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Bridging the gap between clinical practice and public health: Using EHR data to assess trends in the seasonality of blood-pressure control☆

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ABSTRACT

Electronic health records (EHRs) provide timely access to millions of patient data records while limiting errors associated with manual data extraction. To demonstrate these advantages of EHRs to public health practice, we examine the ability of a EHR calculated blood-pressure (BP) measure to replicate seasonal variation as reported by prior studies that used manual data extraction.

Our sample included 609 primary-care practices in New York City. BP control among hypertensives was defined as systolic blood pressure of 140 or less and diastolic blood pressure of 90 or less (BP < 140/90 mm Hg). An innovative query-distribution system was used to extract monthly BP control values from the EHRs of adult patients diagnosed with hypertension over a 25-month period. Generalized estimating equations were used to compare the association between seasonal temperature variations and BP control rates at the practice level, while adjusting for known demographic factors (age, gender), comorbid diseases (diabetes) associated with blood pressure, and months since EHR implementation.

BP control rates increased gradually from the spring months to peak summer months before declining in the fall months. In addition to seasonal variation, the adjusted model showed that a 1% increase in patients with a diabetic comorbidity is associated with an increase of 3% (OR 1.03; CI 1.028–1.032) on the BP measure.

Our findings identified cyclic trends in BP control and highlighted greater association with increased proportion of diabetic patients, therefore confirming the ability of the EHR as a tool for measuring population health outcomes.

1. Introduction

Health information technology can transform population health, and holds great promise for applying information, from clinical practice to support population health initiatives (Diamond et al., 2009). The rapid adoption of electronic health records (EHRs) under the Health Information Technology for Economic and Clinical Health (HITECH) Act promotes the usefulness of EHRs in the bidirectional exchange of data between clinical practices and public health organizations (Public Health Informatics Institute (PHII), 2009; Lurio et al., 2010). Prior to EHRs, data was manually and tediously extracted from individual medical records. The EHRs provide advantages such as immediate access to millions of patient records in a short period of time, while limiting data transfer errors associated with manual extraction from medical records. The advantages of the EHR data makes clinical data readily accessible for public health initiatives. So, we hypothesize that the electronic health records (EHR) can replicate prior research findings on seasonal variation in blood-pressure that relied on the manual extraction of data from medical charts.

1.1. Seasonal Variation in Blood-Pressure Readings

Blood pressure readings are important to diagnosing and monitoring hypertension, which is primary risk factor for cardiovascular disease and hence a major clinical and public health concern. Chronic cardiovascular conditions are among the leading causes of morbidity and mortality (National Heart and Blood Institute, 2012) that significantly contribute to the economic burden of disease (Centers for Disease Control and Prevention (CDC), 2007; Centers for Disease Control and Prevention (CDC), 2008). They are a focal area of health prevention and control efforts for the New York City Department of Health and Mental Hygiene (NYCDOHMH) (New York City Department of Health and Mental Hygiene, 2004).

Seasonal variations in both systolic and diastolic BP readings among normotensive (Tsuchihashi et al., 1995; Abdulla and Taka, 1988) and hypertensive individuals have been well-documented (Abdulla and

☆ IRB: EXEMPT-NYDOHMH #11 055 New York City Population Health System (The Hub).

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Taka, 1988; Rose, 1961; Hata et al., 1982a; Khaw et al., 1984; Kochar et al., 1985; Sharma et al., 1989). Higher BP trend readings in the winter compared to lower BP readings in the summer still persist when readings are adjusted for daily temperature fluctuations, (Minami et al., 1998) or when readings are taken in climate controlled environments (Kristal-Boneh et al., 1995). Some studies also report that seasonality is evident for daytime readings and not night time readings (Minami et al., 1998; Winnicki et al., 1996a). The proffered explanation for this occurrence is the physiological response to seasonal temperature fluctuations (Rosenthal, 2004). Increased sympathetic system activity is correlated with higher blood pressure readings during the cold season (Hata et al., 1982b). During the warmer months, exposure to heat decreases blood pressure because of the dilation of blood vessels in the skin, along with salt and water loss through sweating; thus, lower BPs are reported in the summer months (Hata et al., 1982b).

BP seasonality is associated with patient demographic factors, as well as other clinical risk factors, including hypertension comorbidities (Long and Dagogo-Jack, 2011). Diabetes is one of the most common comorbidities for hypertension (Long and Dagogo-Jack, 2011; Davila and Hlaing, 2008), and patients with diabetes have seasonal variation in both BP readings and hemoglobin A1c levels (Liang, 2007). Body mass index (BMI) is also inversely associated with mean changes in SBP between the cold and warm seasons (Kristal-Boneh et al., 1996). BP seasonal changes have been documented in children (Prineas et al., 1980; De Swiet et al., 1984; Jenner et al., 1987) and adults, including the elderly (Brennan et al., 1982; Charach et al., 2004; Verdon et al., 1997). The change in SBP and DBP are higher in older adults (55 to 64 year olds) and women, in comparison to the younger adults and men respectively. Also findings show that day time temperatures were higher in normotensive 70 to 80 year olds in both winter and summer than younger men aged 20 to 30 years (Goodwin et al., 2001).

The association between seasonal BP fluctuation and gender can depend on age and is expressed in morbidity and mortality differences (Gerber et al., 2006). Elderly men demonstrated seasonal variation in BP, with readings that are comparatively higher than those of younger men in winter. Higher blood pressure readings were associated with higher activity levels during the day among the elderly in the colder months (Goodwin et al., 2001). The gender and age differences result in an increased number of myocardial infarctions and strokes during the winter (Spencer et al., 1998; Ornato et al., 1996). Older women are more prone to sudden death than younger men in winter (Arntz et al., 2001; Katz et al., 2000). Understanding of the blood pressure fluctuations across seasons is critical to prevention, disease management efforts, and population health initiatives.

2. Methods

We used blood pressure readings that were reported during normal processes of care, from April 2012 to April 2014 at primary care practices in underserved areas in New York City. The application of EHR data from primary care practices for public health efforts in NYC is unique because prior efforts have focused on hospital data rather than outpatient data from a large urban environment.

2.1. Preparing the EHR to capture population health measures for NYC practices

The Primary Care Information Project (PCIP) of the New York City Department of Health and Mental Hygiene (NYCDOHMH) helps clinical practices adopt and use EHRs.

The incentivized program selected mostly small practices in underserved areas of the city, or small practices that serve a higher percentage of Medicaid patients. PCIP collaborated with the participating primary care clinicians and the vendor, eClinical Works (eCW) to program the EHR so that it can be applied to health prevention efforts, chronic disease management, and monitoring quality of care (Amirfar et al., 2011).

2.2. Electronic data collection system

PCIP developed the Hub Population Health System (Hub) to facilitate data extraction from the participating primary care practices (Buck et al., 2012). The Hub creates and distributes queries to a virtual network of ambulatory practices in New York City for both historical and real-time health data. It connects to each practice at night through a secure pathway and returns aggregate count of patients at the practice level in response to distributed queries (Buck et al., 2012).

The quality measure requirements are programmed into Structural Query Languages (SQL and MySQL), which then retrieve different components of the measures from information entered by providers in the structured fields (vitals, problem list, demographics) of the EHRs (Kukafka et al., 2007). The different components of the SQL and MySQL code undergo rigorous testing and comparisons to make sure that we are receiving the correct number of patients who meet the definition of the measure.

2.3. Defining the electronic measure

The BP measure in this study is defined as BP control (BP < 140/90 mm Hg) among patients with hypertension and is based on the National Quality Forum measure NQF-0018 (National Quality Forum (NQF), 2014). The appendix (Fig. A1) shows the measure definition and key considerations used in developing the electronic version. In conducting this analysis, we selected a measure that was already defined by a group of experts, a measure that has been tested and verified on our data collection system, and one that is relevant to our population health goals in NYC.

The measure is aggregated to the practice level, and for each practice, the measure denominator is the aggregate for all patients between the ages of 18–100 years with a diagnosis of hypertension who had a documented office visit in the reporting period; while the measure numerator consists of a subset of those patients with controlled blood pressure taking into consideration both the systolic and diastolic BP (BP < 140/90 mm Hg). HTN patients were identified using codes from the International Classification of Diseases, Ninth Revision (ICD-9). Office visit documentation was based on the presence of a valid primary care Evaluation and Management Current Procedural Terminology (E/M CPT) billing code within the month under consideration. When a patient is shown to have multiple visits, we used the most recent recorded BP value. This measure is a snapshot of BP control efforts at the end of the month at the practices, so the last recorded value for patients with multiple visits is more relevant to our calculation. Information on patients outside the plausible BP range (e.g. a BP of 1000/1000) was excluded to eliminate data entry errors by the EHR users. The presence of relevant ICD-9 diagnosis codes was used to identify and categorize patients with the additional diagnosis of diabetes.

We extracted the aggregate number of patients meeting the denominator and numerator definition for each practice. Then we stratified the denominator by age (18–59 years old and 60–100 years old), gender (Male and Female), and diabetic status (Yes or No).

2.4. Practice selection

Initially we extracted data from 703 practices, from which we excluded those with data transmission errors, leaving 695 practices. The transmission errors include those that lack either the denominator or numerator of the measure; and in rare cases those with a denominator lower than the numerator. Practices that had not implemented EHRs at baseline (April 2012) were also excluded, leaving 609 practices eligible for inclusion in this study.

2.5. Statistical analysis

The statistical models estimated the odds of BP control over time. The outcome was defined as the number of patients with controlled BP among the total number of patients with hypertension for a given month at the practice level. We defined a yearly period as starting from April to March the following year. The year period and month were included as categorical variables. Age was defined as the percentage of elderly adults (ages 60 to 100) with hypertension, gender was defined as the percentage of male patients with hypertension and comorbidity was defined as the percentage of patients with hypertension who have diabetes. We controlled for EHR acclimatization by including the number of months since EHR implementation in the primary care practices.

First, we charted the monthly mean BP control rates versus the monthly mean temperatures for NYC over time. To examine the general trend in BP control, we compared the practice means using dependent *t*-tests for BP control rates in July (2012, 2013), January (2013, 2014), and April (2012, 2013, 2014). We expected high BP readings in January and low BP readings in July and hence higher control rates in July and lower control rates in January. Comparing BP means for the same months (Jan 2012 and Jan 2013) established overall performance trends on BP control while controlling for the expected changes due to seasonal variation. The same type of comparison, conducted across three additional time points (April 2012, 2013, 2014), allowed for observing performance over a longer period of time. We then compared the practice means at different seasons (July 2012, January 2013) to assess seasonal variation.

We used generalized estimating equations (GEE) to assess the impact of various factors on BP control (Liang and Zeger, 1986). The GEE model addressed dependency among repeated measures for the study's 25 months and it provides inference for all patients from the sample of practices. Using the Genmod procedure in the Statistical Analysis Software (SAS 9.2), we specified an autoregressive matrix that accounts for possible autocorrelation across the months (SAS Institute Inc, 2004). We used an event trial model with a logit default link that assumes a binomial distribution. The estimates are exponentiated and interpreted as the odds of the occurrence of the event (controlled blood pressure) (SAS Institute Inc, 2015). The preliminary model that included time (month and year) as main effects was compared to a second model that was adjusted for practice level aggregate patient demographic information (age and gender), diabetes comorbidity, interaction between age and gender, and EHR acclimatization.

3. Results

3.1. Practice characteristics

A total of 609 practices across the five boroughs of New York City were included in this analysis. Ninety-four percent of the practices were small with no >10 providers, while 62% were single-provider practices. Across the practices, there was an average of 75,892 monthly visits from patients with hypertension (SD = 6152) with 52,549 (SD = 4779) of these visits attributed to patients with controlled BP (69.2%). Patients were equally divided between genders, and 41% of monthly visits were from those with an additional diagnosis of diabetes. The average EHR acclimatization was 49.76 months (SD = 14.71). Table 1 shows practice characteristics and patient visit information at month 25 (April 2014).

3.2. Preliminary analysis

Table 2 shows the BP control rates by month. Fig. 1 shows the cyclical trend of the monthly BP control rates and average NYC monthly temperatures. Fig. 2 shows the trend of average control rates by patient group. Blood-pressure control rates increased consistently throughout the spring, peaked in the summer month of July and started to decline in August, reaching lower values in the cooler months (November, December, January, and February).

The cyclical highs and lows were replicated from the first year (April 2012–April 2013) to the second year (April 2013–April 2014). Between April and July, BP control rates in the second year were higher than in the first year. The performance gains on the mean BP control rates in the second year were lost between August and December. From December to January, the rates in the first year were higher than in the second year (Fig. 1).

The same cyclical trend was evident across gender, age, and diabetic status. Higher BP control rates were seen for the elderly, females, and those with diabetes. The difference between the high and low BP control rates were greater for the elderly (9%), males (8%), and those with diabetes (6.8%) when compared with the differences between high and low BP control rates for the younger adults (6%), females (6%), and those without diabetes (6%).

Results from the dependent *t*-tests showed that the increases in mean BP control rates from July 2012 to July 2013, and from January 2013 to January 2014 were not statistically significant. The increase from April 2012 (64.1%, SD = 19.65) to April 2013 (66.7%, SD = 19.60) was significant ($P = 0.005$). However, there was no significant change in the mean BP control rates from April 2013 to April 2014 (66.6%, SD = 20.4). Table 2 shows these results.

In comparing the cyclical high and low BP control rates, we observed a statistically significant decrease of 4.5% ($P < 0.001$) from July 2012 to January 2013. We also observed an increase of 5.6% ($P < 0.001$) from January 2013 to July 2013, and a decrease of 5.3% ($P < 0.001$) from July 2013 to January 2014.

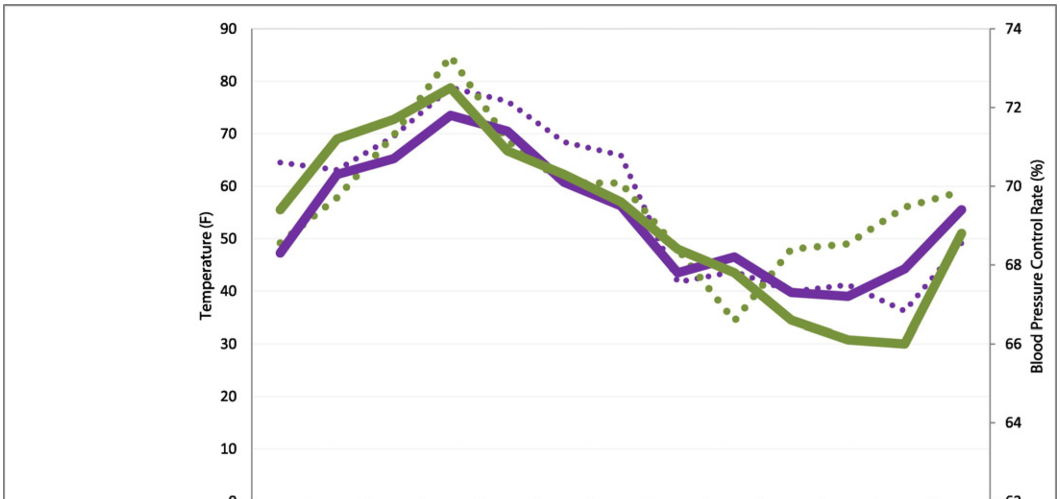
Table 1
Practice and patient characteristics, April 2014 ($n = 609$).

Characteristic	Frequency (%)
Practice type	
*Small practices	571 (94)
Large practices (community health centers/other)	38 (6)
Practice Location	
Practices operating at a single site	455 (76)
Practices operating at multiple sites	145 (24)
Providers	
Practices with single providers	372 (62)
Practices with multiple providers	230 (38)
Patients age category	
18–59	34,426 (49.99)
60–100	49,232 (50.02)
Patient gender category	
Male	35,002 (50.02)
Female	48,656 (49.98)
Patients diagnosed with diabetes	
Patients diagnosed with diabetes	34,436 (41.16)
Patient not diagnosed with diabetes	49,222 (58.84)

*Small practices are those with <10 providers.

Table 2
Comparing the difference in means between months of low (January) and high (July) blood-pressure control rates over time.

From (date)	Mean	(SD)	To (date)	Mean	(SD)	Change	*P* value
Jul-12	68.8	*(20.9)*	Jul-13	69.9	*(19.5)*	+1.0	0.2252
Jan-13	64.3	*(21.7)*	Jan-14	64.6	*(20.4)*	+0.3	0.5564
Jul-12	68.8	*(20.9)*	Jan-13	64.3	*(21.7)*	−4.5	<0.0001
Jan-13	64.3	*(21.7)*	Jul-13	69.9	*(19.5)*	+5.6	<0.0001
Jul-13	69.9	*(19.5)*	Jan-14	64.6	*(20.4)*	−5.3	<0.0001
Apr-12	64.1	(19.7)	Apr-13	66.7	*(19.6)*	+2.6	0.005
Apr-13	66.7	*(19.6)*	Apr-14	66.6	*(20.4)*	−0.2	0.803



	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Mean Temp [2012-2013]	64.5	63.1	69.5	78.8	76.2	68.4	65.9	41.7	43.7	39.9	41.2	36.2	49.2
Mean Temp [2013-2014]	49.2	57.8	69.7	84.8	68.7	60.6	60.6	48	34.3	48	49	56	59
BP Rate [2012-2013]	68.3	70.3	70.7	71.8	71.4	70.1	69.5	67.8	68.2	67.3	67.2	67.9	69.4
BP Rate [2013-2014]	69.4	71.2	71.7	72.5	70.9	70.3	69.6	68.4	67.8	66.6	66.1	66	68.8

Fig. 1. Monthly mean BP control rates and NYC temperatures in 2013 and 2014.

3.3. Statistical modeling

Table 3 shows the estimates from the GEE model. In the preliminary model the main effect was limited to time (month and year period). New York City has four defined seasons reflected in the seasonal temperature changes. The months are correlated to the seasonal temperatures and they reflect the average monthly temperatures. In the second model, we controlled for patient demographic variables (age and gender), comorbidity (diabetes), EHR acclimatization (months since EHR implementation) and the joint effect of gender and age on the seasonal fluctuations. In the initial model, the estimated ORs for the warmer months are significantly different from the reference month of January while the cooler months (November, December, and February) are not significantly different from January. The odds of patients having controlled BP significantly increased gradually in the spring months of April (OR 1.18; CI 1.10–1.26) and peaked from May (OR 1.25; CI 1.14–1.36), through the summer months of June (OR 1.23; CI 1.14–1.33), July (OR 1.25; CI 1.15–1.35), declining from August (OR 1.20; CI 1.11–1.29) through September (OR 1.17; CI 1.08–1.26) and October (OR 1.13; CI 1.05–1.21) .

When the model was adjusted for age, gender, and comorbidity, in general the effect of the months decreased. However, the cyclical pattern of a gradual increase in BP control rate from the summer to the winter months was still significant and the year period (April 2013 to March 2014) is now significantly different, (OR 1.03; CI 1.01–1.04) from the reference year period (April 2012 to March 2013). The percent of the hypertensives who are diabetic (OR 1.03; CI 1.028–1.032) was significant in the adjusted model. So a percent increase in the number

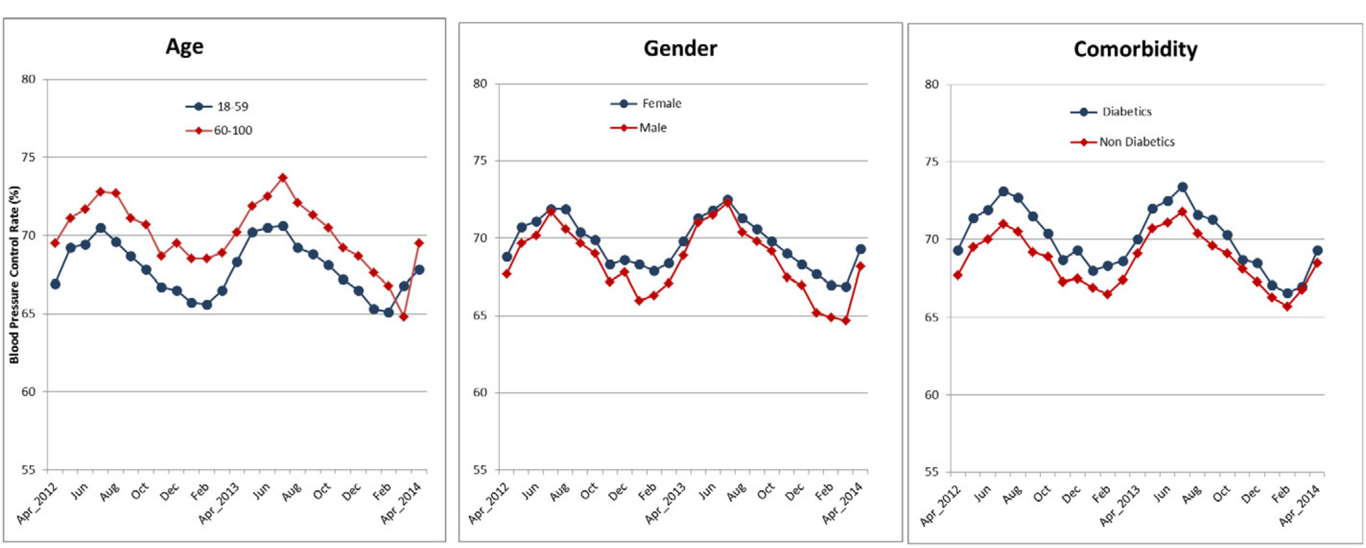


Fig. 2. Trend in monthly BP control rates by demographic group.

Table 3
Estimate of odds ratios from generalized estimating equation (GEE) models.

	Preliminary - Model 1				*Adjusted -Model 2*			
Variable	Odds ratio	Lower limit (95% CI)	Upper limit (95% CI)	*P*-value	Odds Ratio	Lower limit (95% CI)	Upper limit (95% CI)	*P*-value
February	1.00465	0.96635	1.04446		1.02886	1.00508	1.05321	*
March	1.07468	1.01346	1.1396	*	1.13498	1.10138	1.16961	***
April	1.17617	1.0993	1.25841	***	0.99245	0.96879	1.0167	
May	1.24685	1.14199	1.36135	***	1.04473	1.01589	1.07438	**
June	1.23292	1.14013	1.33326	***	1.05131	1.02482	1.07848	***
July	1.24561	1.15184	1.34701	***	1.07063	1.04212	1.09991	***
August	1.20012	1.11229	1.29489	***	1.05301	1.0259	1.08082	***
September	1.16604	1.08132	1.25739	***	1.02277	0.99571	1.05057	
October	1.12809	1.05111	1.2107	***	1.01534	0.99109	1.04018	
November	1.04468	0.9738	1.12072		1.00428	0.98105	1.02807	
December	1.05706	0.99119	1.12731		0.9956	0.97539	1.01623	
Year (Apr 13–Mar 14)	1.00446	0.97534	1.03444		1.02605	1.01105	1.04127	***
Gender (% Male)					1.00077	0.99846	1.00309	
Diabetic (%)					1.03003	1.02822	1.03184	***
Age (% Older adults)					1.00215	0.99985	1.00446	
Age * Gender					1.00001	0.99997	1.00006	
EHR (Months since implementation)					1.00111	0.99929	1.00293	
Intercept	1.88053	1.69531	2.08598	***	0.2218	0.1806	0.2724	***

of diabetics increases the odds of the rate of blood pressure control by 3%. Gender, age and period of time since implementation of EHRs were not significant.

4. Discussion

The cyclical trend we observed for the EHR-derived quality measure was similar to prior research on seasonal variation in BP readings for patients with hypertension (Abdulla and Taka, 1988; Rose, 1961; Hata et al., 1982a; Khaw et al., 1984; Kochar et al., 1985; Sharma et al., 1989). The performance trend over time support those previously reported by other studies. From April to July of the second year, we noted an improvement in the BP rates over the first year period. This corresponds with reported sustained improvement for other EHR-derived measures developed by PCIP (Wang et al., 2013). Contrary to the earlier months, the BP control rates in the second year fell below the first year from November to April. This may be a result of comparatively lower seasonal temperatures in the winter months of the second year (National Weather Service, 2014). The higher control rates in females conform to reports of lower BP readings which could confer an advantage to better control rates (Sandberg and Ji, 2012; Boynton and Todd, 1947; Cutler et al., 2008; Stamler et al., 1976). The BP control rates were higher for the elderly, even though they have been reported to have higher BP readings, and it could be a result of difference in health care utilization among the age groups. Higher control rates in patients with the added diagnosis of diabetes can be attributed to relative arterial stiffness, which has the effect of dampening blood pressure (Henry et al., 2003). Overall, the statistical model confirms that variations in BP control across seasons are consistent, but the magnitude of the variation is reduced when considering gender, age, and diabetic status (Goodwin et al., 2001). Additionally, the primary care practices in the study may have been engaged in one or more quality-improvement initiatives, which could have resulted in the significant increase in BP control in 2013–2014 compared to 2012–2013 (Bardach et al., 2013; Ryan et al., 2014).

Just as seasonal BP variations can influence clinical studies, (Sega et al., 1998; Winnicki et al., 1996b) the seasonality documented for our sample of clinical practices can influence evaluation of health programs. Accurate assessments of the impact of interventions focused on improving BP control must take seasonal fluctuations into account. Our findings can also be applied to ongoing quality-improvement initiatives within the clinical practices. Factoring seasonality of BP-control rates into our communications with providers and patients can improve the accuracy of our messages and enhance strategies in response to expected variations in BP control. For example, providers practicing in regions with extreme seasonal temperature changes may be advised to reassess patients with hypertension following seasonal changes to consider if changes to existing treatment may be necessary.

Our findings also have implications for primary care practices where continuity of care allows providers to play a vital role in managing chronic diseases among their patient panels (Starfield, 1992; Doescher et al., 2004; Flocke et al., 1998; Christakis et al., 2000; Lambrew et al., 1996). Providers can apply information on seasonal variations to smooth out both the cyclical trend and differences across patient groups. Current clinical practice standards focus on titrating to control; understanding the seasonal variation in blood pressure may assist providers in identifying patients who need short-term follow-up and potential changes to their medication to maintain control in response to seasonal variation (Modesti, 2013). Careful diagnosis in winter is important, especially for patients with borderline hypertension who may be misclassified, over-diagnosed, and over-treated (Rosenthal, 2004). During the winter, interventions targeted to the elderly, such as protection against cold weather, may help keep BP under control (Modesti, 2013).

5. Limitations

The key advantages of the EHR include timely, direct and immediate access to millions of patient records; however these maybe offset by limitations. Prior research has demonstrated the effect of the EHR functions and features (management of patient demographics and medications lists) on the calculation of the electronic measures and performance on those measures over time (Amoah et al., 2015a; Amoah et al., 2015b). In addition, the data used for this study is subject to technical errors because providers have the option to customize the EHRs and this can affect where data is stored and how we are able to access the data for calculating the electronic measure. However, our experience has shown that very few providers exercise the option to customize their electronic medical records due to the technical complexity involved in customization. This can result in a lower number of patient counts from the EHR compared to those from the traditional chart reviews (Parsons et al., 2012). Most of the sample practices were recruited for programmatic purposes, with established inclusion criteria for practices in medically underserved areas and/or with a high number of publicly insured patients. Similar to traditional chart reviews, the analysis does not take into account medication therapy or patient behavior, such as adherence to medical advice and therapy, thereby we are unable to access how patient behaviors influence the blood pressure control measure at the practices.

6. Conclusion

Despite the limitations associated with electronic quality measures, the EHR-derived quality measure compares favorably with research findings on seasonal trends in BP control readings. Our analysis supports the use of EHR-derived data for population-level quality measurement, which can in turn inform guidelines and decisions about clinical practice. The advantages of using a system like the Hub is its ability to aggregate a large number of clinical data and variables to quickly identify clinical variations of interest and follow changes over time. Understanding seasonal variations in blood pressure control has particular relevance for public health interventions and health research initiatives, particularly for primary care providers seeking to improve control rates and prevent the hypertension associated morbidity, such as heart attack and stroke, in their patient populations over the course of a year's seasons. These findings demonstrate the utility of using ambulatory EHR-derived quality measures to assess population-level trends.

Conflict of interest

No conflict of interest reported for any of the authors.

Appendix A

Measure Definition: Blood pressure control for patients 18–100 years of age diagnosed with hypertension

Denominator: Number of unique patients between 18–100 years of age, with a diagnosis of hypertension, who were seen for a visit in the reporting period (April 2012–April 2014).

Numerator: Number of patients in denominator having both a systolic blood pressure below 140 mm Hg and a diastolic blood pressure below 90 mm Hg on their most recent BP measurement within the reporting period.

Documentation and Coding Requirements:
- Systolic and diastolic BP entered in structured format (vital signs).
- ICD-9 code for hypertension and diabetes (as a co-morbidity) present in problem list.
- Eligible outpatient visit documented via CPT codes.
- Date of birth and gender entered in structured format (demographics).

Exclusions:
- Lack of systolic or diastolic BP reported for one-year period prior to the month of measure
- Invalid BPs that were substantially outside the plausible range (such as 1000/1000)
- BP not entered in structured format in the EHR

Fig. A1. Defining the Blood Pressure Measure for Electronic Health Records (EHRs).

Table A2
Monthly* Blood Pressure Control Rates from April 2012 to April 2014.

Month-year	Patients with hypertension	Patients with controlled BP	Blood pressure control rate (%) among patients with hypertension						
			Hypertensive	Age		Gender		Comorbidity	
			Overall	18–59	60–100	Female	Male	Diabetes	No diabetes
Apr-12	70,948	48,482	68.3	66.9	69.5	68.8	67.7	69.3	67.7
May-12	72,838	51,199	70.3	69.2	71.1	70.7	69.7	71.4	69.5
Jun-12	72,330	51,167	70.7	69.4	71.7	71.1	70.2	71.9	70.0
Jul-12	70,870	50,913	71.8	70.5	72.8	71.9	71.7	73.1	71.0
Aug-12	72,612	51,825	71.4	69.6	72.7	71.9	70.6	72.7	70.5
Sep-12	72,241	50,646	70.1	68.7	71.1	70.4	69.7	71.5	69.2
Oct-12	74,388	51,699	69.5	67.8	70.7	69.9	69.0	70.4	68.9
Nov-12	72,191	48,973	67.8	66.7	68.7	68.3	67.2	68.7	67.3
Dec-12	71,206	48,590	68.2	66.5	69.5	68.6	67.8	69.3	67.5
Jan-13	79,804	53,725	67.3	65.7	68.5	68.3	66.0	68.0	66.9
Feb-13	71,644	48,170	67.2	65.6	68.5	67.9	66.3	68.3	66.5
Mar-13	78,149	53,058	67.9	66.5	68.9	68.4	67.1	68.6	67.4
Apr-13	83,147	57,733	69.4	68.3	70.2	69.8	68.9	70.0	69.1
May-13	81,496	58,030	71.2	70.2	71.9	71.3	71.0	72.0	70.7
Jun-13	78,535	56,291	71.7	70.5	72.5	71.8	71.5	72.5	71.1
Jul-13	78,660	56,990	72.5	70.6	73.7	72.5	72.3	73.4	71.8
Aug-13	78,168	55,440	70.9	69.2	72.1	71.3	70.4	71.6	70.4
Sep-13	82,532	58,002	70.3	68.8	71.3	70.6	69.8	71.3	69.6
Oct-13	89,557	62,287	69.6	68.1	70.5	69.8	69.2	70.3	69.1
Nov-13	77,899	53,274	68.4	67.2	69.2	69.0	67.5	68.7	68.1
Dec-13	75,437	51,130	67.8	66.5	68.7	68.3	67.0	68.5	67.3
Jan-14	79,060	52,661	66.6	65.3	67.6	67.7	65.2	67.1	66.3
Feb-14	71,201	47,062	66.1	65.1	66.8	67.0	64.9	66.6	65.7
Mar-14	58,741	38,792	66.0	66.8	64.8	66.9	64.7	67	66.8
Apr-14	83,658	57,595	68.8	67.8	69.5	69.3	68.2	69.3	68.5

*Numerators and denominators are aggregated to the monthly level before the rate is estimated

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