Trends in Systematic Recording Errors of Blood Pressure and Associations With Outcomes in Canadian and UK Primary Care

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CDN Webcast, October 11th 2017, 1pm EST

Study team

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- John Williams, UK
- Simon de Lusignan, UK

Outline

- Background
- Data
- Methods
  - Parallel analyses UK and Canada
  - Linkage of survey and EMR data
  - Cardiovascular outcomes in UK
- Results
- Conclusions
- Future directions

Background: Using data patterns for discovery

- Blood pressures are very commonly done in family practice
- Some are done manually, some are done using an Automated Office BP (AOBP) machine
- Guidelines currently **recommend AOBP**
- **We don't know** which BPs are done with AOBP (type of BP measurement poorly recorded in EMRs)

Last digit preference for BP

- Manual BP and AOBP are associated with **different patterns** of data for BP in both routine care and RCTs
- 50% to 60% of manual BPs end in zero (example, 140/90)
    - Nietert PJ, et al. Effect of terminal digit preference on blood pressure measurement and treatment in primary care. Am J Hypertens. 2006 Feb;19(2):147-52
    - de Lusignan S, Belsey J, Hague N, Dzregah B. End-digit preference in blood pressure recordings of patients with ischaemic heart disease in primary care. J Hum Hypertens. 2004 Apr;18(4):261-5. PubMed PMID: 15037875
- Odd last digits other than 5 (1, 3, 7 ,9) are rarely recorded when using manual BP

AOBP and BP measurement

- Use of AOBP is associated with
  - Better **precision** of BP recording: **less End** digit preference, **more odd** last digits
  - Better **accuracy**: closer to **24 hour BP** measurements
  - Less white coat Hypertension
  - **Lower BP readings than manual in RCTs**, by 5 to 10 mm Hg

» Myers MG, Godwin M, Dawes M, Kiss A, Tobe SW, Grant FC, et al. Conventional versus automated measurement of blood pressure in primary care patients with systolic hypertension: randomised parallel design controlled trial. BMJ. 2011;342

Manual cuffs and automated machines

RCT study showed:
Automated office blood pressure can be used in primary care practice to obtain **valid readings without provoking the white coat response** often seen with manual blood pressure measurement

Measurement	Automated office BP group (n=299)	Conventional manual office BP group (n=249)
Last routine manual office BP (mm Hg)	149.5 (10.8)/81.4 (8.3)	149.9 (10.7)/81.8 (8.5)
Office BP (mm Hg) after enrolment	135.6 (17.3)/77.7 (10.9)	141.4 (14.6)/80.2 (9.5)
Difference from last routine office BP (mm Hg)	−13.9 (−11.8 to −16.1)***/−3.7 (−2.5 to −4.8)***	−8.5 (−6.5 to −10.4)***/−1.6 (−0.4 to −2.8)**

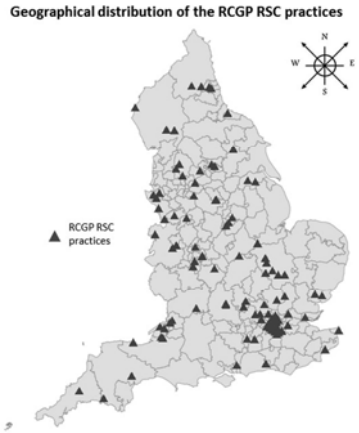
Myers, Martin G., et al. "Conventional versus automated measurement of blood pressure in primary care patients with systolic hypertension: randomised parallel design controlled trial." *Bmj* 342 (2011): d286.

Questions

- Can we **describe** patterns of BP end digit recording in primary care EMR databases?
- Can we **correlate** End digit preference **with AOBP use**?
- Can we **correlate** End digit preference **with cardiovascular outcomes**?

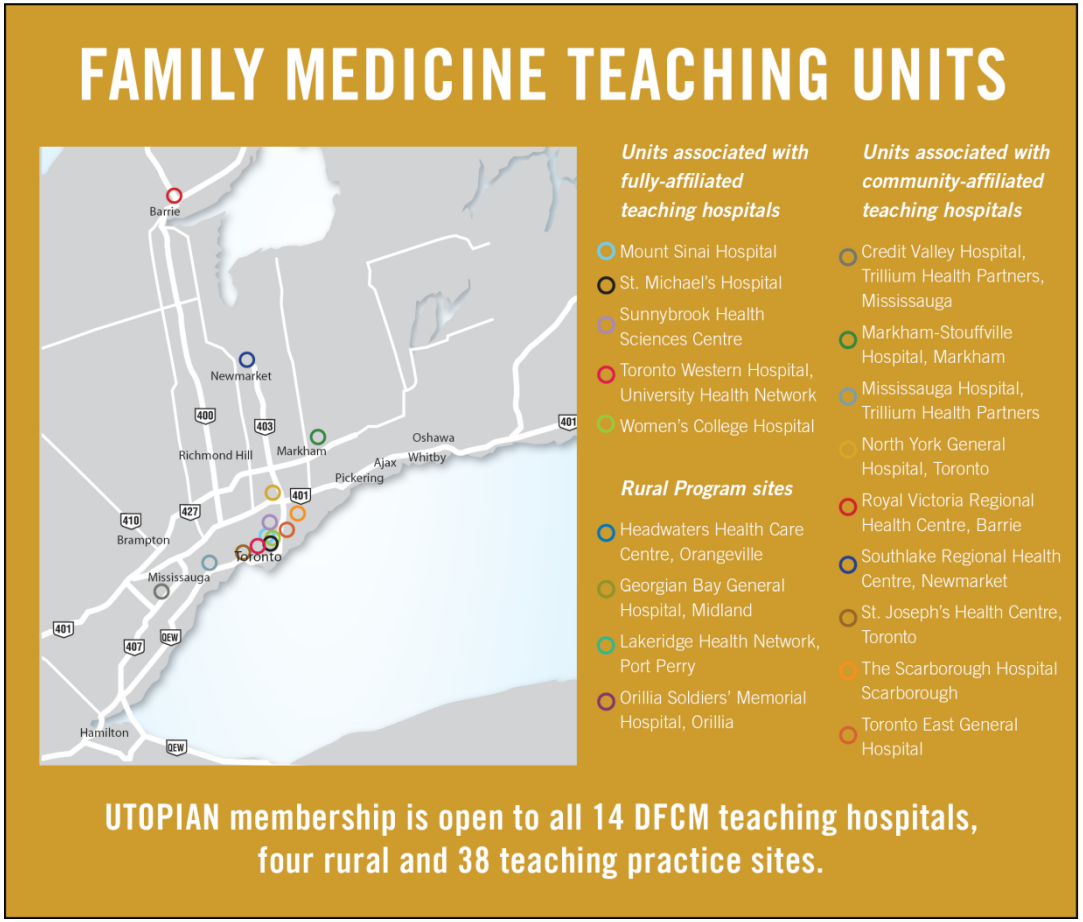
Data: CPCSSN and RCGP – EMR databases

- Routinely collected data extracted from EMRs of primary care providers
- **Canada**: Canadian Primary Care Sentinel Surveillance Network (CPCSSN) database
  - 700k Canadian patients
  - 5.5 million BP records
- **UK**: Royal College of General Practice (RCGP) database
  - 1.8 million patients
  - 19 million BP records
- Both databases undergo extensive data cleaning process (e.g. removing confidential information (names; address; telephone numbers; free text details etc) and outlier information.



UTOPIAN
Toronto, Ontario, Canada

- 14 sites
- ~400 practices
- ~1400 faculty members
- ~1M patients



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Methods

- Repeated cross sectional design
- Canadian and UK data
- Parallel analyses (data does not cross borders)

- Proportion of End Digit Preference (EDP) per family practice for each year
- Clustering of family practices by EDP per year

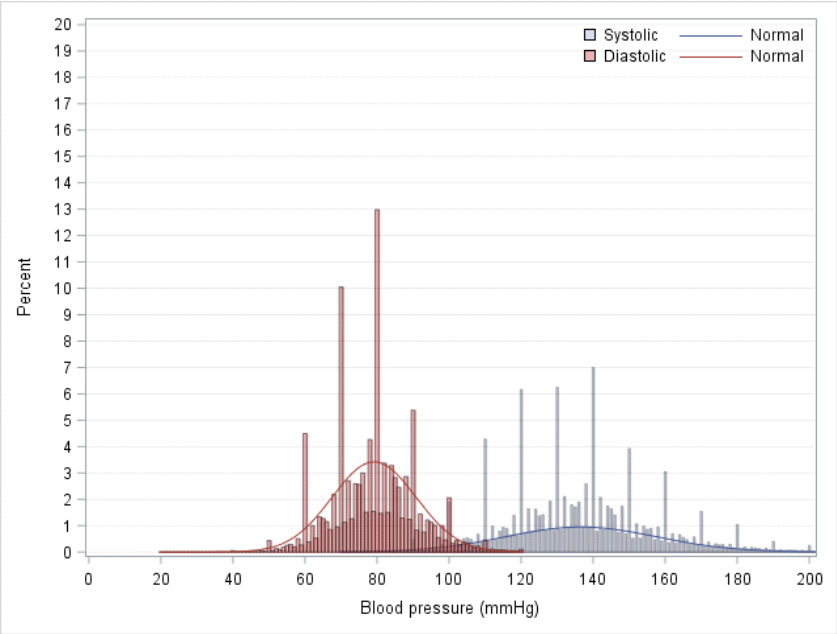
Methods

- Survey of AOBP uptake in UTOPIAN practices
- Linkage of survey with measured BP
- Correlation between AOBP uptake and EDP within practices

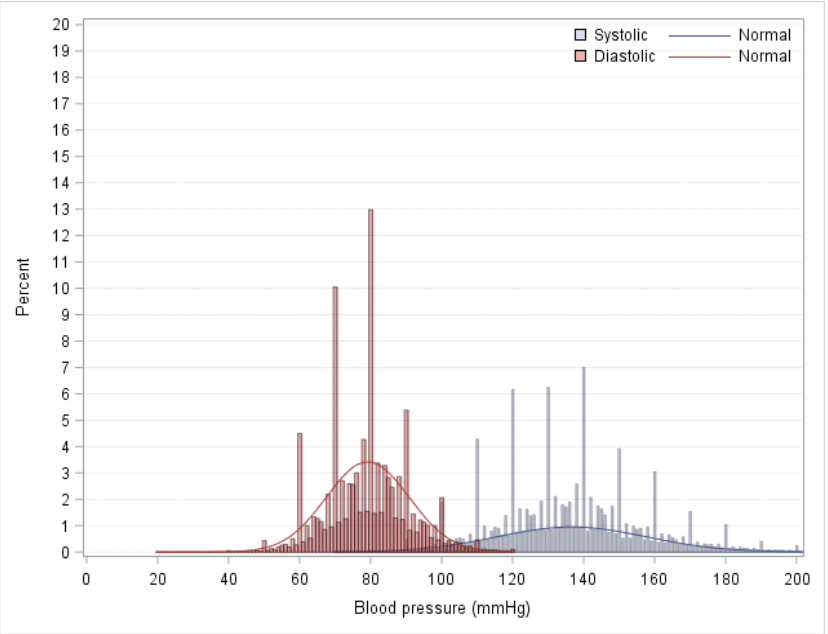
- Associations between EDP and cardiovascular outcomes in UK

Systolic and diastolic BPs in UK and Canadian databases

- Canadian blood pressures

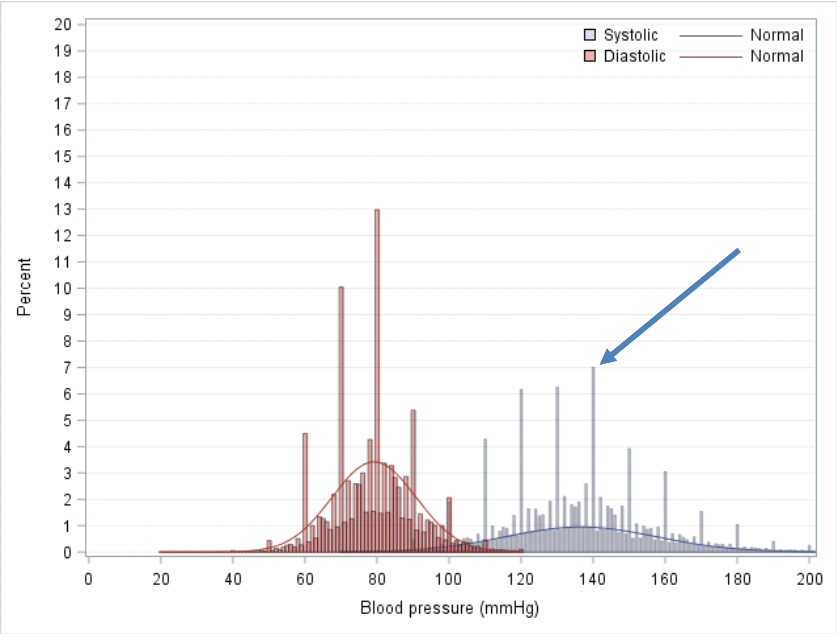


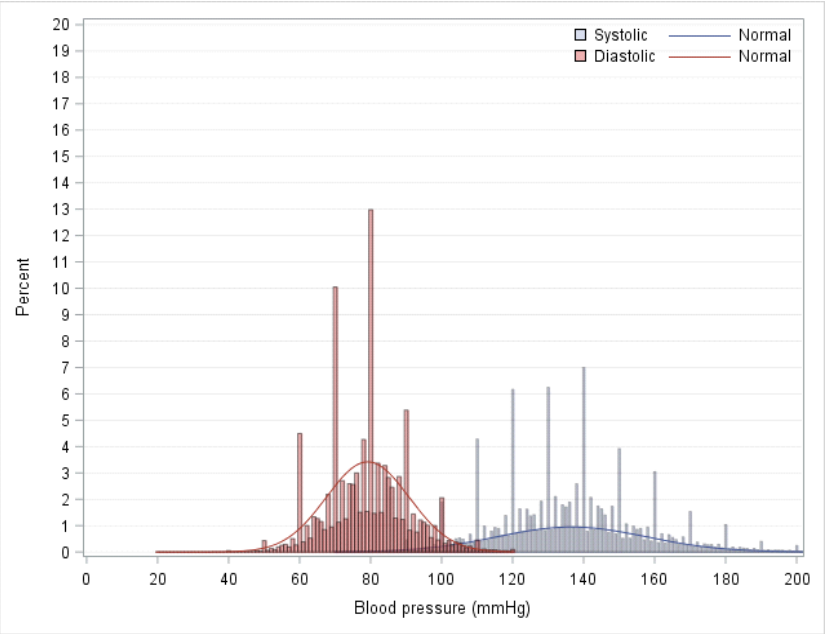
- UK blood pressures



Systolic and diastolic BPs in UK and Canadian databases

- Canadian blood pressures
- UK blood pressures





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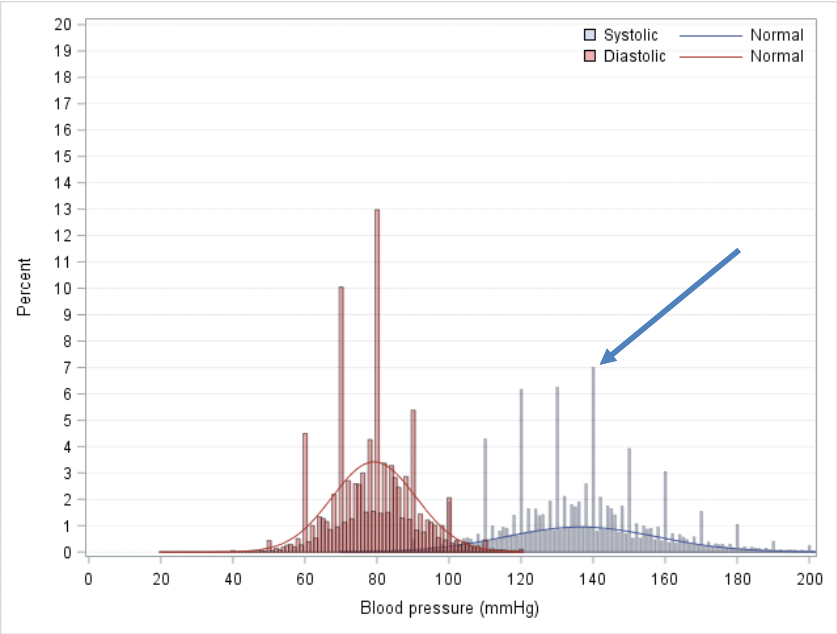
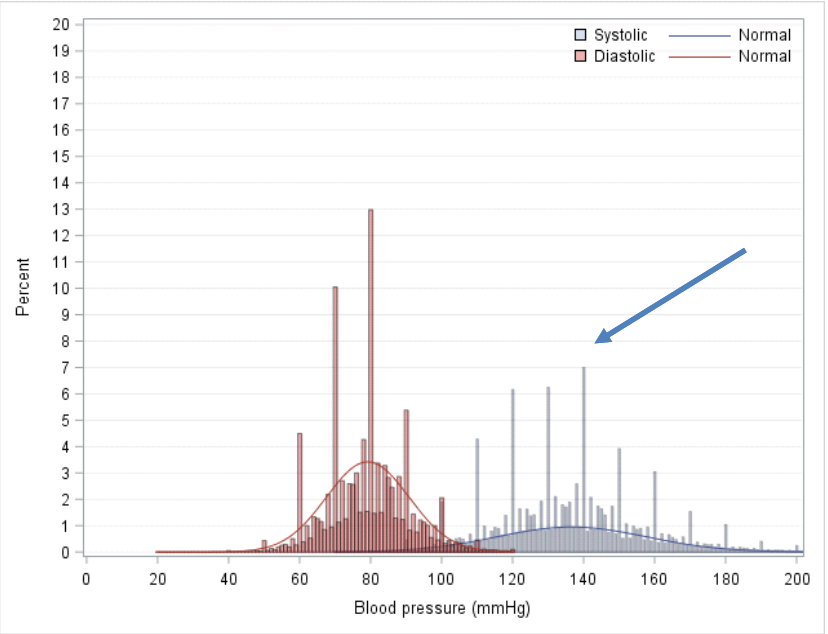


- UK blood pressures



Frequency of recording end digit for Systolic BP in Canada and UK database

sBP end-digit	CPCSSN database	RCGP database
0	32.4%	36.5 %
1	3.6%	4.2 %
2	13.1%	9.7 %
3	3.8%	4.5 %
4	10.4%	8.8 %
5	7.2%	8.3 %
6	9.3%	8.1 %
7	3.9%	4.6 %
8	12.6%	10.6 %
9	3.8%	4.5 %

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4	10.4%	8.8 %
5	7.2%	8.3 %
6	9.3%	8.1 %
7	3.9%	4.6 %
8	12.6%	10.6 %
9	3.8%	4.5 %

Estimates of sBP and dBP both ending in zero (%) by year (after adjusting for patient/provider characteristics)

Measurement year	CPCSSN database	RCGP database
2001	.	34.12 %
2002	.	28.89 %
2003	.	25.57 %
2004	.	24.26 %
2005	.	24.19 %
2006	27.63 %	23.08 %
2007	26.31 %	21.52 %
2008	25.22 %	20.27 %
2009	23.41 %	19.57 %
2010	21.03 %	18.98 %
2011	19.33 %	18.16 %
2012	16.85 %	17.70 %
2013	15.05 %	17.26 %
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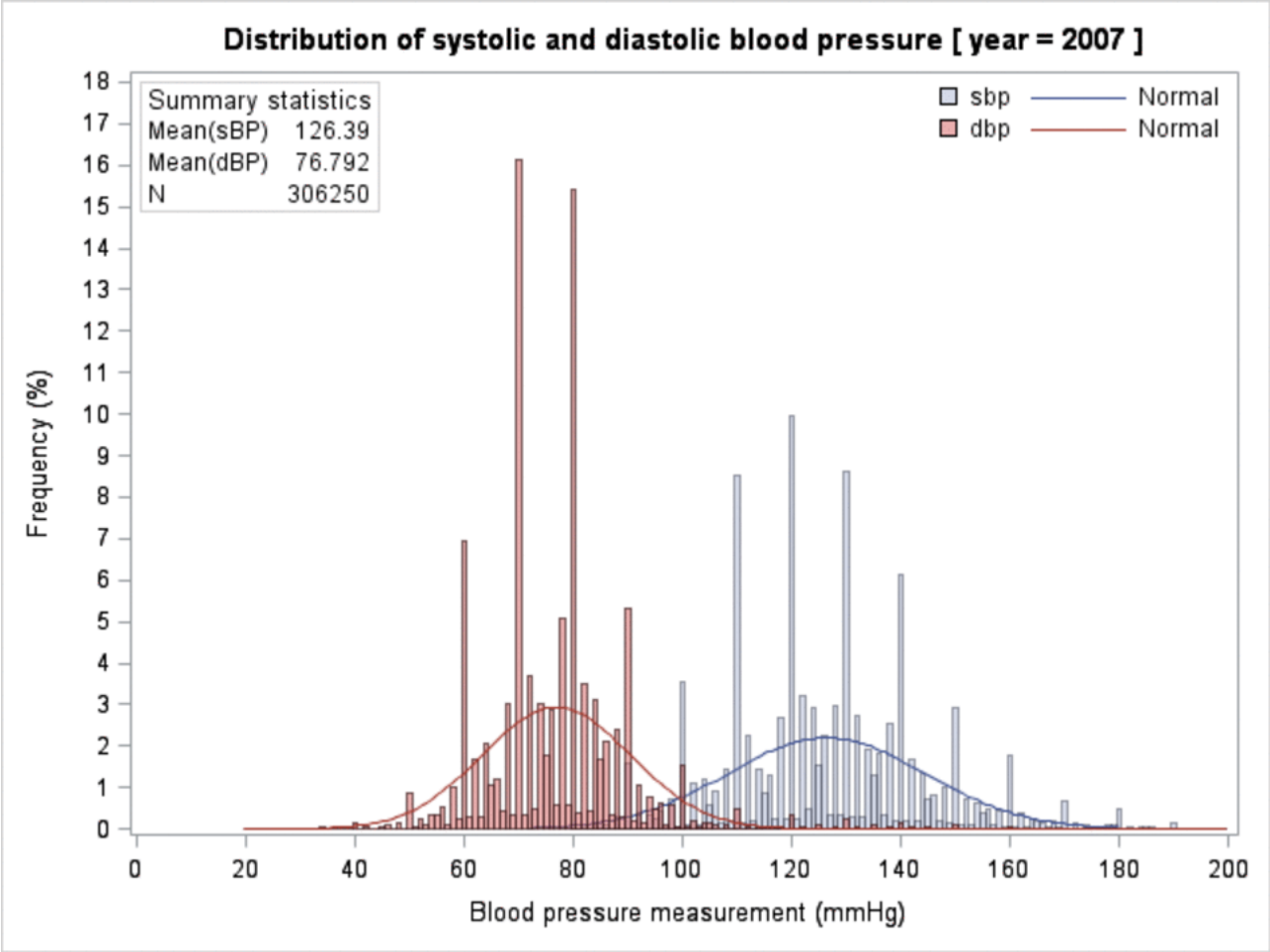
sBP/ dBP distribution over time



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- End digit preference is decreasing over time in UK and Canada

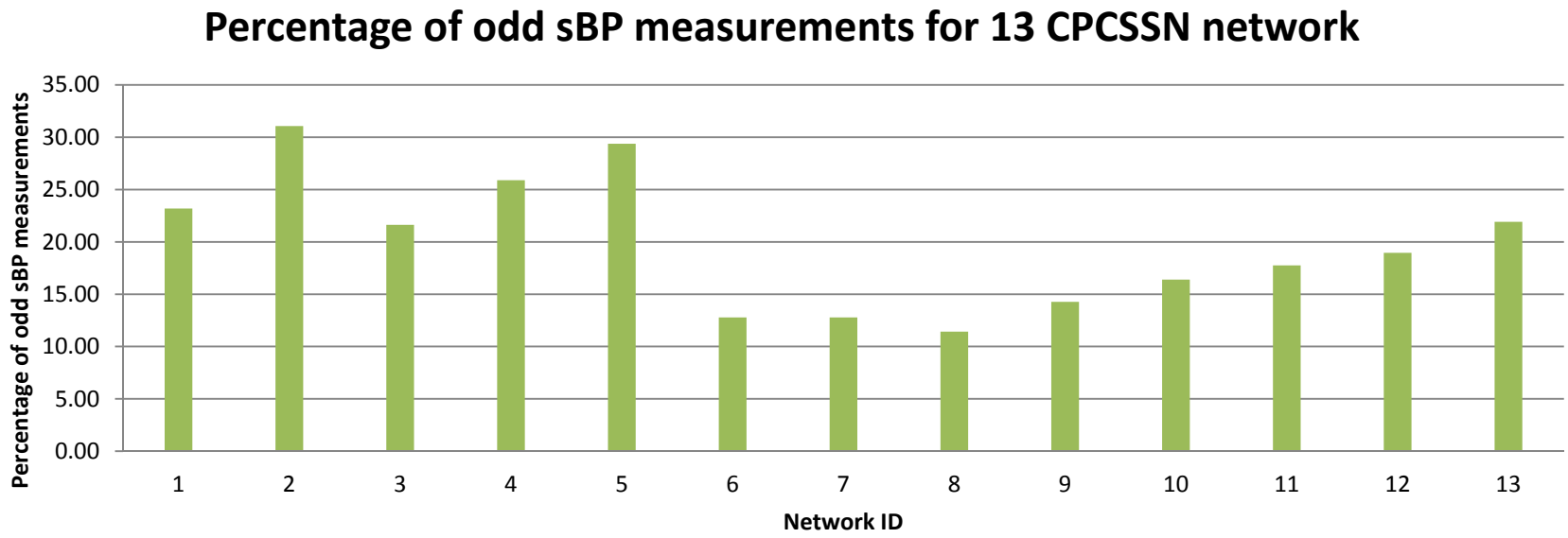
- Measurement of BP is becoming more precise

EDP and clinical factors

- Patients living with hypertension and/or diabetes were **less likely** to have a last digit zero than those without these conditions,
  - OR=0.91 for hypertension (95% CI: 0.90 -0.92; p-value <0.001)
  - OR=0.95 for diabetes (95% CI: 0.95 -0.96; p-value <0.001).
- Patients prescribed blood pressure lowering **medications** were **less likely** to have a last digit of zero
  - OR=0.97 (95% CI: 0.964-0.978; p-value <0.001).

EDP and practice factors

- Practices with the **fewest patients** had less EDP than practices with the most patients
  - OR 0.79, (95% CI 0.64 to 0.99).
- There was a lot of regional variation



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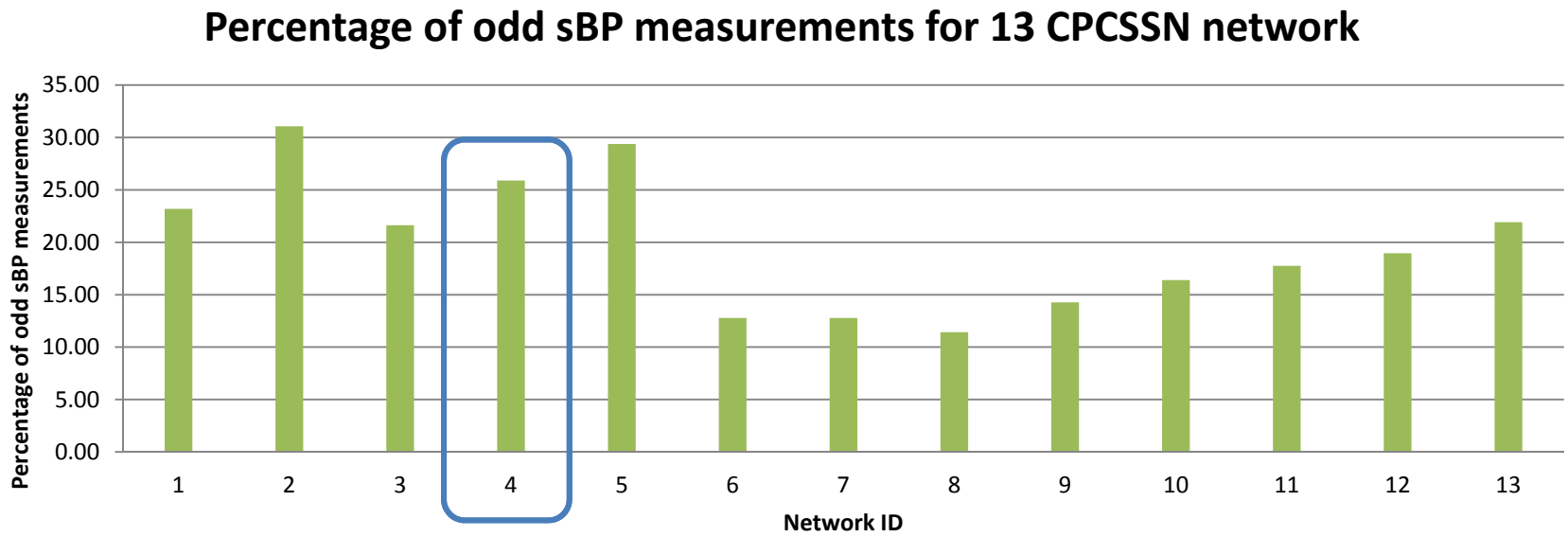
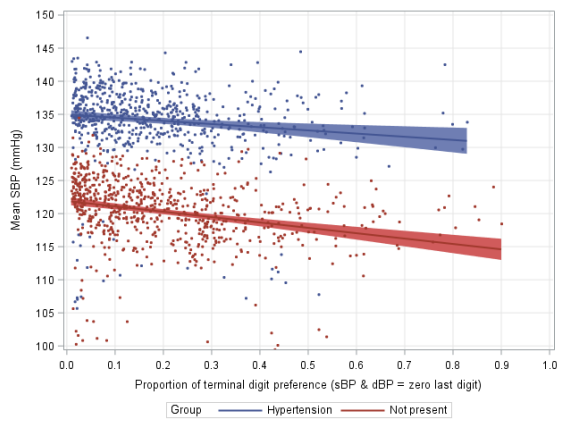


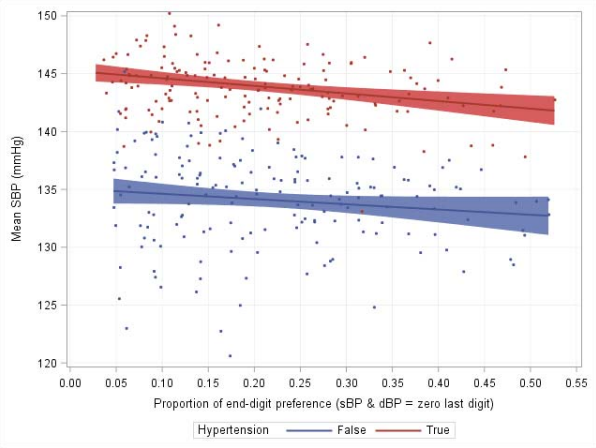
End-digit preference and mean systolic BP

Hypertension

Canada**: 8.1 mm** Hg less (95% CI: -10.4,-5.8)in normotensive, 4.8 less (95% CI: -7.6,-2.0) in hypertensive

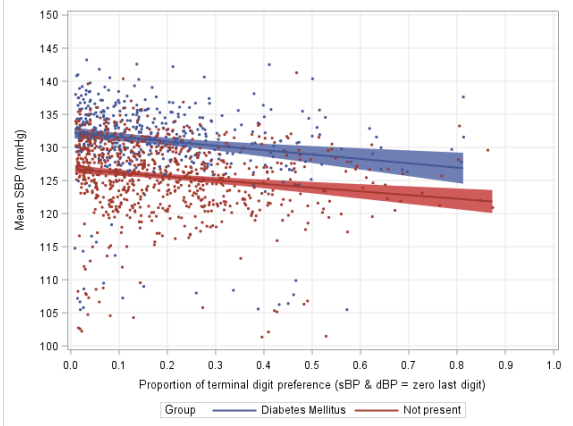


UK



Diabetes

Canada: 6.6 mm Hg less (95% CI: -10.1,-3.1) without DM, 5.6 less (95% CI: -8.2,-3.1) in those with diabetes



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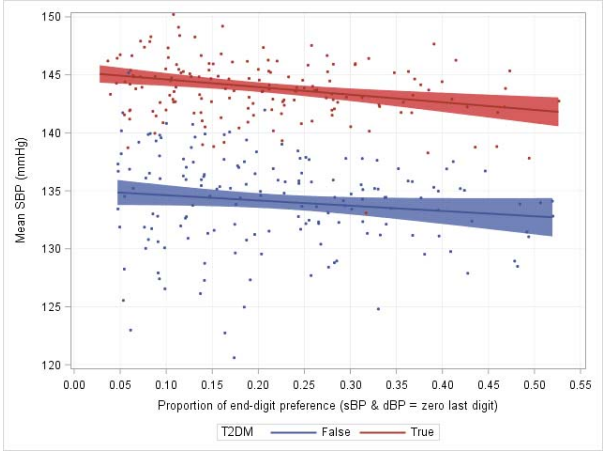

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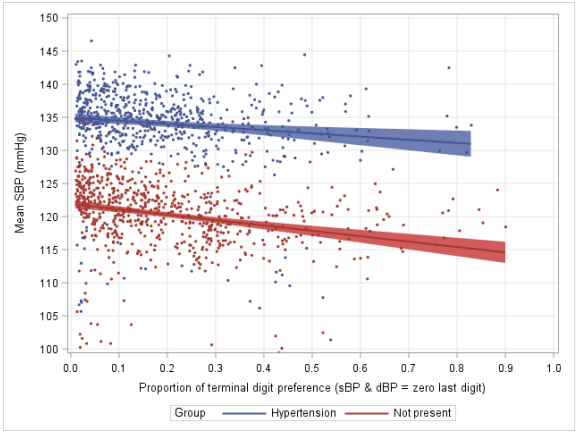

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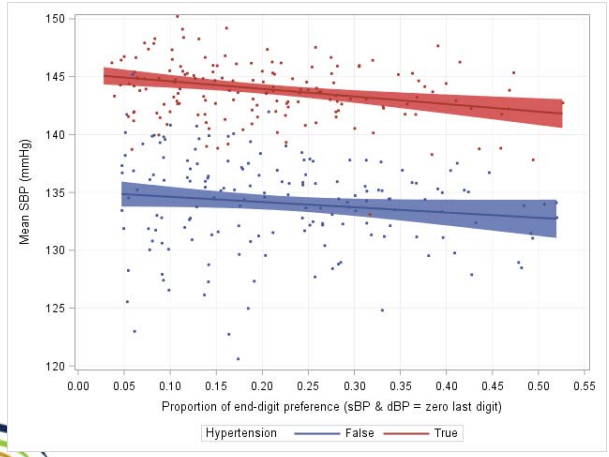

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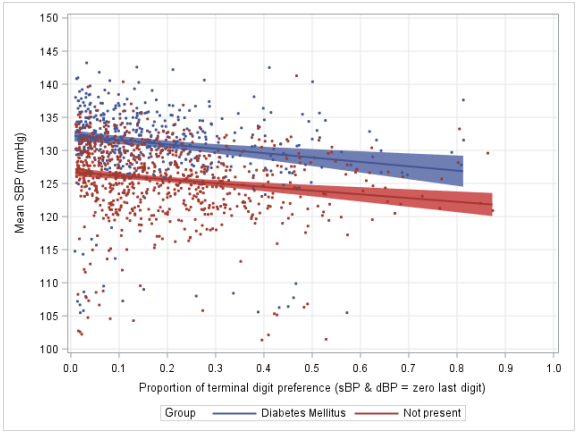

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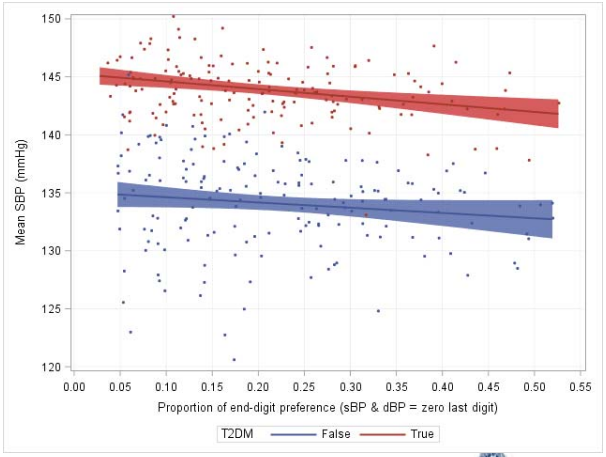

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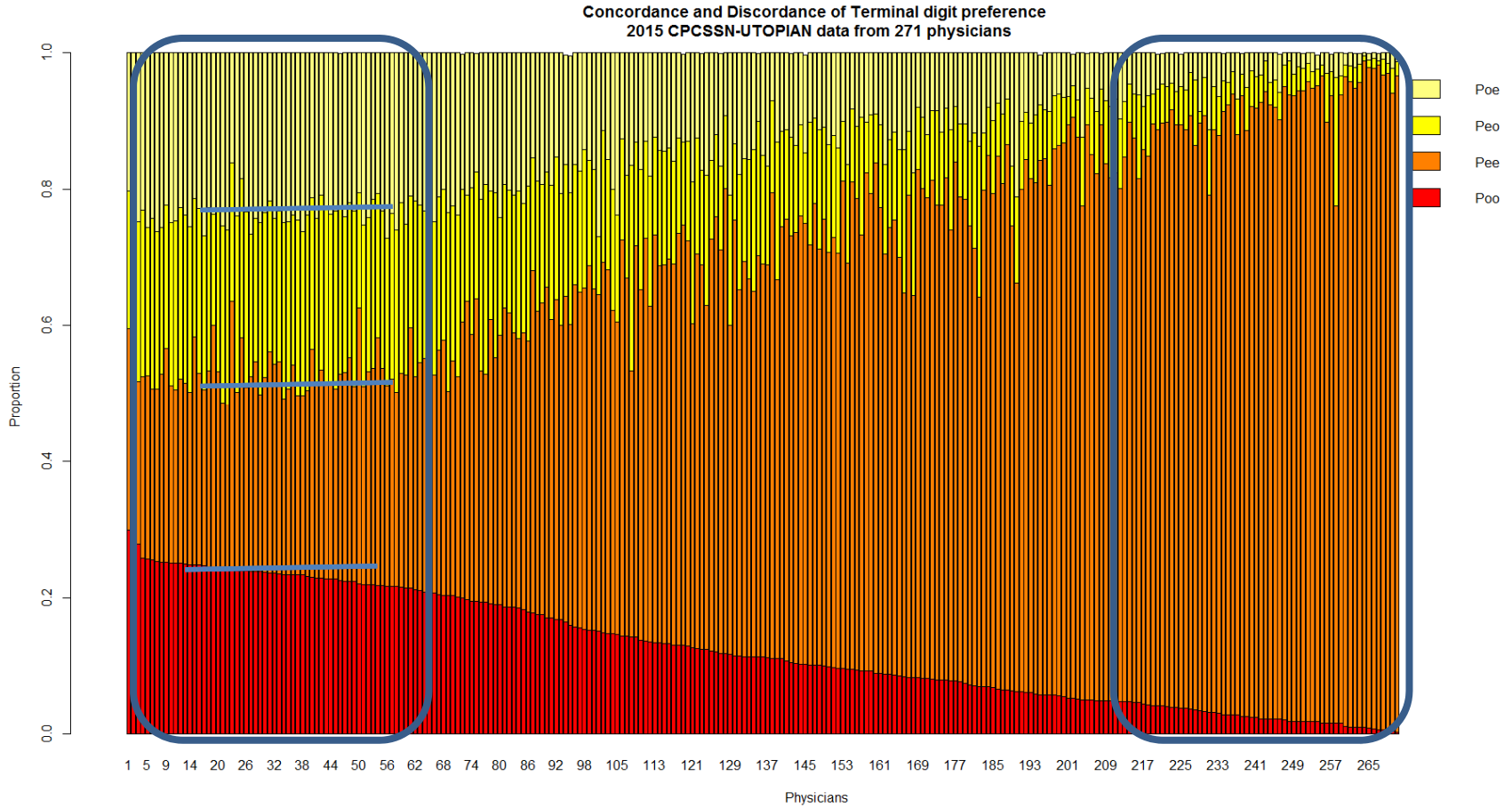
- A greater rate of end digit preference is associated with lower mean blood pressure measurement

- BPs are not just rounded
- They are rounded down

Ratios of sBP and dBP odd/even last digit, ranked practices in 2015



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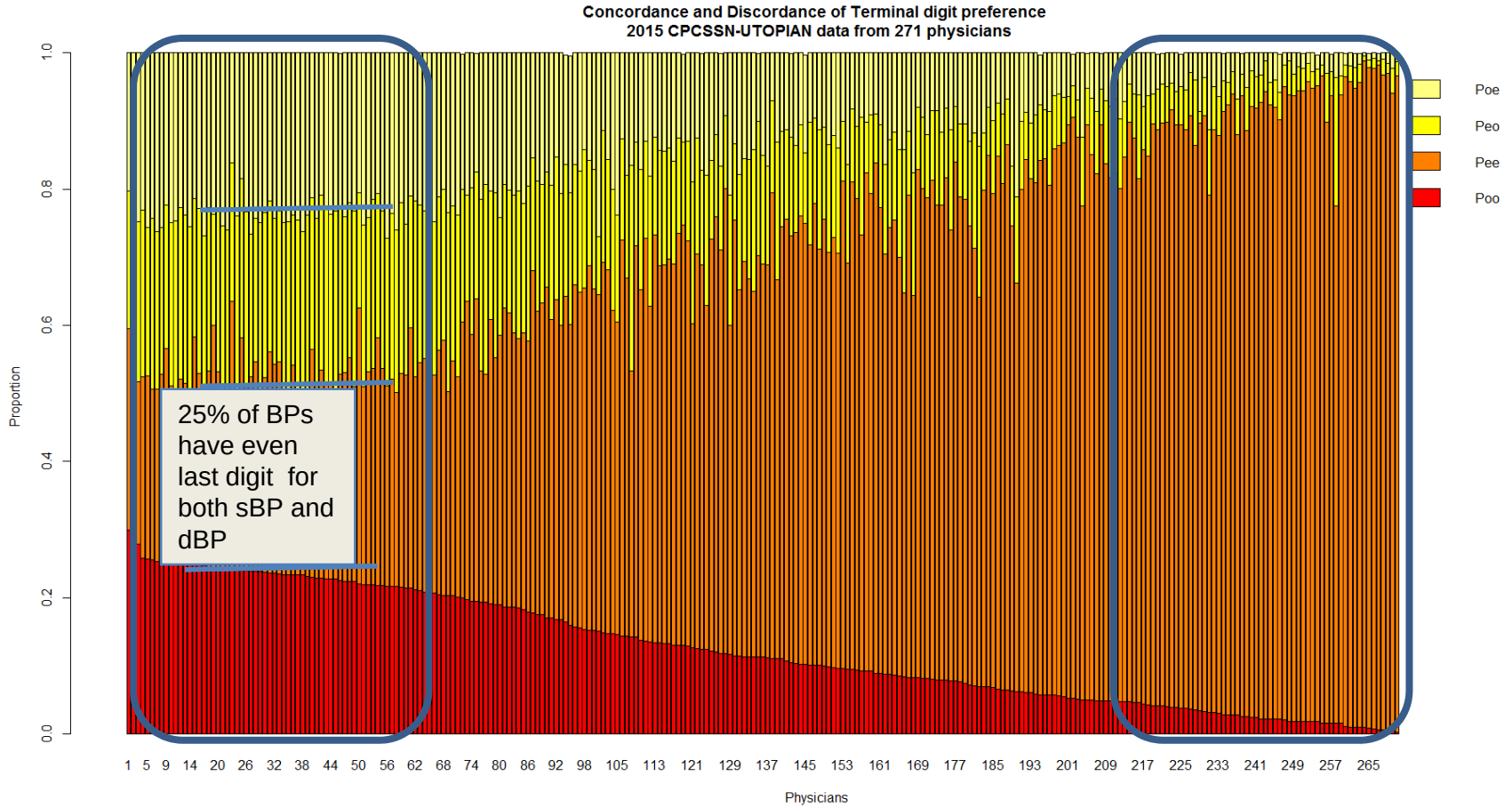

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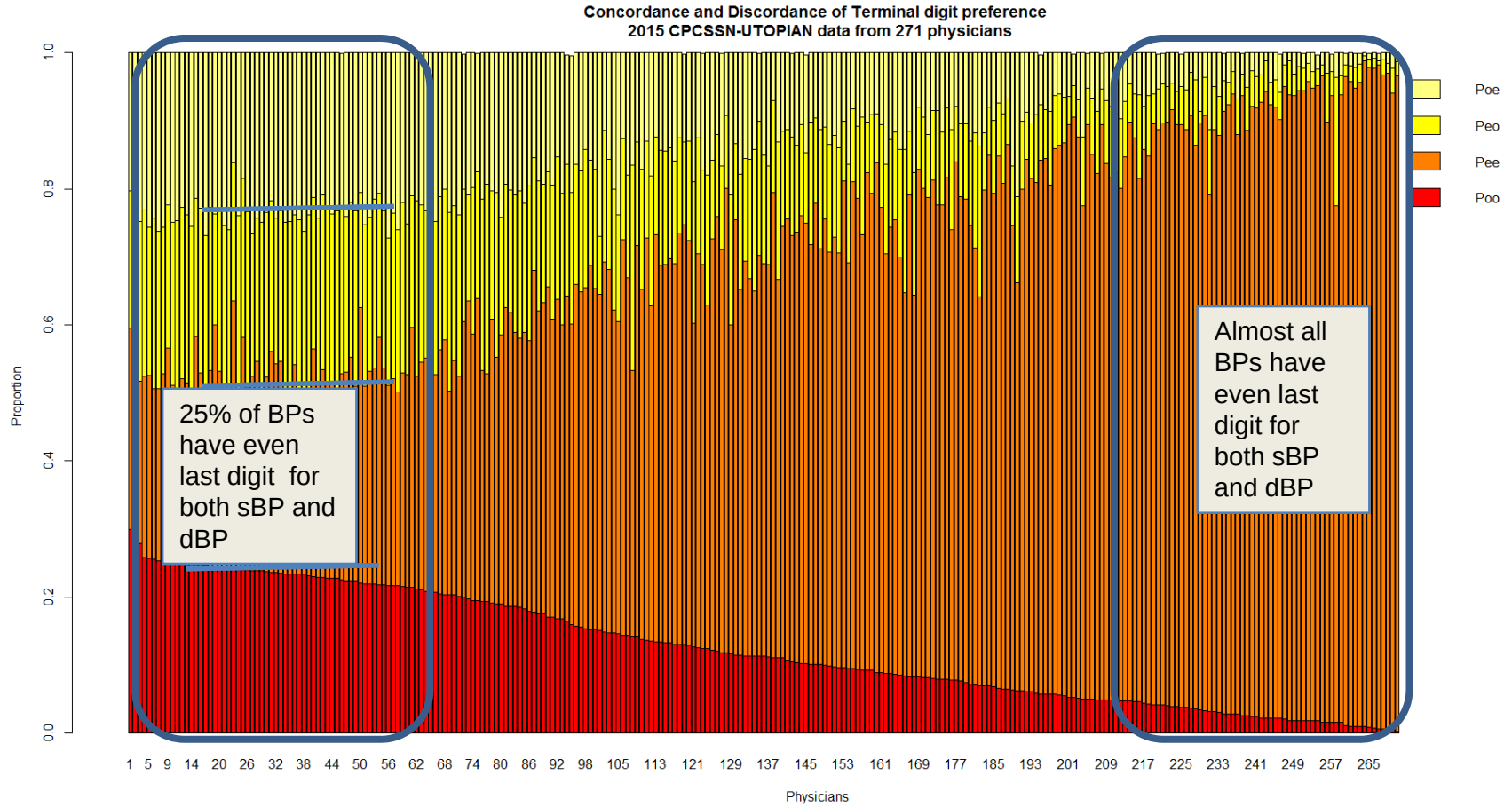

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Can practices be categorized in terms of their end digit preferences?

- We used cluster analysis to classify primary care providers in three groups for each year:

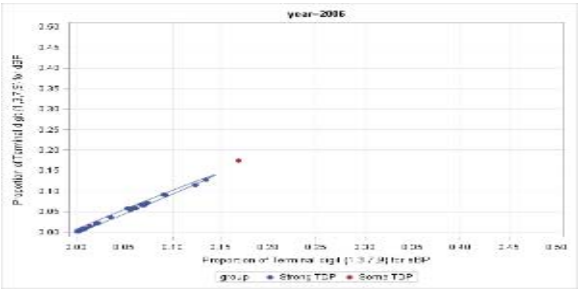
  (1) Those with strong end digit preference;
  (2) Those with some end digit preference;
  (3) Those with potentially no end digit preference.

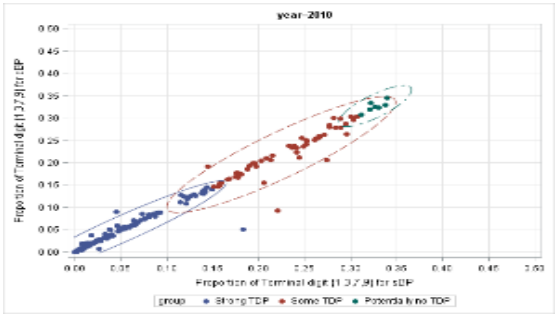
- We used the adjusted probabilities of rare end-digits {1,3,7,9} for sBP and dBP. Adjustments were made for patient/provider/geographical characteristics

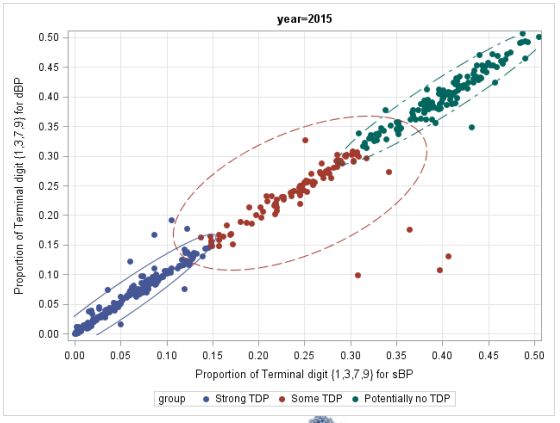
- We implemented the unsupervised machine learning algorithm of k-nearest neighbor across all primary care providers to find the optimal decision boundary to classify family providers into three groups.

Cluster analysis of End Digit Preference

year	Group						Total
	Potentially no EDP		Some EDP		Strong EDP		
	N	Percent	N	Percent	N	Percent	N
2006	.	.	1	3.3%	29	96.7%	30
2007	.	.	10	18.2%	45	81.8%	55
2008	.	.	21	21.9%	75	78.1%	96
2009	.	.	28	20.9%	106	79.1%	134
2010	7	3.7%	57	30.3%	124	66.0%	188
2011	36	16.3%	69	31.2%	116	52.5%	221
2012	64	24.5%	57	21.8%	140	53.6%	261
2013	94	30.7%	68	22.2%	144	47.1%	306
2014	110	31.3%	79	22.5%	162	46.2%	351
2015	129	31.3%	97	23.5%	186	45.1%	412







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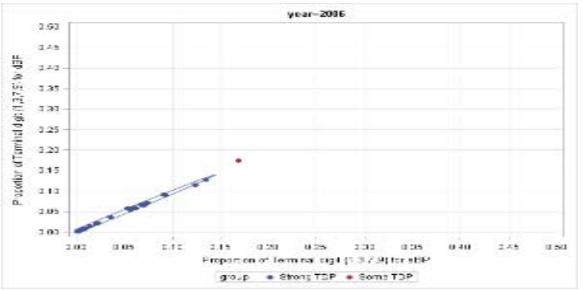

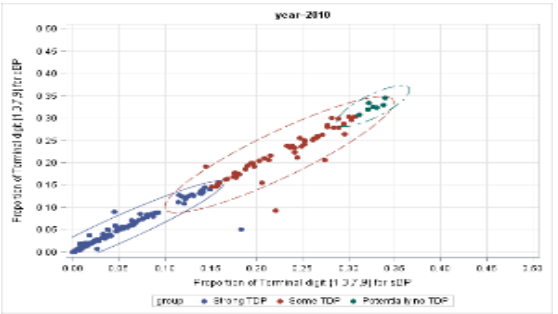

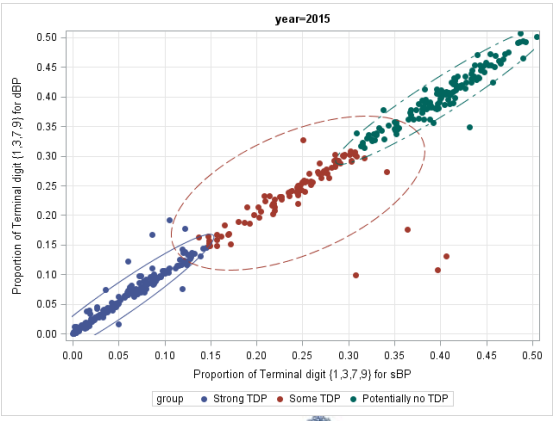

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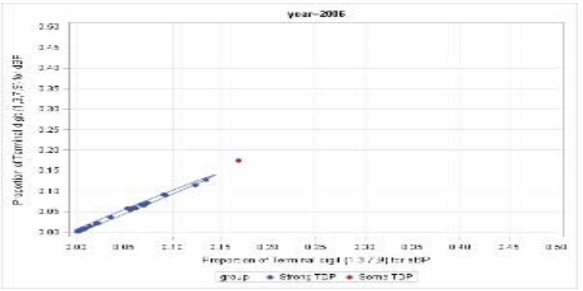
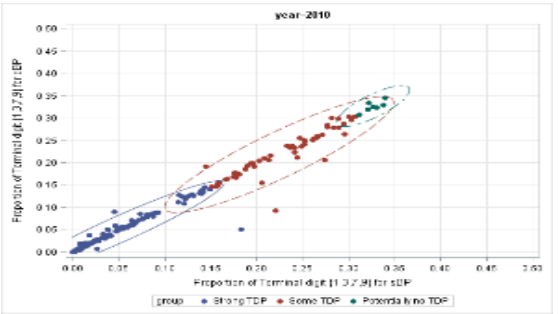
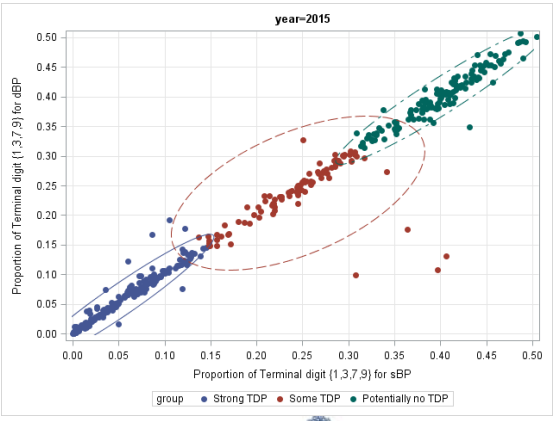
Cluster analysis of End Digit Preference

year	Group						Total
	Potentially no EDP		Some EDP		Strong EDP		
	N	Percent	N	Percent	N	Percent	N
2006	.	.	1	3.3%	29	96.7%	30
2007	.	.	10	18.2%	45	81.8%	55
2008	.	.	21	21.9%	75	78.1%	96
2009	.	.	28	20.9%	106	79.1%	134
2010	7	3.7%	57	30.3%	124	66.0%	188
2011	36	16.3%	69	31.2%	116	52.5%	221
2012	64	24.5%	57	21.8%	140	53.6%	261
2013	94	30.7%	68	22.2%	144	47.1%	306
2014	110	31.3%	79	22.5%	162	46.2%	351
2015	129	31.3%	97	23.5%	186	45.1%	412







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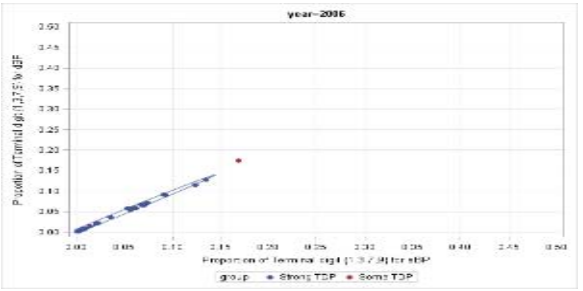

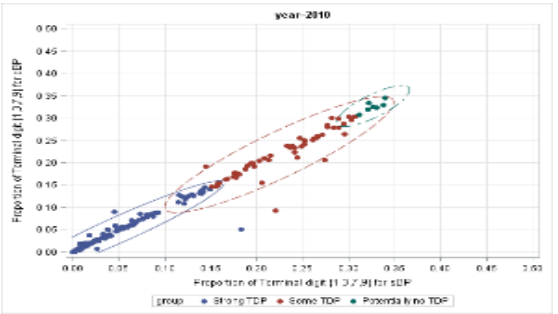

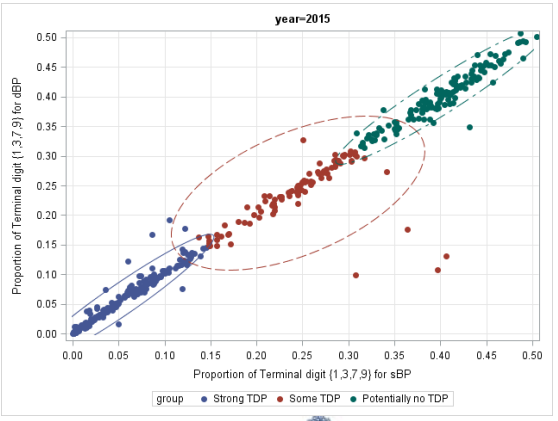

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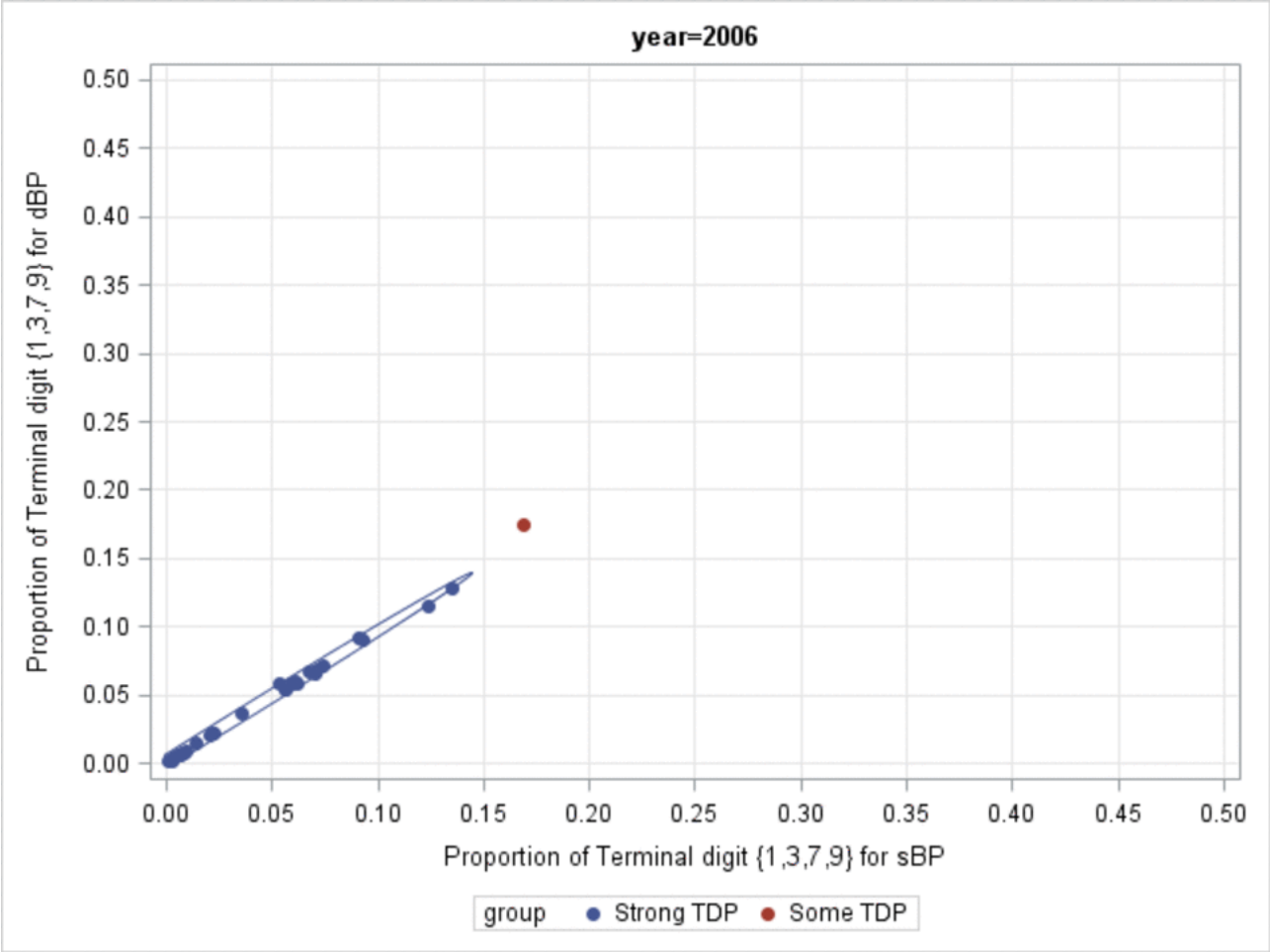
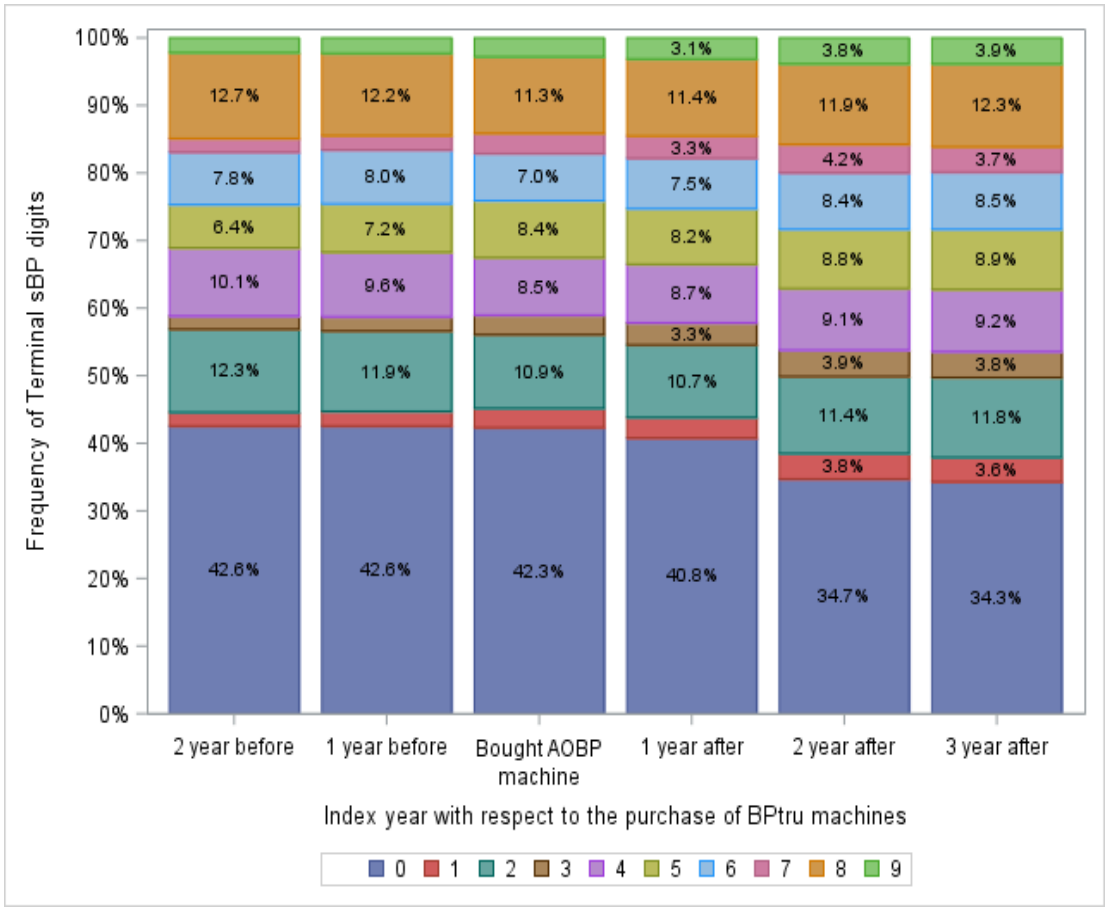
Cluster analysis



- There are practices that tend to have systematically more end digit preference

- This decreased over time; more practices became “end digit neutral”

Impact of adoption of AOBP machine on end digit preference



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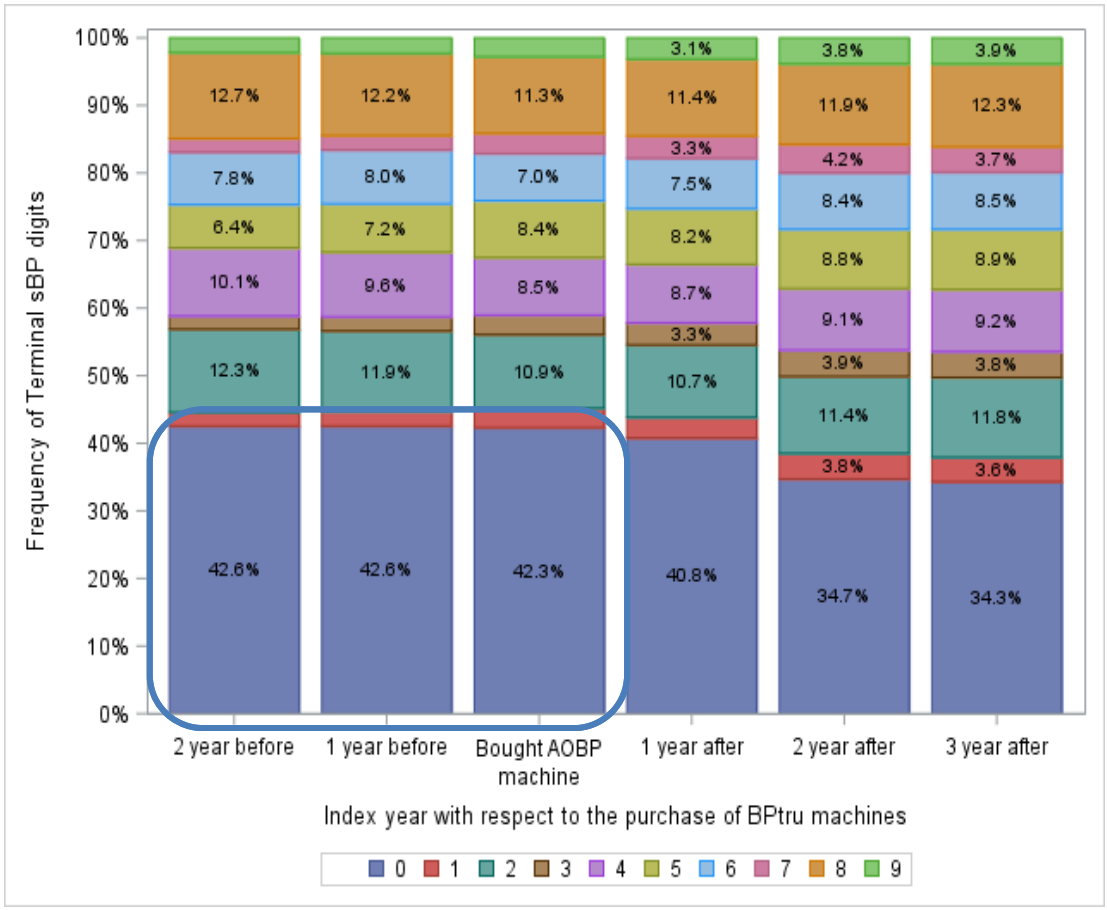

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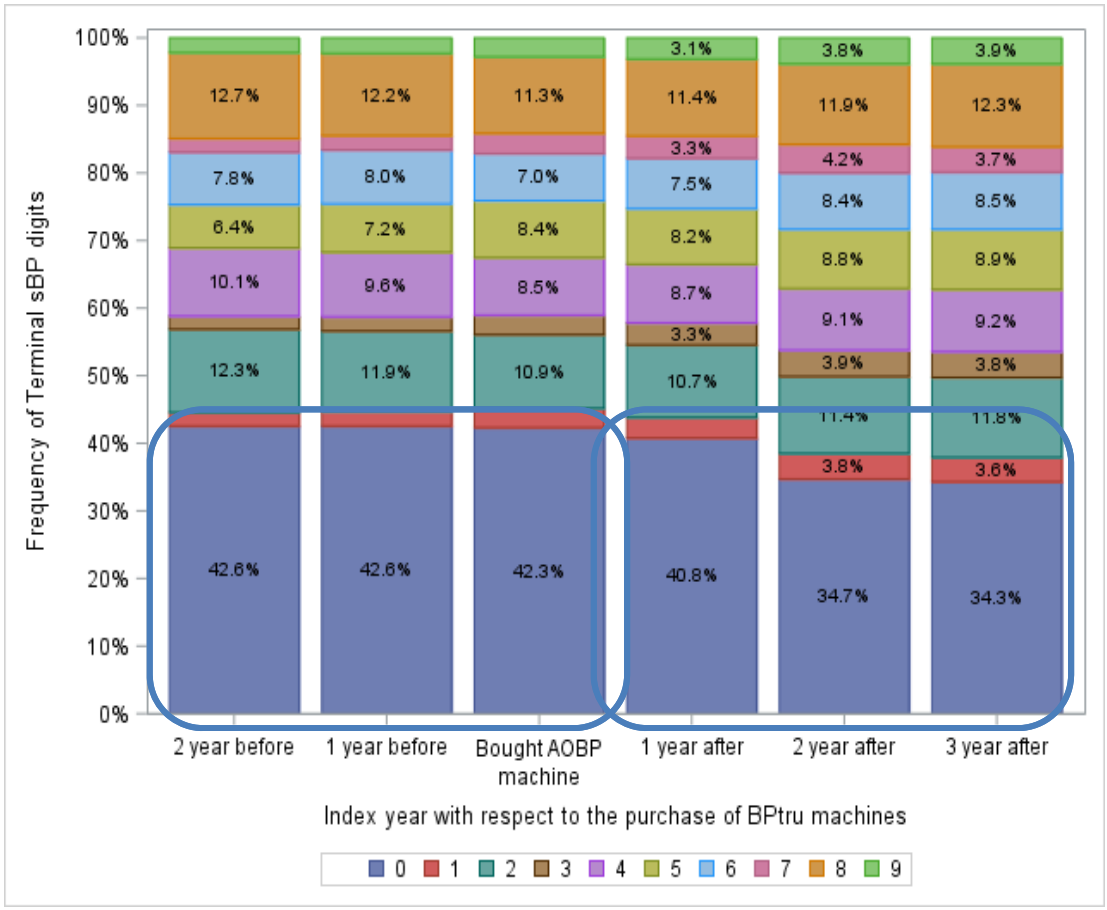
Impact of adoption of AOBP machine on end digit preference



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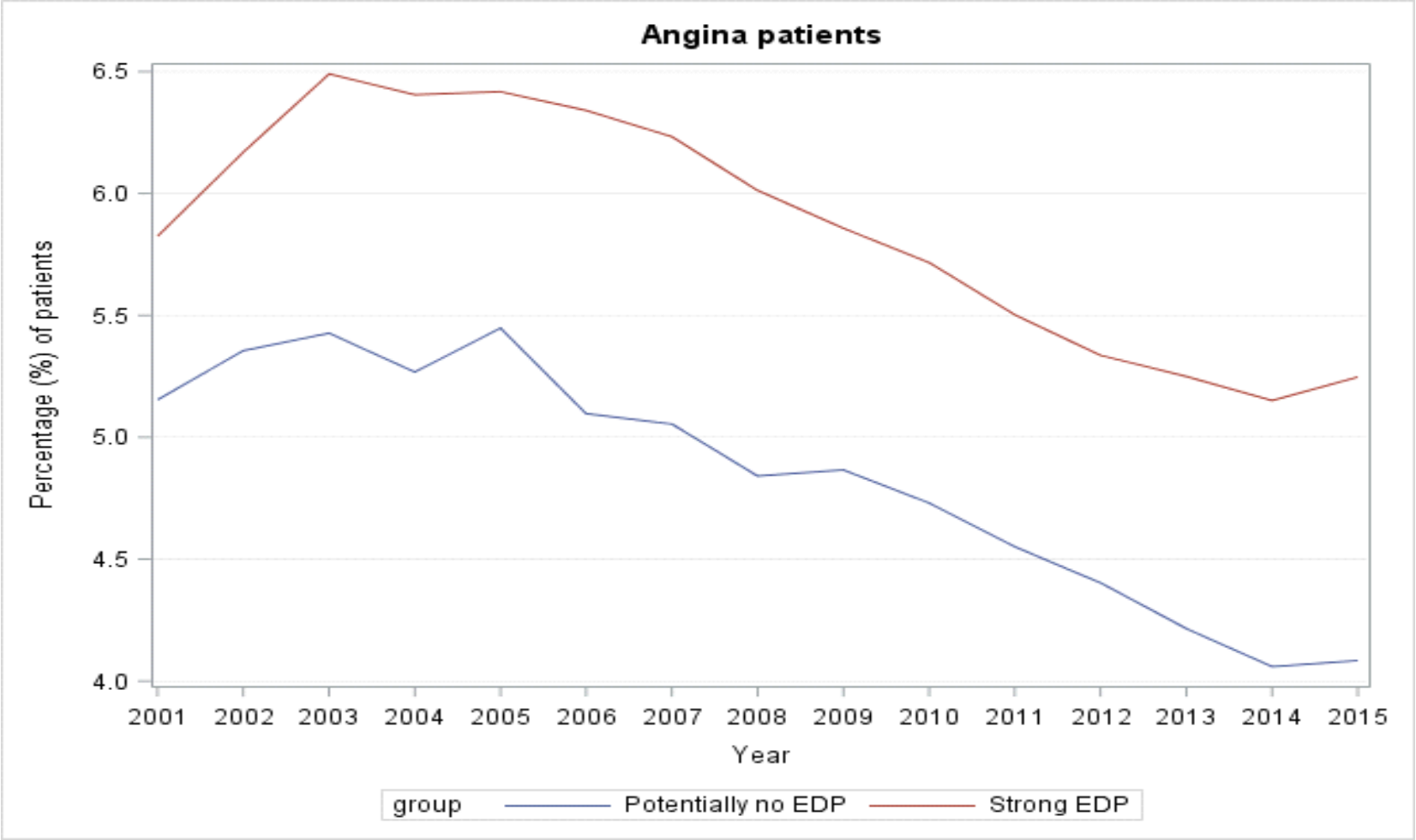
- There appears to be some reduction in end digit preference after an AOBP machine is bought by a practice

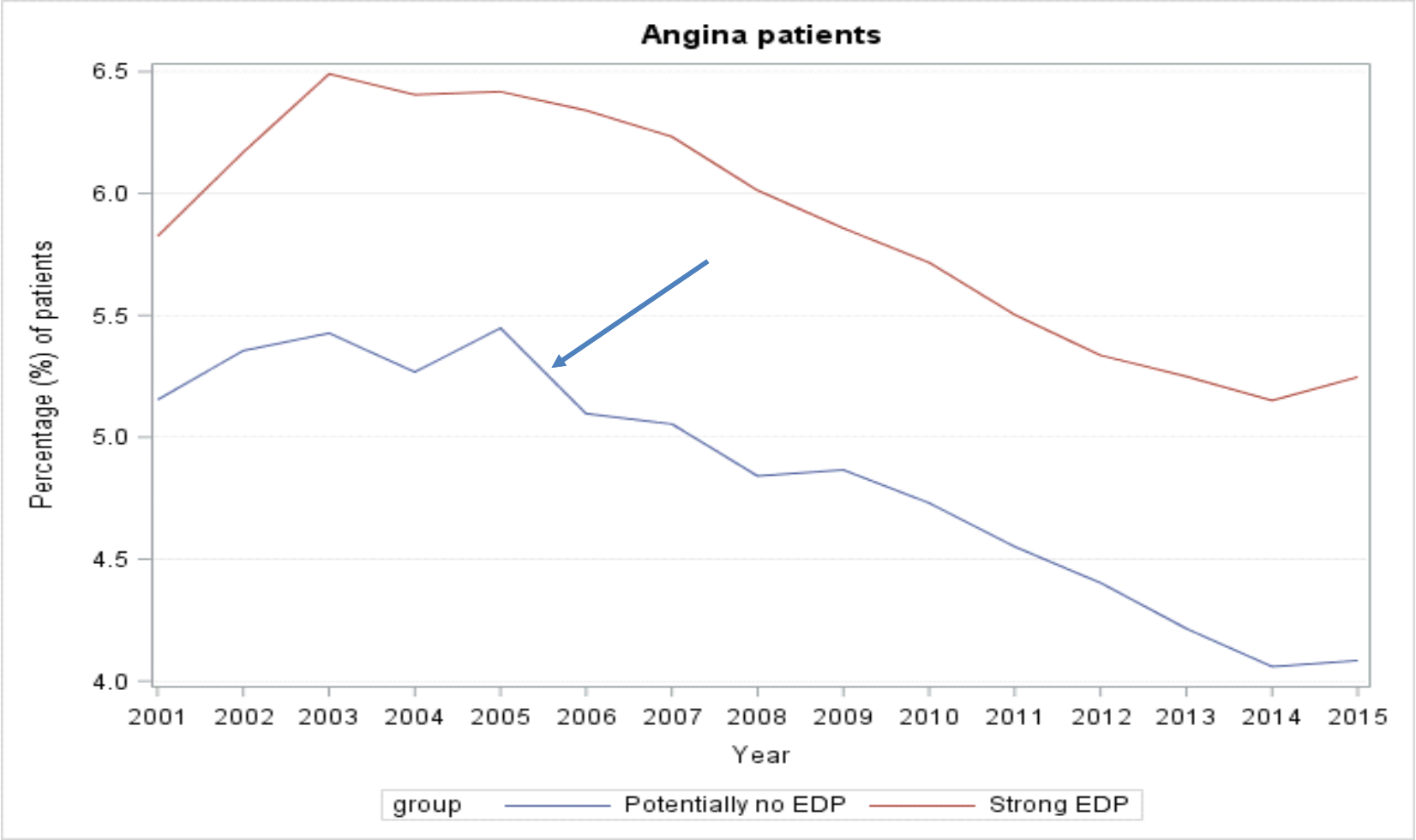
Assessing prevalence of CVD events

- We assessed the prevalence of cardiovascular events (angina, MI, stroke) among the RCGP cohort for no EDP and strong EDP group.
- We defined prevalence using the following numerator and denominator:
  - Denominator: Total number of patients who had BP recorded within the index year
  - Numerator: Total number of patient who had CVD event within the index year (or earlier) and also had BP recorded within the index year

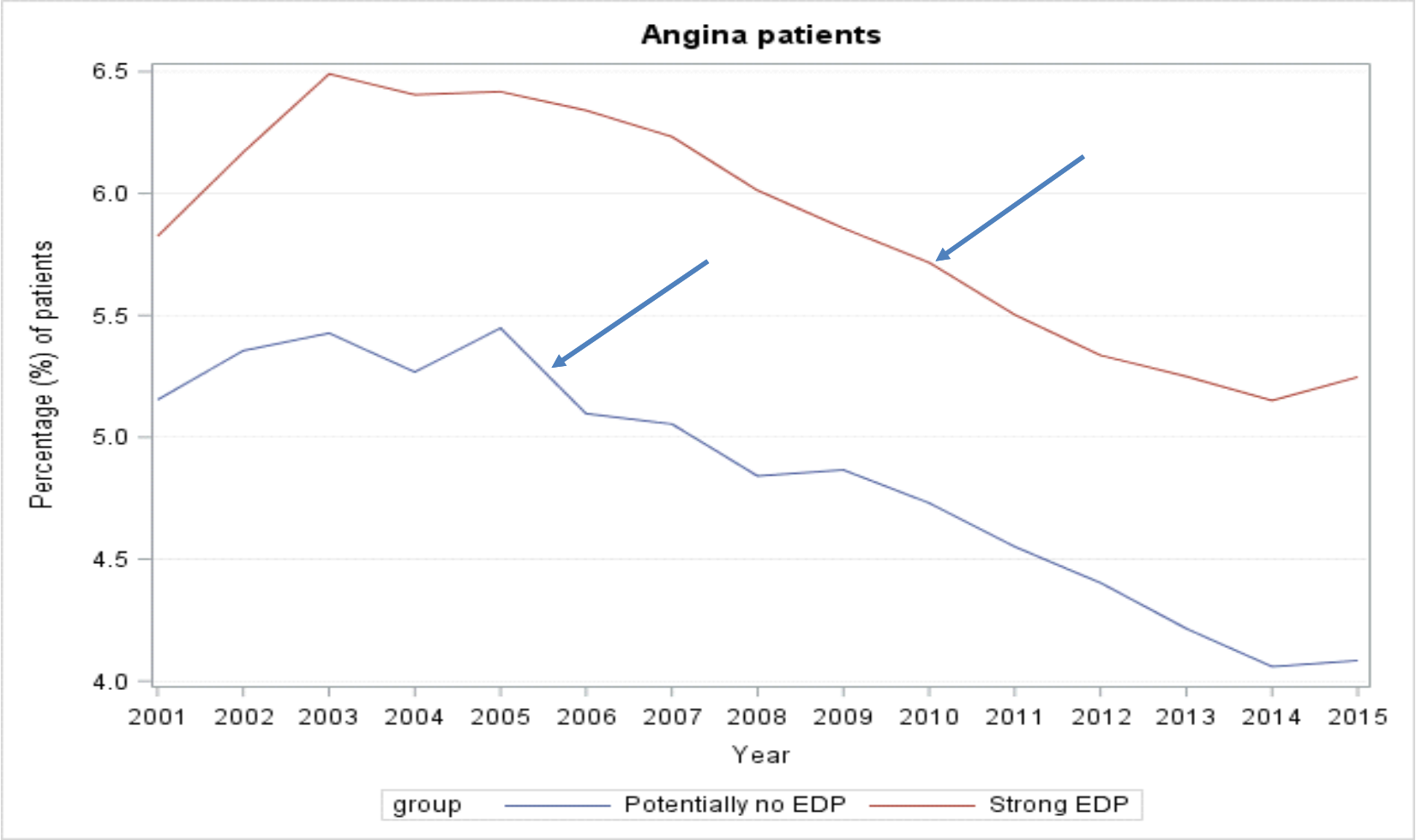
Prevalence of angina among practices with strong EDP vs. No EDP (UK data)



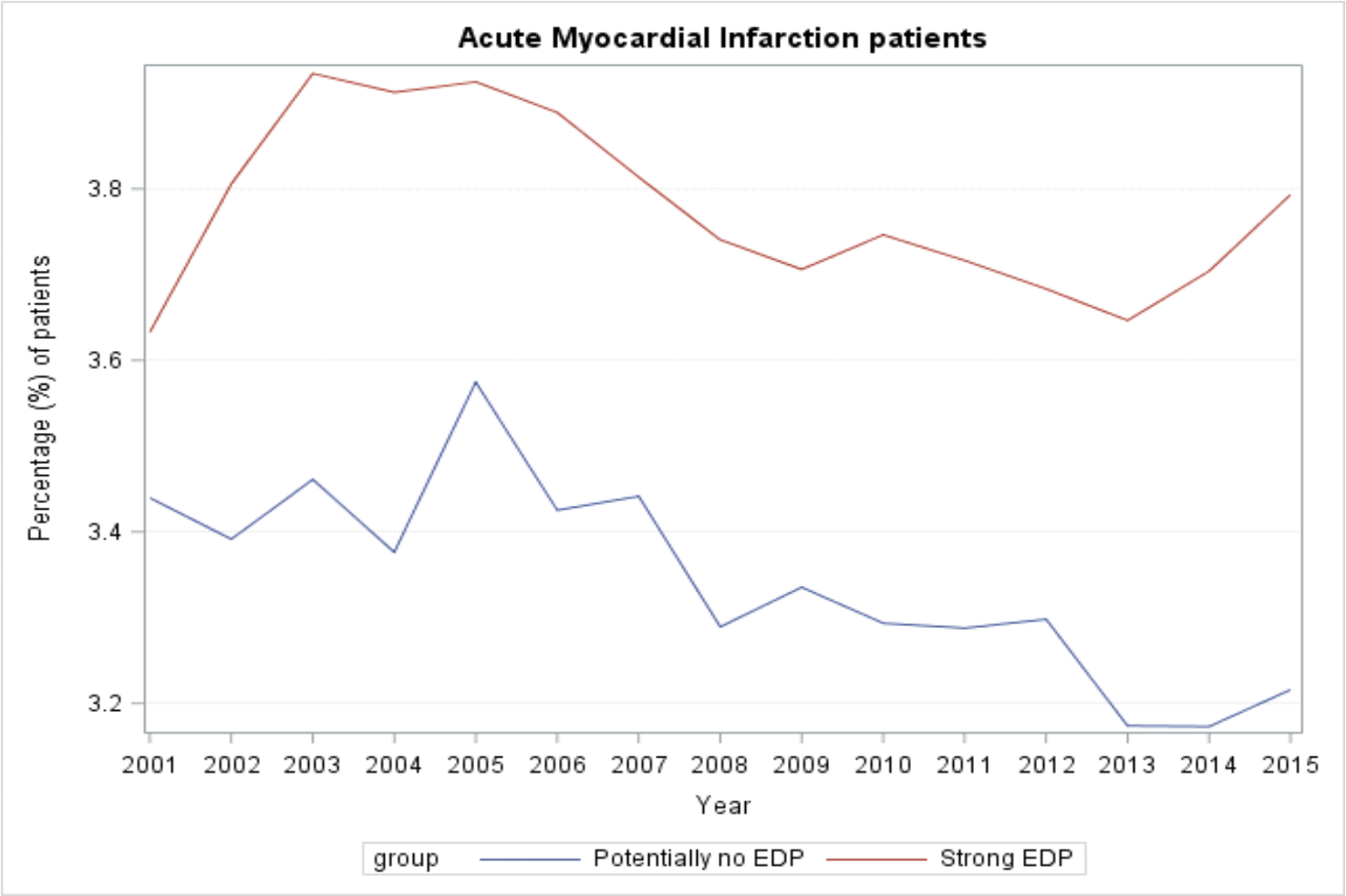
Prevalence of angina among practices with strong EDP vs. No EDP (UK data)



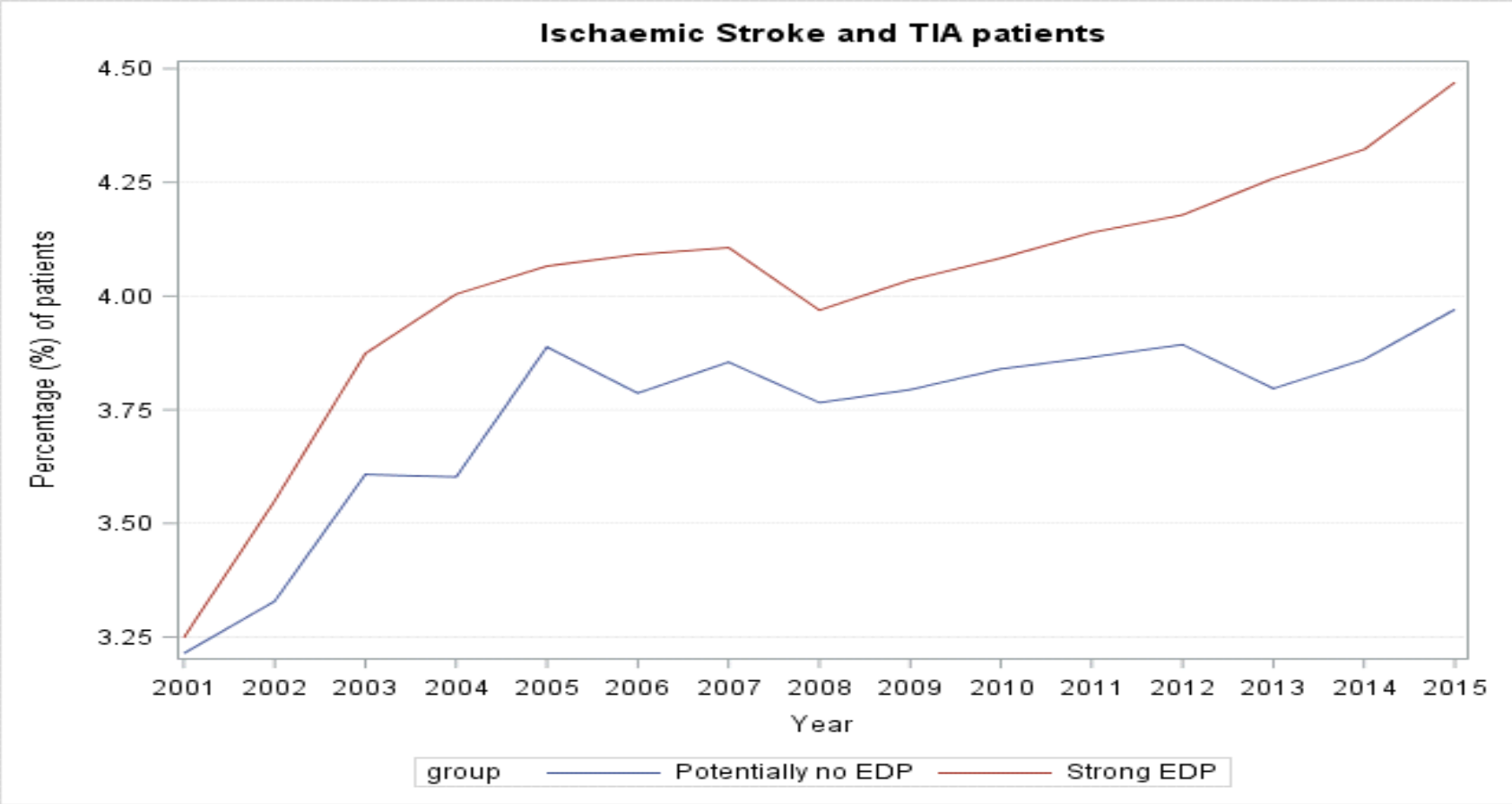
Prevalence of angina among practices with strong EDP vs. No EDP (UK data)



Prevalence of MI among practices with strong EDP vs. No EDP (UK data)



Prevalence of stroke or TIA among practices with strong vs no EDP (UK)



Standardized morbidity ratio for Strong EDP vs No EDP

Angina			
	Estimate	95% Confidence Limits	
Standardized morbidity ratio	**1.21**	1.21	1.22
Acute MI			
Standardized morbidity ratio	**1.13**	1.12	1.13
Stroke			
Standardized morbidity ratio	**1.08**	1.07	1.08

There appears to be an association between greater rates of EDP and higher prevalence of cardiovascular outcomes

Implications of end-digit preference

- Rounding to nearest 5 or 10 contributes towards the biased estimation of mean sBP for various statistical methods (e.g. hypothesis testing; regression modelling).
- This type of data reporting error is known as “heaped” data.
- Advanced statistical methods are required to adjust for the underlying heaping behavior.
- e.g. Bayesian heaping models proposed by Rubin and Heitjan:

Wang, Hao, and Daniel F. Heitjan. "Modeling heaping in self-reported cigarette counts." Statistics in medicine 27.19 (2008): 3789-3804.

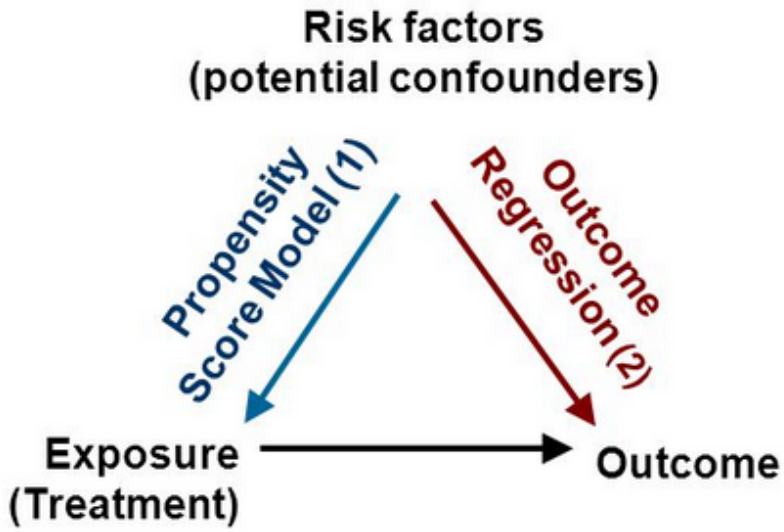
Potential area(s) of future research

How much effect do anti-hypertensive medications have on lowering the blood pressure among hypertensive patients?

- Challenges:
  - Working with observational data [association does not imply causation]
  - Heaped distributions for systolic and diastolic blood pressure
- Strengths:
  - Very large data size (e.g. cohort contains more than 1.5 million patient in CA + 3 million in UK)
  - Routine data in primary care; generalizable to real-life scenario
- Potential solution:
  - combine propensity score modelling with heaped modelling under Bayesian framework

Propensity score modelling

Two stages



Heaping models

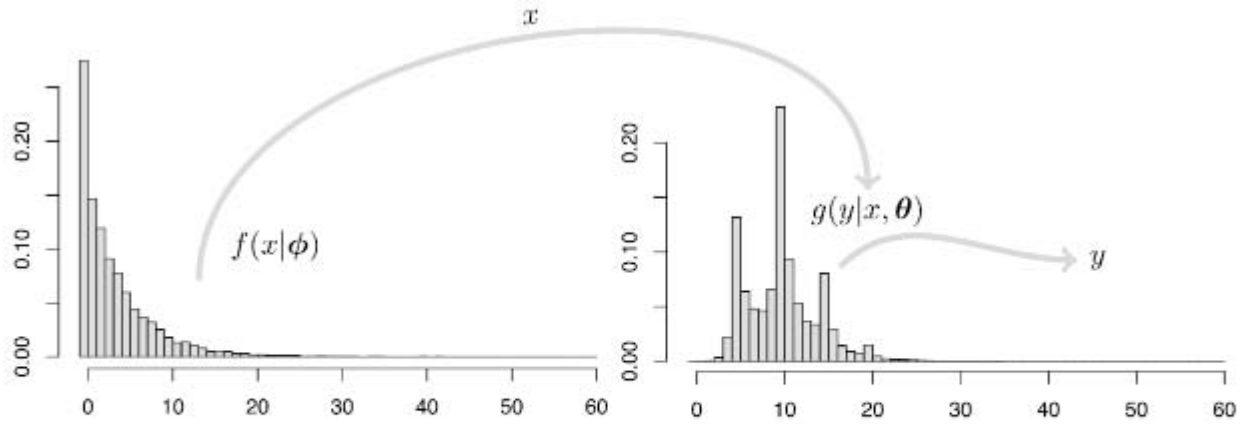
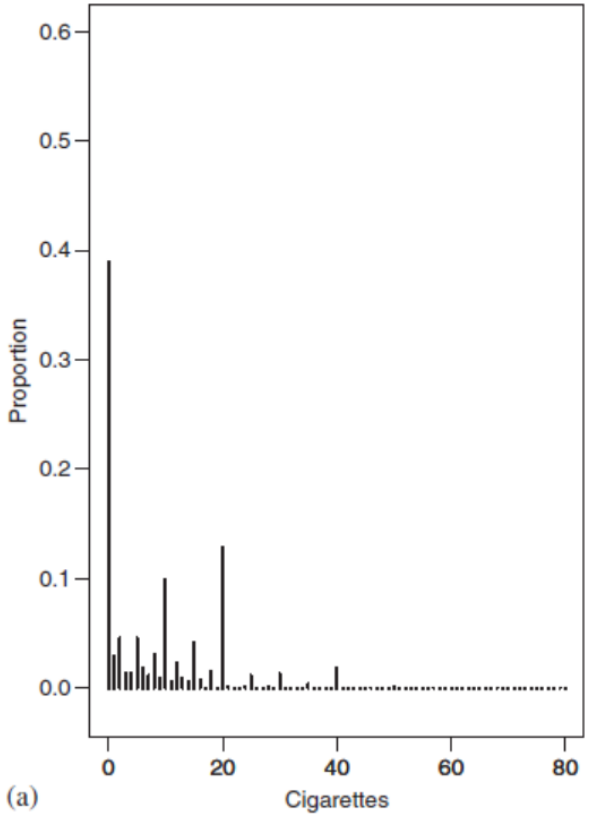


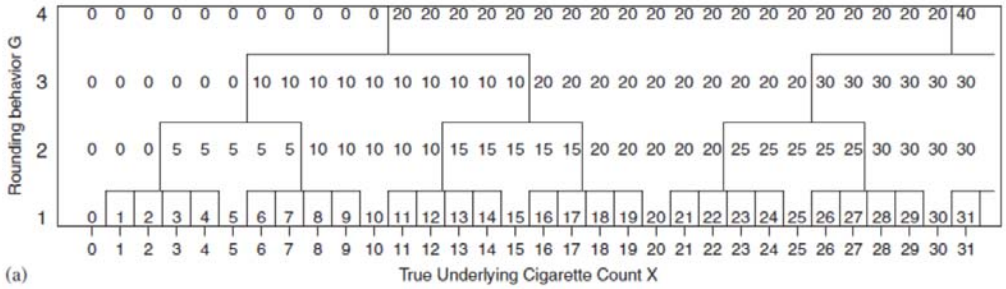
FIG. 1. *Mixture model schematic for reported counts. Each subject chooses their true count x from the distribution $f(x|\phi)$, then reports the possibly different count y drawn from the distribution $g(y|x,\theta)$.*

Crawford, Forrest W., Robert E. Weiss, and Marc A. Suchard. "Sex, lies and self-reported counts: Bayesian mixture models for heaping in longitudinal count data via birth-death processes." *The annals of applied statistics* 9.2 (2015): 572.

Heaping model



$$f_{G|X}(g|x;\gamma)=\begin{cases}(1+\exp(\gamma_1+\gamma_0 x))^{-1} & \text{if } g=1\\ (1+\exp(\gamma_2+\gamma_0 x))^{-1}-(1+\exp(\gamma_1+\gamma_0 x))^{-1} & \text{if } g=2\\ (1+\exp(\gamma_3+\gamma_0 x))^{-1}-(1+\exp(\gamma_2+\gamma_0 x))^{-1} & \text{if } g=3\\ 1-(1+\exp(\gamma_3+\gamma_0 x))^{-1} & \text{if } g=4\end{cases}$$



Wang, Hao, and Daniel F. Heitjan. "Modeling heaping in self-reported cigarette counts." Statistics in medicine 27.19 (2008): 3789-3804.

Conclusions

- More EDP (likely greater use of Manual BP measurement) in practices appears to be associated with **rounding down** of blood pressures
  - This may be associated with systematic underestimation and undertreatment of elevated BP
- More EDP appears to be associated with greater prevalence of cardiovascular illness

- Does **inaccurate measurement** lead to **inaccurate management** of BP?

- Should we **stop using Manual** BP measurement?

- What other studies could be done using data across borders?

- What other US – Canada – UK research collaborations should we think about

International comparisons using care, outcome (and other) data

Possible areas of Collaboration

- **Analyses in parallel**
- **Testing ideas from US using Canadian data and vice versa**
- **Joint data centres in future?**

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Transatlantic Data Science Workshop

National Institutes of Health
Bethesda, Maryland

March 1-2, 2016

Thank you

- Questions