Effectiveness of a Best Practice Alerts at Improving Hypertension Control

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BACKGROUND
Inadequately treated hypertension (HTN) leads to considerable morbidity and mortality. Despite many treatment options, blood pressure (BP) control is suboptimal. Missed opportunities due to the growing complexity of primary care office visits contribute. Electronic health records (EHRs) offer best practice alerts (BPA) tools to support clinicians in identifying poor BP control. BPAs have demonstrated effectiveness for other health outcomes.

METHODS
EHR data were collected for patients ≥18 years old seen for primary care office visits prior to, during, and after the BPA active period and used to identify patients for whom the BPA fired or would have fired during control periods. Logistic regression examined the association of BPA activation with follow-up BP check within 14–90 days and with BP control at follow-up, controlling for demographics and health conditions.

RESULTS
The BPA active period was associated with reduced patient follow-up; however, a number of covariates were predictive of increased follow-up: Black non-Hispanics, Hispanics, patients on the chronic kidney disease, HTN, or diabetes registries, as well as the morbidly obese, insurance status, and seasonal factors. For those who did follow-up, BPA activation was associated with improved BP control.

CONCLUSIONS
BPA activation was associated with worse patient follow-up but improved BP control. Some subgroups had significantly different rates of follow-up and BP control. This study did not have an experimental design as the BPA was a quality improvement initiative. These results highlight the critical importance of planning experimentally designed organizational initiatives to fully understand their impact.

Keywords: blood pressure; clinical decision support; electronic health records; hypertension.

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An estimated 100 million patients in the United States and nearly 1 billion patients worldwide have hypertension (HTN).[1] Untreated HTN leads to considerable long-term morbidity and mortality and is a major risk factor for chronic kidney disease (CKD) and vascular disease, including myocardial infarction and stroke.[2] Direct and indirect costs of HTN are an estimated $53 billion annually,[1] but with improved control of blood pressure (BP), there is potential for significant cost savings.[3] There are a wide variety of effective options for treatment of HTN as well as some well researched and accepted guidelines regarding optimal treatment.[4,5] With effective HTN treatment, cardiovascular morbidity and mortality is improved.[4–7] Despite the wide array of treatment options and accepted guidelines, HTN control remains less than ideal with only about 51% of patients with HTN considered controlled in the United States.[8] While patient-specific factors such as poor medication adherence or lack of willingness to take medications can contribute to poor HTN control, HTN may not always be addressed at medical visits, especially when there is medical complexity which can prevent clinicians from addressing uncontrolled HTN.[9]

Best practice alerts (BPA) are clinician decision support (CDS) tools available in the electronic health record (EHR) to bring clinician attention to uncontrolled HTN during medical visits. As EHR implementation becomes more widespread,[10] the use of BPAs to notify EHR users when a particular element of a patient's care needs additional attention is increasing. Several studies have demonstrated improved HTN control and clinical outcomes when a BPA is utilized in a number of clinical situations[11–20] The results specific to BPAs for HTN management are mixed. Studies by Shih et al. and Samal et al. show improvements in BP control with electronic CDS tools; however, studies by Romano et al., Shojania et al., and Montgomery et al. did not yield any improvement in a number of metrics including BP control.[11,21–24] Due to variability in results from existing

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publications, further evaluation is needed to better understand the role of BPAs in patient care and in managing HTN.

We evaluated the implementation of a BPA targeting HTN in a large Midwestern primary care practice and its relationship with follow-up for patients with an elevated BP at an initial visit and if their BP was controlled at follow-up. We hypothesized that during the study period, there would be improvements in follow-up for BP checks and BP control.

METHODS

This retrospective cohort study used data from the University of Wisconsin (UW) Health EHR. This study was considered exempt according to the UW institutional review board policy.

UW Health is the integrated health system of the UW-Madison serving more than 600,000 patients each year at 6 hospitals and 80 outpatient sites. For this study, EHR data were used to identify patients seen for an office visit with a primary care provider at UW Health.

The BPA in the UW Health EHR underwent several iterations to improve accuracy at identifying patients with meaningful elevations in BP between initial implementation (18 November 2013) and the final version (referred to as the BPA active period) which was active from 23 December 2014 through 24 November 2015. The BPA was deactivated after 24 November 2015 due to concerns about poor integration with provider workflows and lack of efficacy. The final BPA activated if, during an appointment or office visit with family medicine, internal medicine, geriatrics, or gerontology departments, the patient was ≥18 years of age and had systolic pressure ≥140 mm Hg or diastolic pressure ≥90 mm Hg and had no BP goal or their systolic or diastolic was over their associated BP goal. When the BPA was activated, a yellow pop-up box appeared in the EHR indicating that BP was elevated and the BP reading as well as a link to a HTN smartset (commonly used orders and diagnoses that can be quickly selected).

Subjects who had BPA activation during the BPA active period (treatment period) were compared with those who had encounters outside the BPA active period (control period) and would have had the BPA activated had the final BPA been in effect. This control period was evenly split between a period before the final BPA (1 May 2013 through 17 November 2013) and after the final BPA (25 November 2015 through 15 May 2016). The length of these 2 control periods combined (~12 months) was chosen to be similar in length to the BPA active period (~11 months). The time between the end of the first control period and the beginning of the BPA active period (18 November 2013 through 23 December 2014) was not used for patient baseline visits as this was during earlier HTN BPA implementations in the EHR which use different patient selection criteria from the final BPA.

A baseline encounter for a subject is any encounter that the final BPA activation occurred on or would have occurred on for encounters within one of the control periods. Positive follow-up was defined as the subject having a BP measurement at an appointment, office visit, or nurse visit with the included departments, 14–90 days after the baseline encounter. For those with positive follow-up, the outcome of BP control was assessed; positive BP control was defined as, at the first follow-up encounter, the subject's BP <140/90 if they had no goal at baseline (<130/80 if CKD present at baseline) or under their goal if they had 1 at baseline.

At the time of the baseline encounter, subject characteristics that impact HTN control were recorded. These include subjects' age, sex, race/ethnicity (White non-Hispanic, Black non-Hispanic, other non-Hispanic, Hispanic), CKD status, BMI category (<30, ≥30 and <40, ≥40, missing), on the EHR HTN registry, on the EHR diabetes registry, insurance type (Health Maintenance Organization (HMO), contracted, fee for service, Medicaid, Medicare, none, other), along with date of the baseline encounter. For each registry, subjects are "on" a registry if they had a diagnosis of that registry type in their problem list, encounter diagnosis, or invoice diagnosis as of the baseline encounter.

Due to the longitudinal nature of EHR patient data, but the relatively large number of unique subjects available for analysis, sampling was employed in order to eliminate multiple observations on a subject in the analyses. For the follow-up outcome, for each subject, 1 baseline encounter was randomly selected out of all possible baseline encounters for that subject. For the BP control outcome, for each subject, a random baseline encounter that had follow-up was selected (if no baseline encounters had follow-up, the subject was excluded). This resulted in 59,423 subjects for the follow-up analyses, of which 32,142 were in the BP control analyses.

STATISTICAL METHODS

Subject's baseline covariates and outcomes were reported as means and SDs, or counts and percent, as appropriate, separately for each outcome sample. Within a sample, the covariate and outcome distributions between those with a baseline encounter in the BPA active period were compared with those whose encounter was in the control periods. Mann–Whitney tests were used to assess differences in continuous items, and Chi-squared tests used to assess differences in binary/categorical items.

Logistic regression was used to assess the relationship between the period in which subjects' sampled baseline encounter occurred (final BPA vs. control) and the outcomes of interest. For the follow-up outcome, additional model covariates included subjects' age, sex, race/ethnicity, CKD status, BMI category, HTN registry status, diabetes registry status, and insurance type (an indirect measure of socioeconomic status). For the BP control outcome, the same logistic regression covariate structure was also used, except that the sample was inverse probability weighted by the subjects' estimated conditional probability using the fitted follow-up model, using the BP outcome sample covariates. This aids in reducing selection bias which might be present due to differential follow-up.[25] Both models also incorporated monthly time trends for linear and cyclical components (cosine and sine components for both 12- and 6-month periods), in order to try and separate the BPA effect from overarching time trends that could be occurring. Bayesian information

criterion was used to select which of these 5-time components were ultimately kept for each model. Overdispersion and Pearson's goodness-of-fit were assessed for both models. Statistical significance was assessed at $\alpha = 0.05$ level.

RESULTS

Tables 1 and 2 summarize the covariates and outcomes of the sampled subjects used for analyses. For follow-up, 59,423 subjects met sampling criteria, with 29,174 (49.1%) having a baseline encounter in the BPA active period and 25,006 (42.1%) returning for follow-up. Those sampled in the BPA active period were less likely to have a follow-up visit compared with those with a baseline visit in the control periods (41.2% vs. 42.9% follow-up, $P < 0.001$). For BP control, 32,142 subjects met sampling criteria, with 15,602 (48.5%) having a baseline encounter in the BPA active period, and 18,949 (59.0%) having their BP controlled at follow-up. Those sampled in the BPA active period were more likely to have their BP controlled compared with those sampled in a control period (61.0% vs. 57.0%, $P < 0.001$).

For the adjusted regression analyses, associations between the outcomes and the BPA vs. control periods were in similar directions as those of the unadjusted analyses. No concerns were noted in the overdispersion and Pearson's goodness-of-fit model assessments. Bayesian information criterion criteria retained the 6- and 12-month sine trends and a 12-month cosine trend in the follow-up model, and the 12-month sine and cosine trends in the BP control model.

BP FOLLOW-UP ADJUSTED ANALYSES

Overall, those sampled in the BPA period were less likely to have follow-up than those sampled in a control period (odds ratio 0.92, 95% confidence interval 0.89–0.95) (Table 3). However, there were important covariate or subpopulation

Table 1. Primary sample characteristics

	Whole sample	no BPA	BPA active	*P* value	Test
N	59,423	30,249	29,174		
BPA active at baseline (*N* (%))	29174 (49.1)				
Follow-up BP (*N* (%))	25006 (42.1)	12987 (42.9)	12019 (41.2)	<0.001	Chi-squared
Age (mean (SD))	57.02 (16.19)	57.06 (16.29)	56.99 (16.09)	0.892	Mann–Whitney
Male (*N* (%))	29653 (49.9)	15105 (49.9)	14548 (49.9)	0.872	Chi-squared
Race/ethnicity (*N* (%))				0.108	Chi-squared
White non-Hispanic	53709 (90.4)	27409 (90.6)	26300 (90.1)		
Black non-Hispanic	2418 (4.1)	1229 (4.1)	1189 (4.1)		
Hispanic	1167 (2.0)	563 (1.9)	604 (2.1)		
Other non-Hispanic	2129 (3.6)	1048 (3.5)	1081 (3.7)		
CKD (*N* (%))	7473 (12.6)	4061 (13.4)	3412 (11.7)	<0.001	Chi-squared
HTN registry (*N* (%))	34131 (57.4)	17018 (56.3)	17113 (58.7)	<0.001	Chi-squared
Diabetes registry (*N* (%))	9915 (16.7)	5008 (16.6)	4907 (16.8)	0.395	Chi-squared
Diabetes type II (*N* (%))	10369 (17.4)	5419 (17.9)	4950 (17.0)	0.002	Chi-squared
BMI (*N* (%))				<0.001	Chi-squared
<30	25529 (43.0)	12702 (42.0)	12827 (44.0)		
[30,40)	20701 (34.8)	10564 (34.9)	10137 (34.7)		
≥40	6867 (11.6)	3455 (11.4)	3412 (11.7)		
missing	6326 (10.6)	3528 (11.7)	2798 (9.6)		
Insurance (*N* (%))				<0.001	Chi-squared
HMO	17036 (28.7)	8387 (27.7)	8649 (29.6)		
Contracted	10910 (18.4)	5443 (18.0)	5467 (18.7)		
Fee for service	1171 (2.0)	646 (2.1)	525 (1.8)		
Medicaid	2726 (4.6)	1376 (4.5)	1350 (4.6)		
Medicare	21399 (36.0)	10827 (35.8)	10572 (36.2)		
None	6153 (10.4)	3553 (11.7)	2600 (8.9)		
Other	28 (0.0)	17 (0.1)	11 (0.0)		

Follow-up analysis sample characteristics for baseline covariates and follow-up outcome. Abbreviations: BP, blood pressure; BMI, body mass index; BPA, best practice alerts; CKD, chronic kidney disease; HTN, hypertension.

Table 2. Secondary sample characteristics

	Whole sample	no BPA	BPA active	*P* value	Test
N	32,142	16,540	15,602		
BPA active at baseline (*N* (%))	15602 (48.5)				
BP controlled at follow-up (*N* (%))	18949 (59.0)	9436 (57.0)	9513 (61.0)	<0.001	Chi-squared
Age (mean (SD))	58.77 (15.93)	58.81 (16.07)	58.73 (15.79)	0.663	nonnorm
Male (*N* (%))	14979 (46.6)	7671 (46.4)	7308 (46.8)	0.413	Chi-squared
Race/ethnicity (*N* (%))				0.361	Chi-squared
White non-Hispanic	28903 (89.9)	14899 (90.1)	14004 (89.8)		
Black non-Hispanic	1504 (4.7)	779 (4.7)	725 (4.6)		
Hispanic	671 (2.1)	324 (2.0)	347 (2.2)		
Other non-Hispanic	1064 (3.3)	538 (3.3)	526 (3.4)		
CKD (*N* (%))	4972 (15.5)	2747 (16.6)	2225 (14.3)	<0.001	Chi-squared
HTN registry (*N* (%))	21442 (66.7)	10768 (65.1)	10674 (68.4)	<0.001	Chi-squared
Diabetes registry (*N* (%))	6319 (19.7)	3235 (19.6)	3084 (19.8)	0.649	Chi-squared
Diabetes type II (*N* (%))	6643 (20.7)	3516 (21.3)	3127 (20.0)	0.007	Chi-squared
BMI (*N* (%))				<0.001	Chi-squared
<30	13304 (41.4)	6772 (40.9)	6532 (41.9)		
[30,40]	11397 (35.5)	5786 (35.0)	5611 (36.0)		
≥40	4175 (13.0)	2160 (13.1)	2015 (12.9)		
missing	3266 (10.2)	1822 (11.0)	1444 (9.3)		
Insurance (*N* (%))				<0.001	Chi-squared
HMO	8431 (26.2)	4164 (25.2)	4267 (27.3)		
Contracted	5247 (16.3)	2642 (16.0)	2605 (16.7)		
Fee for service	657 (2.0)	358 (2.2)	299 (1.9)		
Medicaid	1627 (5.1)	854 (5.2)	773 (5.0)		
Medicare	13076 (40.7)	6704 (40.5)	6372 (40.8)		
None	3086 (9.6)	1806 (10.9)	1280 (8.2)		
Other	18 (0.1)	12 (0.1)	6 (0.0)		

BP control analysis sample characteristics for baseline covariates and BP control outcome. Abbreviations: BP, blood pressure; BMI, body mass index; BPA, best practice alerts; CKD, chronic kidney disease; HTN, hypertension.

differences. For example, compared with non-Hispanic Whites, non-Hispanic Blacks and Hispanics were significantly more likely to follow-up. This was also true for CKD patients (vs. no CKD), BMI ≥40 (vs. BMI <30) and patients who were on the HTN or diabetes registry (compared with those not on these registries). Lower income patients (e.g., Medicaid) were also more likely to follow-up (vs. HMO insurance). Finally, males were less likely than females to follow-up.

BP CONTROL ADJUSTED ANALYSES

For BP control, those sampled in the BPA period were more likely to have their BP controlled than those sampled in a control period (odds ratio 1.19, 95% confidence interval 1.14–1.25) (Table 3). And again, there were important subpopulation differences. Subpopulations or covariates that were significantly less likely to achieve control included older patients, males (vs. females), Black non-Hispanics (vs. White non-Hispanics), patients with CKD (vs. no CKD), BMI ≥40 (vs. BMI < 30), patients on the HTN registry (vs. not on it), patients with no insurance (vs. HMO insurance). Covariates that demonstrated significantly increased BP control included patients on the diabetes registry (vs. not on it) and Medicare patients (vs. HMO).

DISCUSSION

Our study revealed the unexpected finding that patients were less likely to return for a follow-up BP check after a visit with an elevated BP during the BPA active period but more likely to have their BP controlled. However, improved follow-up was associated with high-risk patients including Black non-Hispanics, Hispanics, patients on the CKD, HTN, or diabetes registries, the morbidly obese, and a number of insurance categories. Yet, it appears increased

Table 3. Logistic regression results for follow-up and control after baseline

	Outcome: follow-up visit			Outcome: BP control		
Covariate	***P* value**	**OR**	**OR 95% CI**	***P* value**	**OR**	**OR 95% CI**
BPA active	<0.0001	0.922	0.891–0.953	<0.0001	1.192	1.136–1.250
Age	0.2612	1.001	0.999–1.002	<0.0001	0.994	0.992–0.997
Male	<0.0001	0.804	0.777–0.832	<0.0001	0.890	0.848–0.934
Black non-Hispanic	0.0023	1.141	1.048–1.242	<0.0001	0.789	0.705–0.882
Hispanic	0.0034	1.195	1.061–1.345	0.5223	1.056	0.894–1.247
Other non-Hispanic	0.5534	0.973	0.889–1.065	0.8567	0.988	0.865–1.128
CKD	<0.0001	1.287	1.220–1.357	<0.0001	0.276	0.257–0.297
BMI [30, 40)	0.2777	1.022	0.983–1.062	0.4435	0.979	0.926–1.034
BMI ≥40	<0.0001	1.185	1.119–1.254	0.0134	0.905	0.837–0.980
BMI missing	0.8983	0.996	0.941–1.055	0.7249	0.985	0.905–1.072
On HTN registry	<0.0001	1.620	1.561–1.681	<0.0001	0.455	0.430–0.481
On diabetes registry	0.0005	1.086	1.037–1.138	<0.0001	1.181	1.109–1.257
Contracted insurance	0.0369	0.948	0.902–0.997	0.9254	0.996	0.925–1.073
Fee for service insurance	0.003	1.202	1.064–1.357	0.5006	1.063	0.890–1.270
Medicaid	<0.0001	1.413	1.299–1.536	0.8826	0.991	0.884–1.112
Medicare	<0.0001	1.130	1.074–1.189	<0.0001	1.232	1.146–1.324
No insurance	<0.0001	1.203	1.131–1.280	0.0041	0.873	0.796–0.958
Other insurance	0.0872	1.926	0.909–4.08	0.5523	0.726	0.253–2.087
12-month seasonal sine	0.0001	1.047	1.023–1.071	<0.0001	1.109	1.072–1.146
12-month seasonal cosine	<0.0001	1.067	1.041–1.093	0.0001	0.935	0.904–0.967
6-month seasonal sine	0.0001	1.049	1.024–1.074		NA	

Reference categories: baseline visit in control period, female, White non-Hispanic, no CKD, BMI <30, not on HTN registry, not on diabetes registry, HMO insurance. Abbreviations: BMI, body mass index; BP, blood pressure; BPA, best practice alerts; CI, confidence interval; CKD, chronic kidney disease; HTN, hypertension; OR, odds ratio.

follow-up likelihood doesn't necessarily translate into improved chances of BP control, as many of these covariates (e.g., on diabetes registry, CKD, etc.) are not associated with improved control. It is unclear whether there is truly a direct effect of the BPA on rates of patient follow-up. We were unable to collect data on whether physicians made different recommendations for follow-up based on the BPA results, so physician behavior may have played a role; however, this is opposite of the effect we hypothesized. This could also be a result of our large sample size leading to a small difference achieving statistical significance. The finding of improved BP control is also difficult to interpret as this outcome is dependent on the follow-up. We did account for follow-up likelihood through weighting in the regression, and the BPA was still associated with a statistically significant improvement in BP control.

Although BPAs allow us to leverage the power of technology to identify gaps in care that can be addressed, there is also potential harm including issues of alert fatigue and break in task.[26–28] These harms need to be considered before implementation, and strategies to mitigate them used to ensure BPAs support effective physician workflows. A critical element is identifying workflows and disease processes that are positively affected by BPAs and crafting them to complement existing physician workflows. Interestingly, the BPA studied here did not effectively consider existing organizational workflows which likely undermined its impact. The BPA fired upon the next provider login to the patient's encounter, yet when providers entered the exam room to meet with patients, they were unlocking a secured computer from the medical assistant (already in the patient's chart) which did not lead to BPA firing. The BPA often would not fire until the provider had left the exam room and was completing their charting at a later time. A significant component of effective BPA implementation is careful consideration of existing workflows and thoughtfulness around who is the optimal recipient of the EHR prompt.

There is growing interest in the effects of EHR based tools on clinical workflows as well as how to apply principles of cognitive science and systems engineering to create the most effective EHR-based tools.[27–29] This is very timely given the recent American College of Cardiology and American Heart Association HTN guidelines which, among other recommendations, involve the introduction of a risk calculator into the decision-making process for the treatment of certain patients.[5] As we increasingly incorporate data

including risk calculators into our diagnosis and treatment algorithms, CDS tools that present such calculators and the relevant data to users through existing clinical workflows will be important and may increase the use and benefit of BPAs and other CDS tools. More studies are needed regarding approaches to the use of CDS and BPAs in practice that support effective workflows and improved outcomes for patients.

A major issue in interpreting these results is the use of a binary status of BP control. While this is consistent with existing clinical quality reporting, it increases the risk of capturing less meaningful improvement and potentially missing more clinically significant changes. For example, a patient with a systolic blood pressure (SBP) of 142 at the visit, triggering the BPA, whose follow-up SBP is 139, would be considered in control, yet a patient with a SBP of 185 at the initial visit with a follow-up SBP of 141 would be determined to be not in control. Although the second example is much more clinically meaningful, a binary control variable fails to capture that nuance. This could potentially be addressed with the use of a continuous BP variable as a better means of assessing control and is a potential future area of research.

There are several additional limitations to this study. EHR data include patients who self-select to receive primary care from the UW Health system, not a random sample, and therefore these results may not be generalizable to a statewide or national population. There was also a gap in time between the pre-BPA control period and the BPA active period, while the post-BPA control period immediately followed the BPA active period. This was due to the presence of 2 other BPAs for HTN immediately prior to the BPA active period which don't represent a control period and used different criteria for the activation of the BPA. This gap, along with being unable to truly separate time and the activation and deactivation of the BPA, introduces the potential for effects of changes in practice over time and organizational workflows affecting HTN management, separate from the BPA, to confound our results. Additionally, as a retrospective observational cohort, random treatment assignment did not occur, only patient-level sampling of the visit to use for baseline. Two different iterations of the BPA occurred before the BPA we studied, and these previous instances could have raised awareness of providers of the BPA prior to the study BPA and may have impacted provider behavior. Finally, the pre-BPA period studied was prior to the initiation of the Affordable Care Act marketplaces, which may have impacted results due to increased numbers of patients with health insurance coverage who may be more likely to follow-up for repeat BP readings and follow through with care recommendations due to adequate health insurance coverage.

In conclusion, these results suggest that for this BPA, patient BP follow-up was worse. However, of those with follow-up, better control was achieved. These results underscore some general principles of EHR tools and organizational initiatives. Clear attention to workflows that allow EHR tools to complement existing provider work is essential to offer an optimal chance for success. Furthermore, organizational initiatives to improve care would benefit greatly from planned, experimentally designed study to allow more rigor in understanding and learning from outcomes.

DISCLOSURE

The authors declared no conflict of interest.

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