans for design or implementation of the study. We received input into the study from Patient and Public representatives who commented on the relevance of the question and the potential impact of the research on outcomes.

Results:

Data from 181 sites and 707,227 patients in CPCSSN were included; there were 5.5 million BP records. Data from 164 sites and 1,558,471 patients in the RCGP RSC database were included; there were 13.4 million BP records. Each patient was counted once, regardless of the number of BPs and number of years in which they had a BP recorded. The most frequently recorded end digit was zero while the least frequent end digits were one, three, seven and nine (Table 1, Figure 1).

Patient and site characteristics and trends in levels of EDP are shown in table 2. The frequency of last digit zero for both systolic and diastolic BP decreased by 11.2% in Canada and by 6.9% in the UK from 2006 to 2015. Table 3 describes the adjusted odds ratios (ORs) of recording zero as the last digit of systolic and diastolic BP. The ORs of last digit zero were greater among female patients (CPCSSN: OR=1.10, 95% CI 1.09-1.11; RCGP: OR=1.16, 95% CI 1.15-1.16). Patients with hypertension were less likely to have EDP than patients without hypertension (CPCSSN: OR=0.89, 95% CI 0.88-0.91; RCGP RSC: OR=0.79, 95% CI 0.78-0.80). Patients with diabetes were less likely to have EDP in Canada (OR=0.98 95% CI: 0.96-0.99) but were more likely to have this in the UK (OR=1.025 95% CI:1.01-1.04). ORs of EDP decreased as BMI levels increased in Canada but not in the UK.

65 UTOPIAN sites were surveyed; 55 (85%) responded. 93% of the UTOPIAN sites reported having at least one AOBP machine in the practice; most were bought between 2007 and 2014. Even when AOBP machines were present, most offices reported still using manual measurement. There was a reduction of 9.3% (from 41.7% to 32.5%) in the proportion of systolic BPs ending in zero within three years of adopting the AOBP machines (95% CI: -8.9% to -9.8%). Family practices who reported rarely or never using AOBP machines had higher end digit preference than those reporting at least some use of AOBP (Figure 2).

As illustrated in Figure 3, cluster analyses were used to find the optimal decision boundaries to classify sites into high EDP, medium EDP, low or no EDP for Canada and UK. Table 4 provides the number and percentage of sites in each group. In 2006 there was only one Canadian site (3.6%) with low or no EDP while in the UK, 61 sites (38.4%) were in this group. Sites exhibiting high EDP decreased by 47.7% in Canada and by 15.1% in the UK from 2006 to 2015. In contrast, the proportion of sites classified as having low or no EDP increased by 22.9% in Canada and 12.8% in the UK.

The mean systolic BP by EDP group is shown on Table 5. Sites with low or no EDP had a higher mean systolic BP than sites with high EDP (1.97mmHg in Canada; 1.76mmHg in UK). When stratified by presence or absence of hypertension or diabetes, the direction was similar with differences ranging from 0.9 to 2.4 mm Hg.

As shown in figure 4, we observed a higher mean frequency of myocardial infarct (0.40%, 95% CI 0.39 to 0.41), stroke (0.64%, 95% CI 0.63 to 0.65) and angina (0.42%, 95% CI 0.41 to 0.43) in sites with high EDP as compared to sites with low or no EDP: 0.34% (95% CI 0.33 to 0.35), 0.56% (95% CI 0.55 to 0.57) and 0.33% (95% CI 0.32 to 0.34)respectively. Table 6 provides the standardized morbidity ratio; this was higher for all three conditions for sites with high EDP compared to sites with low or no EDP.

Discussion:

We found significant levels of systematic recording errors in BP measurement in the UK and Canada; these decreased over time. There was an association between the length of time an AOBP machine was present in an office and a decrease in EDP. Higher rates of EDP,

and presumably more use of manual BP recording in those sites, appeared to be associated with rounding down of BPs and a higher frequency of adverse cardiovascular outcomes.

Our study found decreasing rates of in EDP; there have been increasingly strong guideline recommendations to switch to AOBP.[2,25] While a recent survey found that almost half of Canadian physicians reported using AOBP to screen for hypertension,[14] most offices in this study reported continued use of manual BP measurement for some patients even when an AOBP machine was present in the office. We found a gradual decrease in EDP associated with the length of time that AOBP has been present in the office, indicating that physicians and sites may be increasingly accustomed to its routine use for measurement.

European Guidelines recommending adoption of AOBP were associated with a large decrease in recorded blood pressures ending in zero in the U.K., from 71.2% in 1996-1997 to 36.7% in 2005-2006.[26] UK studies based on the Quality Improvement in Chronic Kidney Disease (QICKD) trial[27] have shown reductions over time, presumably related to the progressive introduction of AOBP – though this assumption was not validated.[28] In addition, there were changes in the patterns of recording odd vs. even terminal digits. Another study in China also noted decreases in EDP over time.[29] Implementation of AOBP in offices thus appears to be correlated with decreases in EDP.[3,7,26]

The use of AOBP measurement resulted in lower readings than manual BP measurement (by 5 to 10 mmg Hg) in a randomized controlled trial (RCT); AOBP readings agreed more closely with the gold standard of 24 hour BP measurement than manual BP readings.[11] The introduction of AOBP should therefore be associated with a combination of lower rates of EDP (greater precision) and lower BP readings that are more consistent with the gold standard (greater accuracy). An observational study, however, found an association between higher rates of EDP and lower mean systolic BP, by 2 to 3 mm Hg.[26] A study in the UK found that the change from manual to AOBP in primary care practices resulted in lower rates of EDP but no changes in mean BP.[3]

We found that sites with low or no EDP (those presumably using AOBP more consistently) had a mean BP that was close to 2 mm Hg higher than those with greater rates of EDP (and presumably more use of manual BP in the practice) rather than the expected 5 mm Hg lower. Therefore, observer errors associated with manual BP may have resulted in both rounding towards zero and systematically rounding down. Rounding down was observed for patients with diabetes and hypertension as well as for those without these conditions. This could potentially lead to under-diagnosis of hypertension and under-treatment of diagnosed hypertension. While there was no clinically significant association between measurement precision and presence of BP lowering medication (ORs close to 1), our data does not permit us to determine whether more precise measurement was associated with medication intensification through increase in dosage or addition of more medications. This could benefit from additional research.

A possible explanation for the observation of rounding down is provided by prospect theory, used in behavioral economics, which describes decisions made under conditions of uncertainty. Negative perceptions about possible risks (or risk aversion) outweigh positive

perceptions about possible gains.[30] There may be a behavioral bias towards rounding down; this may avoid perceived risks associated with adding more medications with less emphasis on gains from cardiovascular outcome prevention.

A large cluster RCT (CHAP) documented improved management of hypertension in communities randomized to the intervention. This consisted of more accurate AOBP-based measurement in pharmacies with forwarding of abnormal BP results to family physicians.[31] The CHAP intervention resulted in a significant decrease in hospitalizations due to cardiovascular disease (myocardial infarction, stroke, heart failure).[31] In that trial, there was an improvement in BP from a mean of 142 mm Hg to 123 mm Hg when the initial pharmacy-based reading was elevated.[32] Systematically more accurate measurement of BP through the use of AOBP in the community, followed by notification of the primary care provider when BP was elevated, may have resulted in more treatment of elevated BP in primary care and decreased adverse cardiovascular outcomes.

The results in this real world observational study in two countries are plausibly consistent with those of the CHAP RCT. We found that practices with greater precision for BP measurement (less EDP) also had a lower prevalence of adverse cardiovascular outcomes for their patients. It is possible that these practices were using AOBP more often and were thus measuring BP with greater accuracy. Systematic rounding down associated with higher rates of EDP and presumably greater use of manual BP measurement by practices in this study appeared to be associated with an elevated frequency of adverse cardiovascular outcomes.

A switch to routine use of AOBP for most office-based BP measurements would require the purchase of enough machines to support the number of physicians and patients in each office, training of staff and health care providers, and changes in offices processes to support more consistent us of AOBP. We are not aware of financial or other practice level incentives in either country promoting this change.

Limitations

The study has several strengths. We used data from routine community-based primary care. We also included a large sample of both patients and primary care providers from multiple settings across Canada and the UK, observed over a decade or more. Therefore, this study reasonably reflects current clinical practices for individuals receiving primary care in both countries.

This study has several shortcomings. This was a convenience sample of primary care practices that contributed EMR data to CPCSSN and the RCGP RSC. We surveyed practices for their use of AOBP in one network only (UTOPIAN); the survey was done at the office level rather than by physician. There may be recall bias and the actual proportion of patients whose BP was measured using an AOBP is unknown.

The study was not randomized; therefore, there may be unmeasured confounders associated with both higher incidence of cardiovascular outcomes and greater rates of EDP. These could include incentives or programs that could lead to improved precision in BP measurement along with lower rates in cardiovascular outcomes, such as quality standards or funding. Our findings are associations rather than causation. Nonetheless, the differences between groups persisted as practices switched to lower rates of EDP over time and there is no a priori reason to expect a change in unmeasured confounders in practices switching to AOBP and lower rates of EDP.

Conclusions

In conclusion, systematic measurement errors including rounding down are associated with higher rates of EDP. It is likely that this is associated with more manual BP measurement in these primary care practices and in turn is correlated with a higher risk of adverse cardiovascular outcomes at a population level, although we cannot infer a causal relationship. Our findings suggest that the continued routine use of manual measurement of BP in primary care offices may be problematic. We recommend the use of AOBP as the standard of care for measuring and monitoring BP in medical offices.

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Michelle Greiver (MG), Frank Sullivan (FS), Sumeet Kalia (SK) and Simon de Lusignan (SdeL) contributed to conception and design. Babak Aliarzadeh (BA) was responsible for

acquisition of Canadian, and SdeL for UK data. Saddaf Syed (SS) was responsible for conducting the survey. SK, Rahim Moineddin (RM) and William Hinton (WH) contributed substantially to the analysis of data. MG and SK with input from SdeL drafted the initial version of the article. All authors, including Teja Voruganti, Martin Dawes and John Williams contributed to the interpretation of data. All authors reviewed and revised the article for important intellectual content and gave final approval of the version to be published. MG is the guarantor of this work, with SdeL for the RCGP RSC data, and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. MG had final responsibility for the decision to submit for publication.

Data are from a nationally representative Canadian repository of primary care EMR data, the Canadian Primary Care Sentinel Surveillance Network (http://cpcssn.ca). CPCSSN data are available to researchers as outlined in the process available on the website, cpcssn.ca . Similarly, the Royal College of General Practitioners (RCGP) Research and Surveillance Centre (RSC) network database can be accessed by researchers following the process set out at: www.rcgp.org.uk/rsc. Extra data is available by emailing michelle.greiver@nygh.on.ca.

Table 1: Frequency of end-digits for systolic and diastolic blood pressures

End-digits	Canada		UK	
	Systolic BP	Diastolic BP	Systolic BP	Diastolic BP
0	32.4%	35.9%	33.8%	34.0%
1	3.6%	3.7%	4.5%	4.5%
2	13.1%	10.9%	10.3%	9.6%
3	3.8%	3.8%	4.8%	4.7%
4	10.4%	10.0%	9.1%	9.3%
5	7.2%	6.8%	8.3%	8.2%
6	9.3%	8.9%	8.5%	8.4%
7	3.9%	3.8%	4.9%	4.8%
8	12.6%	12.4%	11.2%	11.6%
9	3.8%	3.4%	4.8%	4.9%

Table 2: Patient/site characteristics and blood pressure measurements ending in zero for both systolic BP and diastolic BP in Canada (CPCSSN) and the UK (RCGP RSC database)

	Canada			UK		
Characteristics	**Number of Patients (% of patients)**	**Number of Blood Pressures (% of BPs)**	**Number of BPs with both systolic and diastolic BP ending in zero (% with both ending in zero)**	**Number of Patients (% of patients)**	**Number of Blood Pressures (% of BPs)**	**Number of BPs with both systolic and diastolic BP ending in zero (% with both ending in zero)**
Total	707,227	5,503,663	1,044,031 (19.0%)	1,558,471	13,424,678	2,674,497 (19.9%)
Age in years						
18 to 39	189,254 (26.8%)	816,136 (14.8%)	165,025 (20.2%)	531,632 (34.1%)	2,330,344 (17.4%)	538,786(23.1%)
40 to 59	247,771 (35%)	1,534,126 (27.9%)	292,435 (19.1%)	498,272 (32.0%)	3,298,174 (24.6%)	631,260(19.1%)
60 to 79	201,364 (28.5%)	2,115,655 (38.4%)	377,724 (17.9%)	352,483 (22.6%)	4,879,583 (36.3%)	868,894(17.8%)
80+	68,838 (9.7%)	1,037,716 (18.9%)	208,847 (20.1%)	176,084 (11.3%)	2,916,577 (21.7%)	635,557(21.8%)
Sex						
Female	414,644 (58.6%)	3,325,256 (60.4%)	648,357 (19.5%)	901,866 (57.9%)	8,133,678 (60.6%)	1,708,742(21.0%)
Male	292,583 (41.4%)	2,178,377 (39.6%)	395,674 (18.2%)	656,605 (42.13%)	5,291,000 (39.4%)	965,755(18.3%)
BMI range						
Underweight (BMI <18.5)	10,233 (1.4%)	70,776 (1.3%)	14,649 (20.7%)	44,654 (2.9%)	308,481 (2.3%)	71,234(23.1%)
Normal weight (18.5 to 24.9)	170,684 (24.1%)	1,177,970 (21.4%)	236,883 (20.1%)	560,214 (36.0%)	4,071,114 (30.3%)	852,192(20.9%)
Overweight (25 to 29.9)	182,141 (25.8%)	1,545,777 (28.1%)	283,163 (18.3%)	446,850(28.7%)	4,412,326 (32.9%)	842,338(19.1%)
Obesity class I (30 to 34.9)	101,980 (14.4%)	1,013,286 (18.4%)	175,781 (17.3%)	200,761 (12.9%)	2,421,241 (18.0%)	455,572(18.8%)
Obesity class II (35 to 39.9)	42,235 (6.0%)	468,239 (8.5%)	77,408 (16.5%)	71,450 (4.6%)	928,259 (6.9%)	176,969(19.1%)
Obesity class III (≥40)	27,451 (3.9%)	320,682 (5.8%)	52,327 (16.3%)	37,370 (2.4%)	491,533 (3.7%)	96,589(19.7%)
Not available	172,503 (24.4%)	906,903 (16.5%)	203,820 (22.5%)	197,172 (12.7%)	791,724 (5.9%)	179,603(22.7%)
Diabetes						

Yes	86,103 (12.2%)	1,299,693 (23.6%)	233,944 (18%)	65,335(4.2%)	1,909,804 (14.2%)	359,324(18.8%)
No	621,124 (87.8%)	4,203,940 (76.4%)	810,087 (19.3%)	1,493,136 (95.1%)	11,514,874 (85.8%)	2,315,173(20.1%)
Hypertension						
Yes	185,508 (26.2%)	2,704,921 (49.1%)	486,787 (18%)	235,716 (15.1%)	6,359,131 (47.4%)	1,141,665(18.0%)
No	521,719 (73.8%)	2,798,712 (50.9%)	557,244 (19.9%)	1,322,755 (84.9%)	7,065,547 (52.6%)	1,532,832(21.7%)
Hypertension medications						
Yes	125,484 (17.7%)	2,704,947 (49.1%)	395,371 (17.7%)	466,800 (30.0%)	8,327,009 (62.0%)	1,571,464(18.9%)
No	581,743 (82.3%)	2,798,686 (50.9%)	648,660 (19.8%)	1,091,671 (70.1%)	5,097,669 (38.0%)	1,103,033(21.6%)
Practice site size						
1st quartile (smallest site)	36,363 (5.1%)	249,957 (4.5%)	63,781 (25.5%)	173,610(11.1%)	1,671,387 (12.5%)	303,084(18.1%)
2nd quartile	77,776 (11%)	584,575 (10.6%)	110,411 (18.9%)	305,460(19.6%)	2,836,288 (21.1%)	480,604(16.9%)
3rd quartile	156,601 (22.1%)	1,156,892 (21.0%)	228,521 (19.8%)	416,580(26.7%)	3,774,278 (28.1%)	846,481(22.4%)
4th quartile (largest site)	436,487 (61.7%)	3,512,209 (63.8%)	641,318 (18.3%)	662,821(42.5%)	5,142,725 (38.3%)	1,044,328(20.3%)
Measurement year*						
2006	52,168 (7.4%)	121,355 (2.2%)	32,335 (26.6%)	542,695(34.8%)	1,347,400 (10.0%)	325,843(24.2%)
2007	81,699 (11.6%)	183,591 (3.3%)	49,030 (26.7%)	553,033(35.5%)	1,342,979 (10.1%)	303,477(22.6%)
2008	125,781(17.8%)	277,858 (5.0%)	72,772 (26.2%)	563,222(36.1%)	1,353,092 (10.1%)	288,418(21.3%)
2009	167,345(23.7%)	368,245 (6.7%)	94,871 (25.8%)	572,940(36.8%)	1,358,664 (10.1%)	278,829(20.5%)
2010	213,250(30.2%)	531,316 (9.7%)	117,612 (22.1%)	580,069(37.2%)	1,340,279 (10.0%)	266,242(19.9%)
2011	263,691(37.3%)	615,364 (11.2%)	125,282 (20.4%)	590,921(37.9%)	1,354,956 (10.1%)	257,309(19.0%)
2012	299,590(42.4%)	700,903 (12.7%)	128,192 (18.3%)	602,642(38.7%)	1,347,042 (10.0%)	249,344(18.5%)
2013	332,809(47.1%)	813,009 (14.8%)	133,434 (16.4%)	617,073(39.6%)	1,366,085 (10.2%)	246,754(18.1%)
2014	360,180(50.9%)	894,350 (16.3%)	137,181 (15.3%)	612,382(39.3%)	1,325,141 (9.9%)	235,377(17.8%)
2015	386,541(54.7%)	997,642 (18.1%)	153,322 (15.4%)	594,589(38.2%)	1,289,040 (9.6%)	222,904(17.3%)

*considering repeated measurements of blood pressure for each patient with respect to measurement year.

BMI - body mass index (weight in kg / height in meters^2)

Table 3: Adjusted odds ratios of recording zero as the last digit for both systolic and diastolic blood pressure by patient and site characteristics

			Canada				UK			
Effect	**Index Group**	**Reference group**	**Odds ratio**	**95% confidence interval**		**P-value**	**Odds ratio**	**95% confidence interval**		**P-value**
Age	18 to 39	80+	1.088	1.063	1.112	<0.001	0.784	0.773	0.795	<0.001
	40 to 59	80+	1.012	0.990	1.034	0.294	0.788	0.777	0.798	<0.001
	60 to 79	80+	0.942	0.923	0.963	<0.001	0.783	0.772	0.794	<0.001
Sex	Female	Male	1.100	1.089	1.112	<0.001	1.156	1.148	1.163	<0.001
BMI	Underweight (BMI <18.5)	Obesity class III (BMI ≥40)	1.316	1.267	1.366	<0.001	1.047	1.019	1.074	0.001
	Normal (BMI 18.5 to 24.9)	Obesity class III	1.226	1.192	1.258	<0.001	0.960	0.939	0.980	<0.001
	Overweight (BMI 25 to 29.9)	Obesity class III	1.135	1.104	1.166	<0.001	0.947	0.926	0.966	<0.001
	Obesity class I (BMI 30 to 34.9)	Obesity class III	1.065	1.036	1.096	<0.001	0.953	0.932	0.973	<0.001
	Obesity class II (BMI 35 to 39.9)	Obesity class III	1.008	0.978	1.040	0.618	0.967	0.943	0.992	0.007
Diabetes	Yes	No	0.982	0.964	0.999	0.047	1.025	1.008	1.042	0.004
Hypertension	Yes	No	0.892	0.877	0.908	<0.001	0.790	0.780	0.799	<0.001
Hypertension medications	Yes	No	0.967	0.947	0.986	0.001	1.057	1.047	1.068	<0.001
Practice Site size	1st quartile (smallest site)	4th quartile (largest site)	1.950	1.908	1.990	<0.001	0.816	0.809	0.823	<0.001
	2nd quartile	4th quartile (largest site)	1.075	1.058	1.094	<0.001	0.893	0.885	0.900	<0.001
	3rd quartile	4th quartile (largest site)	1.087	1.074	1.100	<0.001	0.891	0.883	0.899	<0.001
Measurement year	2006	2015	1.910	1.833	1.990	<0.001	1.647	1.625	1.668	<0.001
	2007	2015	1.923	1.857	1.989	<0.001	1.473	1.451	1.494	<0.001
	2008	2015	1.840	1.790	1.895	<0.001	1.376	1.357	1.396	<0.001
	2009	2015	1.858	1.815	1.903	<0.001	1.321	1.300	1.341	<0.001
	2010	2015	1.582	1.548	1.617	<0.001	1.257	1.238	1.275	<0.001
	2011	2015	1.379	1.352	1.407	<0.001	1.178	1.161	1.196	<0.001
	2012	2015	1.239	1.216	1.262	<0.001	1.112	1.094	1.129	<0.001
	2013	2015	1.096	1.077	1.116	<0.001	1.052	1.038	1.067	<0.001
	2014	2015	1.037	1.021	1.052	<0.001	1.016	1.000	1.030	0.041

BMI - body mass index (weight in kg / height in meters^2)

Odds ratios were adjusted for patient age, sex, presence of hypertension and/or diabetes, BMI, use of hypertensive medications. ORs were also adjusted for the size of the practice panels and year of measurement

Table 4: Number and percentage of sites in each EDP group from 2006 to 2015

Year	Canada						UK					
	Low or no EDP		Medium EDP		High EDP		Low or no EDP		Medium EDP		High EDP	
	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)	N	Percent (%)
2006	1	3.6%	1	3.6%	26	92.9%	61	38.4%	39	24.5%	59	37.1%
2007	3	7.3%	3	7.3%	35	85.4%	69	42.9%	41	25.5%	51	31.7%
2008	8	13.8%	3	5.2%	47	81.0%	71	44.1%	45	28.0%	45	28.0%
2009	8	11.1%	7	9.7%	57	79.2%	74	46.0%	45	28.0%	42	26.1%
2010	15	15.3%	11	11.2%	72	73.5%	76	46.6%	45	27.6%	42	25.8%
2011	17	15.5%	16	14.5%	77	70.0%	78	47.9%	45	27.6%	40	24.5%
2012	27	21.8%	25	20.2%	72	58.1%	82	50.3%	40	24.5%	41	25.2%
2013	33	22.8%	33	22.8%	79	54.5%	79	48.5%	48	29.4%	36	22.1%
2014	30	20.0%	41	27.3%	79	52.7%	85	52.1%	42	25.8%	36	22.1%
2015	41	26.5%	44	28.4%	70	45.2%	84	51.2%	44	26.8%	36	22.0%

EDP – End digit preference

Table 5: Mean systolic blood pressure by EDP group

		CPCSSN database (Canada)			RCGP RSC database (UK)		
		No. of BP measurements	Mean sBP in mm Hg	Std. Dev.	No. of BP measurements	Mean sBP in mm Hg	Std. Dev.
All patients	**Low or no EDP**	1,151,795	128.21	18.92	5,618,800	135.05	20.09
	High EDP	2,925,279	126.24	18.52	3,624,391	133.29	19.63
	Difference		1.97			1.76	
Hypertensive	**Low or no EDP**	584,082	134.59	19.29	2,687,218	142.63	19.03
	High EDP	1,436,251	133.51	18.36	1,715,006	141.23	18.19
	Difference		1.08			1.40	
Non-hypertensive	**Low or no EDP**	567,713	121.65	16.09	2,931,582	128.10	18.44
	High EDP	1,489,028	119.23	15.77	1,909,385	126.15	18.07
	Difference		2.42			1.95	
Diabetic	**Low or no EDP**	300,630	131.42	18.81	823,959	138.89	18.75
	High EDP	675,920	130.52	18.09	515,843	136.76	17.79
	Difference		0.9			2.13	
Non-Diabetic	**Low or no EDP**	851,165	127.08	18.83	4,794,841	134.39	20.23
	High EDP	2,249,359	124.96	18.46	3,108,548	132.71	19.86
	Difference		2.12			1.68	

EDP – End digit preference
sBP – systolic blood pressure
Std. Dev – standard deviation

Table 6: Standardized morbidity ratio for groups with high EDP group when compared to groups with low or no EDP

Angina			
Parameter	**Estimate**	**95% Confidence Limits**	
Standardized morbidity ratio	1.25	1.22	1.28
Acute Myocardial infraction			
Standardized morbidity ratio	1.16	1.14	1.19
Stroke			
Standardized morbidity ratio	1.15	1.12	1.17

EDP – End digit preference

Figure legends

Figure 1: Histogram of systolic and diastolic blood pressure in Canada and the UK

Figure 2: Impact of adopting automated office blood pressure machines on end digit preference for systolic blood pressure in Toronto

Figure 3: Proportions of systolic and diastolic BPs ending in 1, 3, 7 or 9 per practice site for each year of interest in Canada and UK from 2006 to 2015

Figure 4: Frequency of cardiovascular events in high EDP and no or low EDP group in the UK

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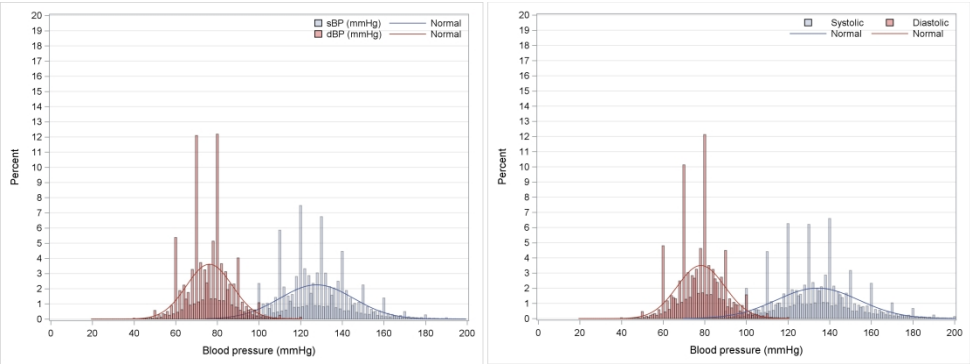

Figure 1: Histogram of systolic and diastolic blood pressure in Canada(left) and the UK (right)

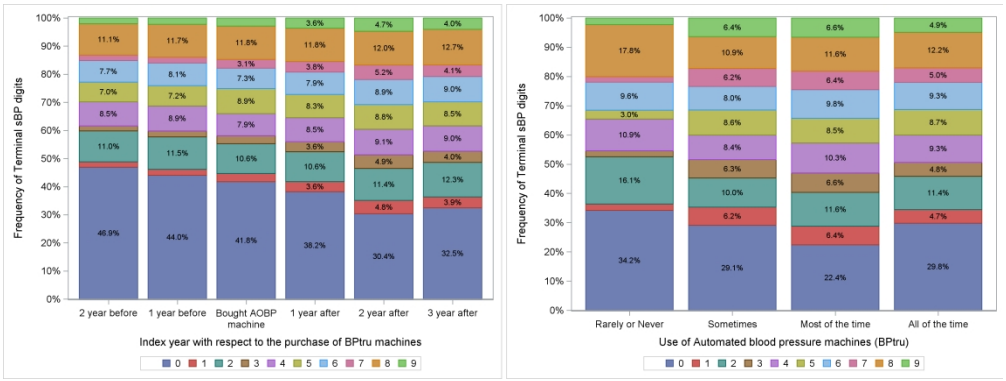

Figure 2: Impact of adopting automated office blood pressure machines on end digit preference for systolic blood pressure in Toronto

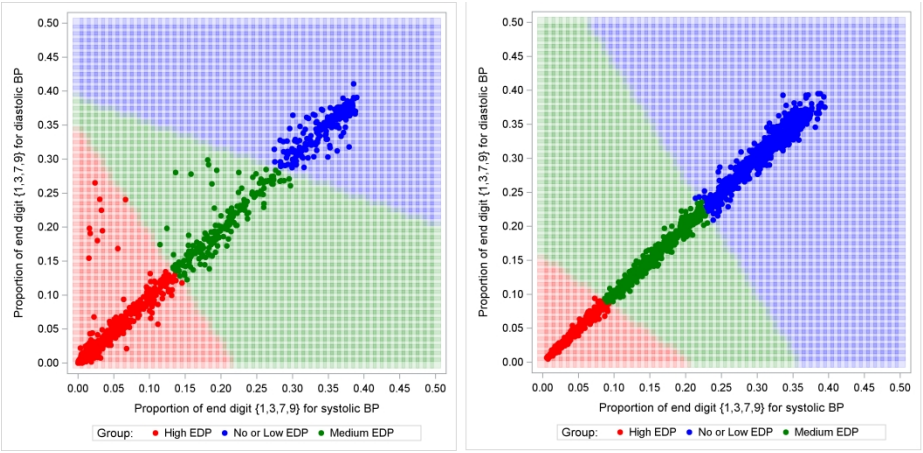

Figure 3: Proportions of systolic and diastolic BPs ending in 1, 3, 7 or 9 per practice site for each year of interest in Canada (left) and UK (right) from 2006 to 2015

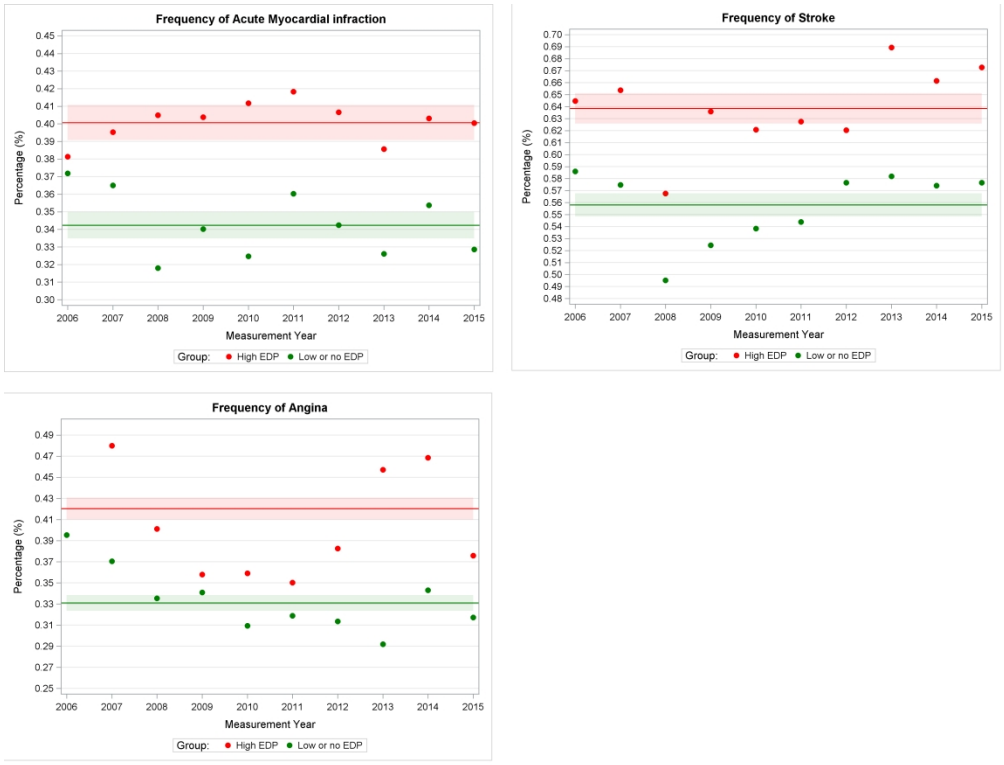

Figure 4: Frequency of cardiovascular events in high EDP and no or low EDP group in the UK

1) Is there an automated machine (e.g. BPTru) in your office?

Yes [ ]
No [ ]

2) If Yes, when was the machine purchased?

Year [ ]
Month [ ]

3) If Yes, how many BP machines are there at your office?

Enter digit [ ]

4) How many exam rooms are there at your office?

Enter digit [ ]

5. Thinking of the past year, how often is the automated BP machine used to take blood pressures in your office?

-rarely or never

-some of the time

-most of the time

-almost all the time or all the time

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract: **Page 1**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found: **Page 2**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **Page 3-4**
Objectives	3	State specific objectives, including any prespecified hypotheses **Page 3**
Methods		
Study design	4	Present key elements of study design early in the paper **Page 3**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **Page 4-5**
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants **Page 4**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **Page 4**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **Page 5-6**
Bias	9	Describe any efforts to address potential sources of bias **N/A**
Study size	10	Explain how the study size was arrived at **N/A**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **Page 5-6**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **Page 5-6**
		(*b*) Describe any methods used to examine subgroups and interactions **Page 5-6**
		(*c*) Explain how missing data were addressed **N/A**
		(*d*) If applicable, describe analytical methods taking account of sampling strategy **N/A**
		(*e*) Describe any sensitivity analyses **N/A**
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **Page 6**
		(b) Give reasons for non-participation at each stage **N/A**
		(c) Consider use of a flow diagram **N/A**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **Page 6**
		(b) Indicate number of participants with missing data for each variable of interest **Page 7**
Outcome data	15*	Report numbers of outcome events or summary measures **Page 7**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **Page 7**

		(*b*) Report category boundaries when continuous variables were categorized **Page 7**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **N/A**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **Page 7**
Discussion		
Key results	18	Summarise key results with reference to study objectives **Page 7**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **Page 8-9**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **Page 7-9**
Generalisability	21	Discuss the generalisability (external validity) of the study results **Page 9**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **Page 10**

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.