A Pharmacist-Driven Education and Intervention Program that Improves Outcomes for Hypertensive Patients

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Abstract

***Purpose**: Uncontrolled hypertension is serious and may lead to severe cardiovascular events and death. To better educate and empower patients to meet their blood pressure (BP) management goals, a large, integrated academic healthcare system implemented the Blood Pressure Goals Achievement Program (BPGAP), a longitudinal intervention embedding community pharmacists within healthcare teams. This study evaluated BPGAP on its ability to promote patient BP management goals.*

***Methods**: A pre-/post-intervention analysis was conducted whereby BP measurements were evaluated longitudinally within acuity groups determined by k-means clustering. Generalized linear mixed models evaluated trends in BP by time period, and proportions of patients meeting BP management goals (<140/90 mmHg) were assessed in relation to BPGAP enrollment date.*

***Results**: There were 5,125 patients who were clustered into Uncontrolled, Borderline, and Controlled blood pressure groups; 2,108 patients had BP measurements across 4 time periods before and after BPGAP enrollment. Groups differed by patient age, sex, and other demographics (p<0.0001). Patients in the Uncontrolled and Borderline BP clusters demonstrated significant BP decreases after BPGAP enrollment, continuing at least to 1-year post-intervention; Controlled cluster patients maintained BPs throughout the study period. The proportion of patients with controlled BPs increased from 56% immediately pre-BPGAP to 74% in the 3- to 6-months following enrollment.*

***Conclusion**: BPGAP is effective at helping patients achieve their BP management goals. Pharmacists may play a key role in hypertension control through measuring BPs and including updates and recommendations in the electronic health record, educating patients, and engaging in communication with healthcare teams.*

Clinical hypertension is common among United States adults, with an estimated one-third of adults diagnosed as hypertensive and half of cases having uncontrolled blood pressure according to 2003 guidelines;[1] these rates are much higher according to more stringent blood pressure guidelines adopted in 2017.[2, 3] Hypertension is the most prevalent modifiable risk factor for cardiovascular disease,[4] and its inadequate management increases the risk of cardiovascular diseases such as myocardial infarction, ischemic stroke, heart failure, and atrial fibrillation.[4, 5] Downstream cardiovascular diseases then account for an estimated $216 billion in annual medical costs (13% of health expenditures in the United States),[2] and have been the leading causes of death for a century in the United States.[6] Aside from its role in cardiovascular disease, hypertension is also associated with renal disease, cognitive impairment, and other disease processes,[2, 7] indicating the significance of healthy blood pressure control on the functioning and well-being of bodily systems and processes.

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Maintaining blood pressure at target levels reduces the risk for cardiovascular sequelae, thus increasing quality of life and lowering financial burden.[2] Lifestyle modification through diet and exercise alterations is always a first line therapy for hypertension, though it often is practiced in concert with prescription of antihypertensive medications.[2, 8, 9] Non-adherence to these medications is common, with studies indicating upwards of 40% of patients not taking antihypertensive medications as prescribed;[9, 10] this contributes to uncontrolled hypertension and its adverse sequelae which include death.[2, 9] While community pharmacists can play a role in improving blood pressure management by offering more frequent blood pressure assessments and counseling patients on medication adherence,[11] progress and results of these initiatives are often not accessible to treating physicians since they are not documented within a patient's electronic health record (EHR). Similarly, without availability of historical clinical blood pressure readings, pharmacists are unable to respond to patients' unique needs regarding their blood pressure control.[12] This disconnect between clinics and community pharmacies impedes synergistic, collaborative hypertension management that is necessary to provide efficient benefit to patients.

In order to promote an alliance between community pharmacists and ambulatory care providers, our large integrated care, academic health system began the Blood Pressure Goals Achievement Program (BPGAP) in 2012 with the ultimate goal of improving blood pressure control among hypertensive patients by improving patient access to regular blood pressure screening within health system retail pharmacy

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locations and focusing on effective medication management for the treatment of hypertension and its related comorbidities. The current study is an evaluation of this program, and seeks to evaluate the longitudinal effects of participating in BPGAP and examine the rate of controlled blood pressure prior to and following BPGAP implementation.

Methods

Study site and practice description. This study was conducted within a large academic health system that serves both urban and rural communities throughout the upper Midwest and includes 12 hospitals, 56 primary care clinics, over 100 specialty clinics, and 36 community retail pharmacies. All locations access the same EHR for visit documentation purposes and communications among care team members in order to provide collaborative care throughout the system. This study was determined to be exempt from review by our organization's Institutional Review Board.

Blood Pressure Goals Achievement Program. In November of 2012, our large, academic health system initiated the Blood Pressure Goals Achievement Program (BPGAP) in 21 of its existing retail pharmacies. The program objective was to support clinical efforts to improve the number of patients meeting their blood pressure goals. Goal blood pressure was set to be <140/90 mmHg, aligning with the National Heart, Lung, and Blood Institute's 2003 guidelines[1] and as per our health system's protocols, and evaluated to be a threshold for pharmacologic treatment among all hypertensive patients in more recent 2017 guidelines.[3] Patients seen at our institution's ambulatory care clinics may be enrolled in BPGAP through referral by either the ambulatory clinic team or directly by the community pharmacist within the institution's retail pharmacy locations; providers were encouraged to offer BPGAP to patients as a way to monitor blood pressure progress without requiring additional clinic visits.

Following patient enrollment, the BPGAP intervention occurred within health system-owned retail pharmacy locations by a pharmacist with training in hypertension pharmacotherapy and blood pressure measurement. Pharmacist training entailed learning modules with simulations and live, interactive assessments occurring within our health system; blood pressure measurement technique was reassessed 6-weeks after initial trainings. The BPGAP intervention occurred generally as a blood pressure check with patient education occurring in the retail pharmacy, and full documentation and communication with primary care physicians through the EHR. Patients were offered blood pressure measurements every time they visited retail pharmacies following enrollment in the program with the goal of measuring at least two blood pressures within a calendar year, though they could opt-out of any measurement. More specifically, blood pressure was assessed using a manual sphygmomanometer and measurements were repeated if the initial reading was higher than the patient's goal. Blood pressure measurements were documented in the patient's EHR. If blood pressure was above goal, the patient's primary care physician was alerted through EHR messaging and the patient was referred for appropriate follow-up care to either the primary care clinic or a medication therapy management pharmacist. In cases where blood pressure measured >180/110 mmHg, the patient was sent to the clinic for immediate care during clinic hours, or to urgent care or the emergency department for same day evaluation when primary care physicians were unavailable.

Following blood pressure assessment, community pharmacists led patient education about blood pressure readings and patient-specific goals, and made medication recommendations following patient counsel that were documented in the EHR and communicated with primary care providers. Medication changes ultimately were made by the primary care provider or medication therapy management pharmacist in response to recommendations by community pharmacists. If medication changes were deemed unnecessary by the primary care physician or medication therapy management pharmacist, the patient would continue follow-up at the retail pharmacy for regular blood pressure rechecks and communication with treating providers.

Study design. This was a retrospective, longitudinal analysis of data from the EHR. Patients who utilized our health system's retail pharmacies to fill antihypertensive medications and enrolled into BPGAP between January 1, 2013 and November 19, 2019, when the most current data were available, were included in this study if they had a patient encounter within the health system documenting their hypertension diagnosis (*International Classification of Diseases, Tenth Revision* codes I10-I16) and they had at least one blood pressure measurement available in the EHR within 15 months prior to BPGAP enrollment. Clinical, anthropometric, demographic, and pharmacy data were extracted from the EHR for the one-year before and after each patient's BPGAP enrollment data.

Variable definitions. Patient baseline blood pressures were determined to be the mean systolic and diastolic blood pressures across all measures taken within the 1 year prior to BPGAP enrollment for each patient, not inclusive of the BPGAP enrollment date. Study time periods were categorized as follows: Baseline Period (twelve-months to six-months prior to BPGAP start), Trigger Period (six-months to one-day prior to BPGAP start), Initiation Period (BPGAP start through three-months post-start), and Follow-up Period (three-months to six-months after BPGAP start).

Statistical analysis. In order to best understand patient baseline blood pressure management success, k-means clustering was employed in Microsoft Power BI (Microsoft Corp, Redmond, WA USA) to partition patient baseline blood pressure readings within the one-year prior to BPGAP enrollment. Optimal K-value selection was determined by the elbow method. Following clustering, differences in categorical

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variables of demographic and clinical information were presented as frequency and percentage and compared utilizing chi-square tests for categorical variables across clusters. Continuous variables were evaluated for normality utilizing histograms and Q-Q plots and formally tested utilizing the Kolmorgorov-Smirnov test with a cutoff set at α=0.05; variables considered normally distributed were presented as mean and standard deviations and compared across clusters using one-way ANOVA tests; similarly, non-normally distributed continuous variables had distributions presented utilizing their median and interquartile range (IQR) and were compared across clusters utilizing Kruskall-Wallis tests. Trends in blood pressure measurements for each cluster were analyzed using 90-day moving averages that were anchored on participants' program start dates, and trends were evaluated utilizing linear regression.

In order to examine success of BPGAP in managing blood pressure, BPGAP participants with at least one blood pressure reading occurring in each of four time periods (Baseline Period: 12-months to six-months prior to BPGAP start, Trigger Period: six-months to one-day prior to BPGAP start, Initiation Period: BPGAP start through three-months post-start, and Follow-up Period: three-months to six-months after BPGAP start) were included. To examine the ordinal effects of blood pressure acuity cluster across variables, categorical variables were compared utilizing Cochran-Armitage tests for trend, and continuous variables were compared across blood pressure acuity cluster utilizing generalized linear models with patient as the random effect. Further, trends in blood pressures were assessed across BPGAP time periods within each blood pressure acuity cluster also utilizing generalized linear models with patient as the random effect. Finally, the percentages of patients whose mean blood pressures were in control (<140/90 mmHg) utilizing the 2003 recommendations of Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure[1] were evaluated within each time period, as an overall population and within each blood pressure cluster. Statistical significance was set at α = .05, and analyses were conducted using SAS Version 9.4 (Cary, NC).

Results

There were 5,182 patients who enrolled in BPGAP between January 2013 and November 2019, and 5,125 (98.9%) patients had at least one blood pressure measurement recorded in the EHR during the baseline period and thus were eligible for analysis. Notably, most of the sample were prescribed antihypertensive pharmacotherapy prior to enrollment in BPGAP (n=4,058, 79.18%), with angiotensin-converting enzyme inhibitors being most commonly prescribed (n=2,199; 42.91%). K-means clustering was optimized with three clusters that identified distinct patient groups by their mean blood pressure prior to beginning BPGAP. Clusters were defined as Uncontrolled (n = 786, 15.34%; mean blood pressure = 151/93 mmHg), Borderline (n = 2,620, 51.12%; mean blood pressure = 137/83 mmHg), and Controlled (n = 1,719, 33.54%; mean blood pressure = 127/72 mmHg) based on data within the 1-year previous to BPGAP enrollment.

Table 1 indicates descriptive statistics of the study population by their designated baseline blood pressure acuity cluster. In general, those in the Controlled blood pressure cluster were older (median (IQR) years = 65 (56, 74)) than those in other clusters (Borderline: 56 (48, 65); Uncontrolled: 53 (45, 61); p<.0001). Those in the Controlled blood pressure cluster also were statistically significantly more likely to be female (n=990, 57.59%) and documented as white race (n=1,532, 89.12%) compared to the Borderline (female: n=1,346, 51.37%; white race: 2,210, 84.35%) and Uncontrolled blood pressure clusters (female: n=310, 39.44%; white race: 628, 79.90%; p<0.0001 for all comparisons). The Controlled blood pressure cluster were more commonly prescribed medications from more antihypertensive therapy classes than their counterparts, with 44.21% of patients taking medications from 2 or more therapy classes prior to BPGAP enrollment compared to 34.74% and 34.23% of the Uncontrolled and Borderline blood pressure clusters, respectively (p<0.001).

Figure 1 indicates the 90-day moving average trajectories over time of each of the three blood pressure acuity clusters one-year before and after the BPGAP intervention. While the Controlled cluster remained relatively stable before and after the BPGAP intervention, both the Borderline and Uncontrolled blood pressure clusters indicated dramatic declines following BPGAP enrollment, as measured by 90-day moving averages. More specifically, during the 3-month Initiation period, among Borderline blood pressure cluster patients the systolic and diastolic blood pressures dropped 4.17 and 2.57 mmHg, respectively, and 10.40 and 6.62 mmHg, respectively, among Uncontrolled blood pressure cluster patients (p_{trend}<0.001 for all). During that same time period, Controlled blood pressure cluster patients indicated an increase of 0.20 mmHg (p=0.01) in systolic and a decrease of -0.04 mmHg (p=0.05) in diastolic blood pressures.

When limiting the sample to patients who had blood pressure readings spanning all four periods related to BPGAP (Baseline Period: 12-months to six-months prior to BPGAP start, Trigger Period: six-months to one-day prior to BPGAP start, Initiation Period: BPGAP start through three-months post-start, and Follow-up Period: three-months to six-months after BPGAP start), 2,108 (40.68%) patients were included. Table 2 indicates demographics and characteristics of these patients by their original blood pressure acuity clusters, and a comparison between these patients and patients without blood pressure readings spanning all four periods is available in Supplementary Table 1. Patients who were eligible for this analysis showed a different distribution than the previous analysis, with a similar percentage of those in the Borderline blood pressure cluster (n=1,092; 51.80%), but a much lower percentage of those in the Uncontrolled blood pressure cluster (n=161; 7.64%) and a higher proportion of Controlled blood pressure (n=855; 40.56%;

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p<.0001). Similar to the previous analysis, patients in the Controlled blood pressure cluster had higher rates of diabetes than other clusters (p_{trend} <0.0001), and had lower systolic and diastolic blood pressures across all periods of BPGAP than Borderline and Uncontrolled blood pressure clusters (p_{trend} across all comparisons <0.0001). Notably, median blood pressures reached levels of control by 3- to 6-months after BPGAP enrollment in the Uncontrolled blood pressure cluster. Additionally, mixed effects regression analysis with patient as the random intercept noted that for each change in BPGAP period, the Uncontrolled blood pressure cluster decreased nearly 5 mmHg in systolic blood pressure and 3 mmHg in diastolic, while the Borderline cluster decreased 1 mmHg for each systolic and diastolic blood pressure. Results of mixed effect regression models are available in Table 3.

Figure 2 indicates the percentage of BPGAP participants whose mean blood pressures were within control range (<140/90 mmHg) within the different phases of the program. Overall, 71.58% of the participants had average blood pressures that were controlled in the Baseline Period (6- to 12-months before BPGAP enrollment), but that dropped to 55.65% during the 6 months prior to enrollment. Following enrollment, 69.92% of participants had their average blood pressures within control range in the first 3 months following enrollment, and that increased to 74.43% of patients during the Follow-up Period of 3- to 6-months following BPGAP enrollment. These proportions differed by blood pressure acuity cluster.

Discussion

The Blood Pressure Goals Achievement Program (BPGAP) enrolled more than 5,000 patients between 2013 and 2019 with the goal of working collaboratively and cross-disciplinarily to control hypertension among patients within a large, academic health system. This analysis indicated great benefit for patients who enrolled in BPGAP, especially those with Uncontrolled or Borderline initial blood pressures, as those patients exhibited dramatic decreases in blood pressures over the trajectory of the study period; patients whose blood pressures were initially indicated as Controlled remained fairly stable during the study period. These results indicate the advantage of adding a community pharmacist intervention to the traditional clinician-patient dyad to enhance hypertension control.

This study found marked decreases in blood pressure over time among the study population. Specifically, 90-day moving averages showed rapid decreases in blood pressures among patients who were clustered within the Uncontrolled and Borderline blood pressure groups, such that blood pressures were, on average, meeting the standard of <140/90 mmHg as outlined by the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of Uncontrolled Blood Pressure[1] at 3-months following BPGAP enrollment, and remained stable throughout the duration of the study period. Further a subanalysis across patients who had blood pressure measurements spanning four periods of time across the study duration indicated that those who were clustered in the Uncontrolled blood pressure group decreased their systolic and diastolic blood pressures, on average, 5 and 3 mmHg, respectively, across each study period, and also indicated statistically significant blood pressure decreases among those in the Borderline blood pressure group. Previous studies have found the benefit of team-based care within the management of chronic disease, especially when nurses and pharmacists are among team members to promote education and assist with medication prescribing or management of adverse events.[13] Pharmacists, in particular, have a unique role within hypertension management whereby interventions they may introduce include providing patient education and counseling, communication with healthcare providers to relay feedback or education, measuring blood pressure, medication management, or supplying medication reminders, and found similar reductions in blood pressure as the current study.[11, 13] The BPGAP intervention encompasses all of those aspects of pharmacist intervention, and, further, since it is uniquely embedded within a large health system, allows for smooth care coordination and continuous communication between pharmacists and providers to quickly aid patients with medication issues and disease state questions.

The dramatic effects of team-based blood pressure management success within a health system retail pharmacy that emerged within the context of the current study may be due to multiple factors. For example, by forging trusting relationships with patients, community pharmacists can better assess and address adverse reactions to medications, and adjust medications and doses which can ensure the medication is effective and may ultimately increase medication adherence.[14] Further, when pharmacists have real-time access to patient medical history through the EHR, they are able to inform clinical decision-making such as medication management and addressing drug therapy problems with respect to patient laboratory and clinical history, address medication safety alerts quickly, collaborate with providers and document healthcare decisions, and update patient medication profiles to maintain accurate and current records.[12] Additionally, consistent patient education and frequent dialogue with community pharmacists throughout the BPGAP intervention may aid in patient adherence to medication, thus serving to lower patient blood pressure. Adherence to hypertensive medications has historically been suboptimal, and is reported at <50% one-year after initiation.[9] Therapy management is one method that has been employed to drastically increase adherence to antihypertensive medications among those who need them.[15, 16] The ability for pharmacists to listen to patient concerns and counsel patients on medication use and disease processes increases patient health literacy and trust in their care team.[17, 18] Involving pharmacists as collaborators within the care team for hypertensive patients allows for more rapid resolution of medication therapy problems in response to both historical trends in patient blood pressure and treatment from EHR data as well as close

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communication with patients to allay medication anxiety and other issues.

In general, patients with hypertension are responsible for monitoring their own blood pressures at home which may result in inaccurate blood pressure measurements,[19] and could potentially delay important changes to antihypertensive therapies since they are not reported to clinicians frequently. Further, general health literacy among adults in the United States is low,[20] and often hypertensive patients with low health literacy, specifically numeracy levels, do not regularly check their blood pressures as often as recommended by their physicians.[21] While patients with hypertension often are followed by physicians less frequently than guidelines recommend,[22] indicating the likelihood of less frequent clinical blood pressure measurements than advised, patients do visit their retail pharmacy to pick up prescriptions frequently, usually every 30-days.[23] By ensuring hypertensive patients are working with community pharmacists to check their blood pressure at regular intervals, understand what measurements mean for their health, and add context to their treatment and health trends, patients may feel empowered in their health care decision-making and may increase health literacy regarding their condition, thus increasing adherence to diet, lifestyle, and medication recommendations from their healthcare team. The support and education provided by community pharmacists through BPGAP likely plays a critical role in helping patients and their physicians achieve blood pressure goals through patient education and support program.

While it is widely recognized that uncontrolled hypertension increases the risk of adverse cardiovascular events and death,[2] studies have shown the vast protective effects of controlling hypertension with lifestyle and medication. For example, a large meta-analysis noted that a 5 mmHg reduction of systolic blood pressure reduced risk of major cardiovascular events over time by 10% regardless of preexisting cardiovascular disease.[24] Further, since there is a significant association between high antihypertension medication adherence and lower risk of long-term cardiovascular outcomes,[10] patients who actively participate in BPGAP may have significant long-term advantages through the inclusion of community pharmacists directly within their healthcare teams.

Since this study utilized retrospective data available through the EHR data warehouse, it is subject to many of the same limitations as other studies utilizing retrospective administrative data. For instance, data may be subject to errors due to miskeying or inaccurately documenting information at patient visits. While this study employed stringent data cleaning techniques, we do note the possibility of inaccurate results, especially in race and ethnicity data, which are known to be poorly recorded.[25, 26] Further, while we are unable to discern the effects of new antihypertensive medications or medication adherence on blood pressure trajectories within the analysis, antihypertensive medication guidance, changes, and adherence are likely closely tied to the relationship forged between pharmacists and patients during the course of BPGAP, and, thus, we consider medication adjustments to be a part of the service that a pharmacist adds to a patient-clinician team when working to control hypertension. Lastly, it should be noted that goal blood pressure measurements of <140/90 mmHg from 2003 guidelines[1] were utilized to define controlled blood pressure for this study; recent blood pressure guidelines published in November 2017 outline more stringent standards to represent controlled blood pressures, though still utilize that threshold for pharmacologic management among hypertensive patients.[3] We acknowledge this change in guidelines as a potential limitation of our study since our data were predominantly in existence prior to this guideline change, and expect subsequent evaluations of the success of BPGAP to utilize 2017 guidelines with respect to more recently available data.

Conclusion

The current analysis shows significant improvement in blood pressure control for BPGAP participants within a large, academic health system. Enrollment in the BPGAP initiative resulted in dramatic decreases in blood pressures among those within the Uncontrolled and Borderline blood pressure clusters that persisted through the first year following BPGAP enrollment, and maintained a controlled blood pressure among those patients who clustered in the Controlled blood pressure group throughout that time. BPGAP establishes community pharmacists as healthcare team members who have open lines of communication with both patients and providers, serving to educate and empower patients regarding their disease state, and aid in the rapid resolution of drug therapy problems to improve hypertension management. These effects may be far-reaching beyond the confines of this study as controlled blood pressure decreases the risk of major cardiovascular events and death.[2, 24]

Author contributions: Dr. Zagel was responsible for study design, formal analysis, manuscript drafting and editing.
Mr. Rhodes was responsible for study design and methodology, formal analysis, manuscript drafting and editing.
Dr. Brummel was responsible for study conceptualization and design, project administration, and manuscript review and editing.
Dr. Nowak were responsible for study conceptualization, critical review and manuscript editing.

Abbreviations:
BP: Blood Pressure
BPGAP: Blood Pressure Goals and Achievements Program
EHR: Electronic Health Record

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Table 1. Demographics and clinical characteristics of participants enrolled in the Blood Pressure Goals Achievement Program participants between January 2013 and November 2019.

			Total Population	Uncontrolled BP Cluster	Borderline BP Cluster	Controlled BP Cluster	p-value
Total Population, N (%)			5125 (100)	786 (15.34)	2620 (51.12)	1,719 (33.54)	
Age, years; mean (SD)			58.69 (13.58)	52.85 (12.12)	56.64 (12.86)	64.49 (13.24)	<.0001
Female sex; N (%)			2646 (51.63)	310 (39.44)	1346 (51.37)	990 (57.59)	<.0001
Race; N (%)	**White**		4370 (85.27)	628 (79.90)	2210 (84.35)	1532 (89.12)	
	Black/African American		352 (6.87)	78 (9.92)	194 (7.40)	80 (4.65)	
	Asian		174 (3.40)	28 (3.56)	93 (3.55)	53 (3.08)	
	Other/Unknown		229 (4.47)	52 (6.62)	123 (4.69)	54 (3.14)	<.0001
Ethnicity; N (%)	**Hispanic / Latino**		64 (1.25)	13 (1.65)	32 (1.22)	19 (1.11)	0.51
Insurance; N (%)	**Commercial**		2250 (43.90)	442 (56.23)	1305 (49.81)	503 (29.26)	
	Medicare		2115 (41.27)	186 (23.66)	914 (34.89)	1015 (59.05)	
	Medicaid		455 (8.88)	91 (11.58)	245 (9.35)	119 (6.92)	
	CHAMPUS/CHAMPVA		21 (0.41)	3 (0.38)	16 (0.61)	2 (0.12)	
	Self-Pay/Unknown		284 (5.54)	64 (8.14)	140 (5.34)	80 (4.65)	<.0001
Primary language; N (%)	**Non-English**		162 (3.16)	29 (3.69)	78 (2.98)	55 (3.20)	0.61
Diabetes diagnosis before BPGAP enrollment; N (%)			972 (18.97)	79 (10.05)	410 (15.65)	483 (28.10)	<.0001
Antihypertensive therapy classes utilized in 1-year prior to BPGAP enrollment, N (%)	**No therapies utilized**		1067 (20.82)	138 (17.56)	593 (22.63)	336 (19.55)	0.0025
	Angiotensin receptor blockers		896 (17.48)	127 (16.16)	467 (17.82)	302 (17.57)	0.56
	Beta blockers		1442 (28.14)	163 (20.74)	687 (26.22)	592 (34.44)	<.0001
	Angiotensin-converting enzyme inhibitors		2199 (42.91)	379 (48.22)	1047 (39.96)	773 (44.97)	<.0001
	Calcium channel blockers		1067 (20.82)	184 (23.41)	528 (20.15)	355 (20.65)	0.14
	Diuretics		1146 (22.36)	167 (21.25)	556 (21.22)	423 (24.61)	0.023
	Alpha blockers		263 (5.13)	34 (4.33)	114 (4.35)	115 (6.69)	0.0016
	Carbonic anhydrase inhibitors		18 (0.35)	1 (0.13)	7 (0.27)	10 (0.58)	0.12
Number of therapy classes utilized during 1-year prior to BPGAP enrollment, N (%)	**0**		1067 (20.82)	138 (17.56)	593 (22.63)	336 (19.55)	
	1		2128 (41.52)	375 (47.71)	1130 (43.13)	623 (36.24)	
	2		1183 (23.08)	174 (22.14)	556 (21.22)	453 (26.35)	
	3		502 (9.80)	69 (8.78)	230 (8.78)	203 (11.81)	
	4+		245 (4.78)	30 (3.82)	111 (4.23)	104 (6.05)	<.0001
Blood pressure measurements (mmHg) by time period surrounding BPGAP enrollment; median (IQR)	**6-12 months before**	**Systolic**	132 (123, 143)	152 (140, 164)	136 (128, 146)	126 (118, 136)	<.0001
		Diastolic	80 (71, 86)	94 (86, 100)	83 (78, 88)	72 (66, 79)	<.0001
	1 day-6 months before	**Systolic**	138 (126, 150)	158 (146, 170)	140 (130, 150)	128 (118, 138)	<.0001
		Diastolic	81 (72, 90)	96 (88, 102)	84 (79, 90)	72 (66, 80)	<.0001
	0-3 months after	**Systolic**	134 (124, 144)	140 (132, 152)	136 (128, 145)	130 (120, 139)	<.0001
		Diastolic	80 (72, 86)	86 (78, 92)	82 (76, 88)	73 (66, 80)	<.0001
	3-6 months after	**Systolic**	132 (122, 142)	138 (128, 150)	134 (124, 142)	129 (120, 138)	<.0001
		Diastolic	78 (70, 85)	84 (78, 90)	80 (74, 87)	73 (66, 80)	<.0001
	6-12 months after	**Systolic**	132 (122, 142)	138 (128, 149)	133 (124, 142)	130 (120, 138)	<.0001
		Diastolic	78 (70, 84)	84 (78, 90)	80 (74, 86)	73 (66, 80)	<.0001

BP = Blood Pressure; BPGAP = Blood Pressure Goals Achievement Program; IQR = Interquartile Range

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Table 2. Demographics and clinical characteristics of participants of the Blood Pressure Goals Achievement Program enrolled between January 2013 and November 2019 who had at least one blood pressure measurement in each of 4 study time periods.

			Total Population	Uncontrolled BP Cluster	Borderline BP Cluster	Controlled BP Cluster	p-value
Total Population, N (%)			2108 (100)	161 (7.64)	1092 (51.8)	855 (40.56)	
Age, years; mean (SD)			60.95 (13.87)	54.52 (13.43)	57.95 (13.36)	54.52 (13.43)	<.0001
Female sex; N (%)			1225 (58.11)	84 (52.17)	619 (56.68)	522 (61.05)	0.043
Race; N (%)	**White**		1811 (85.91)	132 (81.99)	925 (84.71)	754 (88.19)	
	Black or African American		158 (7.50)	12 (7.45)	99 (9.07)	47 (5.50)	
	Asian		62 (2.94)	5 (3.11)	24 (2.20)	33 (3.86)	
	Other/Unknown		77 (3.65)	12 (7.45)	44 (4.03)	21 (2.46)	0.0006
Ethnicity; N (%)	**Hispanic / Latino**		24 (1.14)	3 (1.86)	13 (1.19)	8 (0.94)	0.58
Insurance; N (%)	**Commercial**		761 (36.10)	86 (53.42)	475 (43.50)	200 (23.39)	
	Medicare		1056 (50.09)	53 (32.92)	452 (41.39)	551 (64.44)	
	Medicaid		182 (8.63)	17 (10.56)	106 (9.71)	59 (6.90)	
	CHAMPUS/CHAMPVA		9 (0.43)	1 (0.62)	7 (0.64)	1 (0.12)	
	Self-Pay/Unknown		100 (4.74)	4 (2.48)	52 (4.76)	44 (5.15)	<.0001
Primary language; N (%)	**Non-English**		48 (2.28)	1 (0.62)	19 (1.74)	28 (3.27)	0.027
Diabetes diagnosis before BPGAP enrollment; N (%)			521 (24.72)	20 (12.42)	198 (18.13)	303 (35.44)	<.0001
Antihypertensive therapy classes utilized in 1-year prior to BPGAP enrollment, N (%)	**No therapies utilized**		478 (22.68)	34 (21.12)	263 (24.08)	181 (21.17)	0.28
	Angiotensin receptor blockers		411 (19.50)	34 (21.12)	219 (20.05)	158 (18.48)	0.59
	Beta blockers		685 (32.50)	43 (26.71)	318 (29.12)	324 (37.89)	<.0001
	Angiotensin-converting enzyme inhibitors		835 (39.61)	62 (38.51)	400 (36.63)	373 (43.63)	0.0071
	Calcium channel blockers		493 (23.39)	47 (29.19)	255 (23.35)	191 (22.34)	0.172
	Diuretics		503 (23.86)	44 (27.33)	240 (21.98)	219 (25.61)	0.10
	Alpha blockers		140 (6.64)	10 (6.21)	63 (5.77)	67 (7.84)	0.19
	Carbonic anhydrase inhibitors		10 (0.47)	1 (0.62)	3 (0.27)	6 (0.70)	0.38
Number of therapy classes utilized during 1-year prior to BPGAP enrollment, N (%)	**0**		478 (22.68)	34 (21.12)	263 (24.08)	181 (21.17)	
	1		741 (35.15)	55 (34.16)	422 (38.64)	264 (30.88)	
	2		509 (24.15)	44 (27.33)	230 (21.06)	235 (27.49)	
	3		234 (11.10)	15 (9.32)	109 (9.98)	110 (12.87)	
	4+		146 (6.93)	13 (8.07)	68 (6.24)	65 (7.59)	0.0016
Blood pressure measurements (mmHg) by time period surrounding BPGAP enrollment; median (IQR)	**6-12 months before**	**Systolic**	132 (122, 142)	153 (140, 165)	136 (128, 146)	126 (118, 136)	<.0001
		Diastolic	79 (70, 86)	92 (85, 100)	83 (78, 88)	72 (65, 79)	<.0001
	1 day-6 months before	**Systolic**	136 (124, 148)	156 (146, 168)	139 (130, 150)	128 (118, 138)	<.0001
		Diastolic	80 (71, 88)	94 (86, 100)	84 (78, 90)	72 (66, 80)	<.0001
	0-3 months after	**Systolic**	134 (124, 144)	142 (132, 155)	136 (128, 146)	130 (120, 139)	<.0001
		Diastolic	79 (70, 86)	85 (78, 92)	82 (76, 88)	72 (66, 80)	<.0001
	3-6 months after	**Systolic**	132 (122, 142)	140 (130, 151)	134 (125, 142)	129 (120, 138)	<.0001
		Diastolic	78 (70, 85)	84 (78, 91)	80 (75, 88)	73 (66, 80)	<.0001
	6-12 months after	**Systolic**	132 (122, 142)	136 (127, 148)	134 (124, 143)	130 (120, 140)	<.0001
		Diastolic	78 (70, 84)	84 (77, 90)	80 (74, 87)	73 (66, 80)	<.0001

BP = Blood Pressure; BPGAP = Blood Pressure Goals Achievement Program; IQR = Interquartile Range

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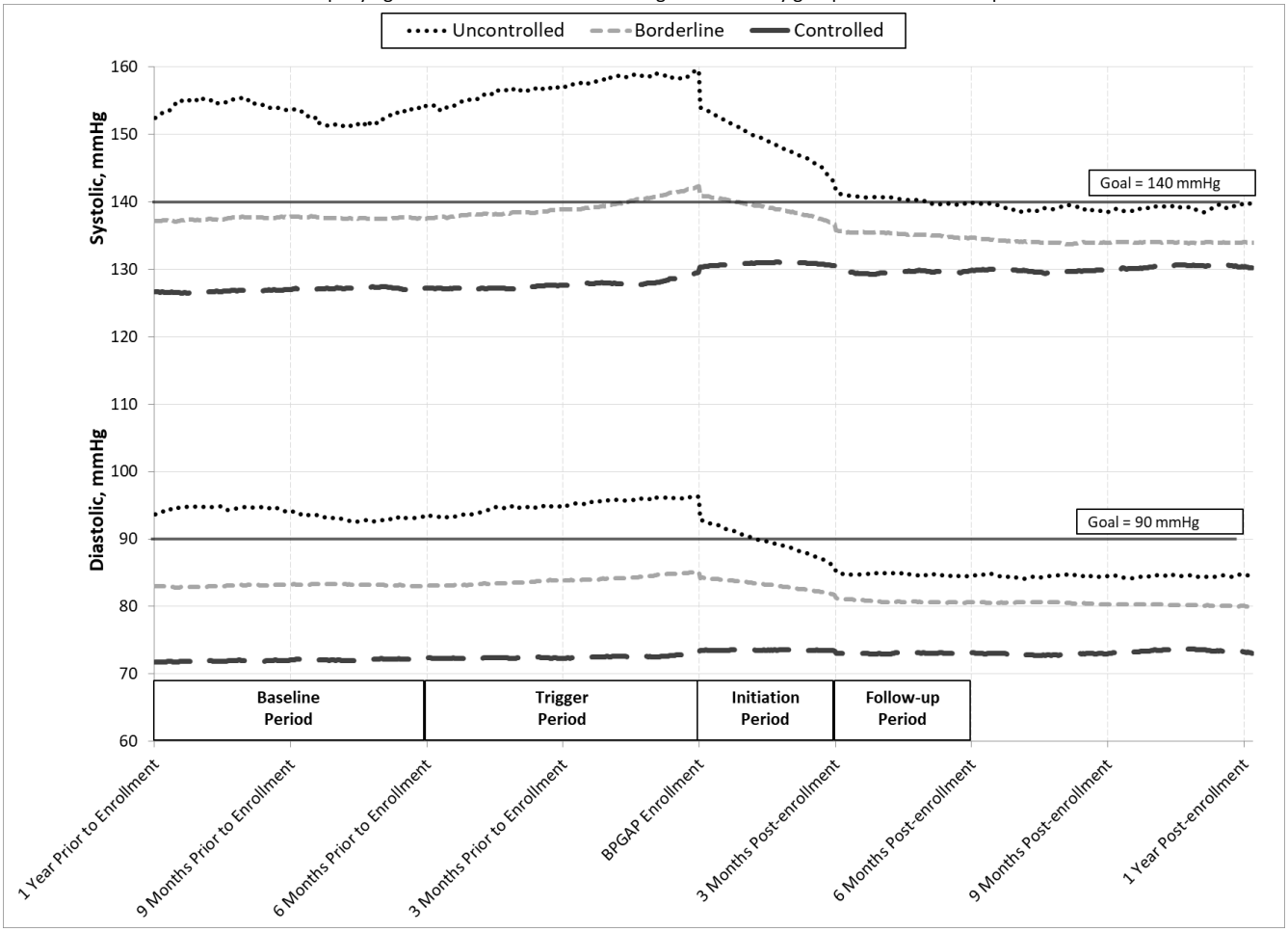
Table 3. Results of generalized linear mixed models to describe the relationship between blood pressures and study time period among 2,108 BPGAP study participants.

	Overall Population N=2108		Uncontrolled blood pressure N=161		Borderline blood pressure N=1092		Controlled blood pressure N=855	
	Estimate	**p-value**	**Estimate**	**p-value**	**Estimate**	**p-value**	**Estimate**	**p-value**
Systolic, mmHg	-0.20	0.027	-5.28	<.0001	-1.06	<.0001	1.05	<.0001
Diastolic mmHg	-0.23	0.0002	-3.36	<.0001	-0.80	<.0001	0.46	<.0001

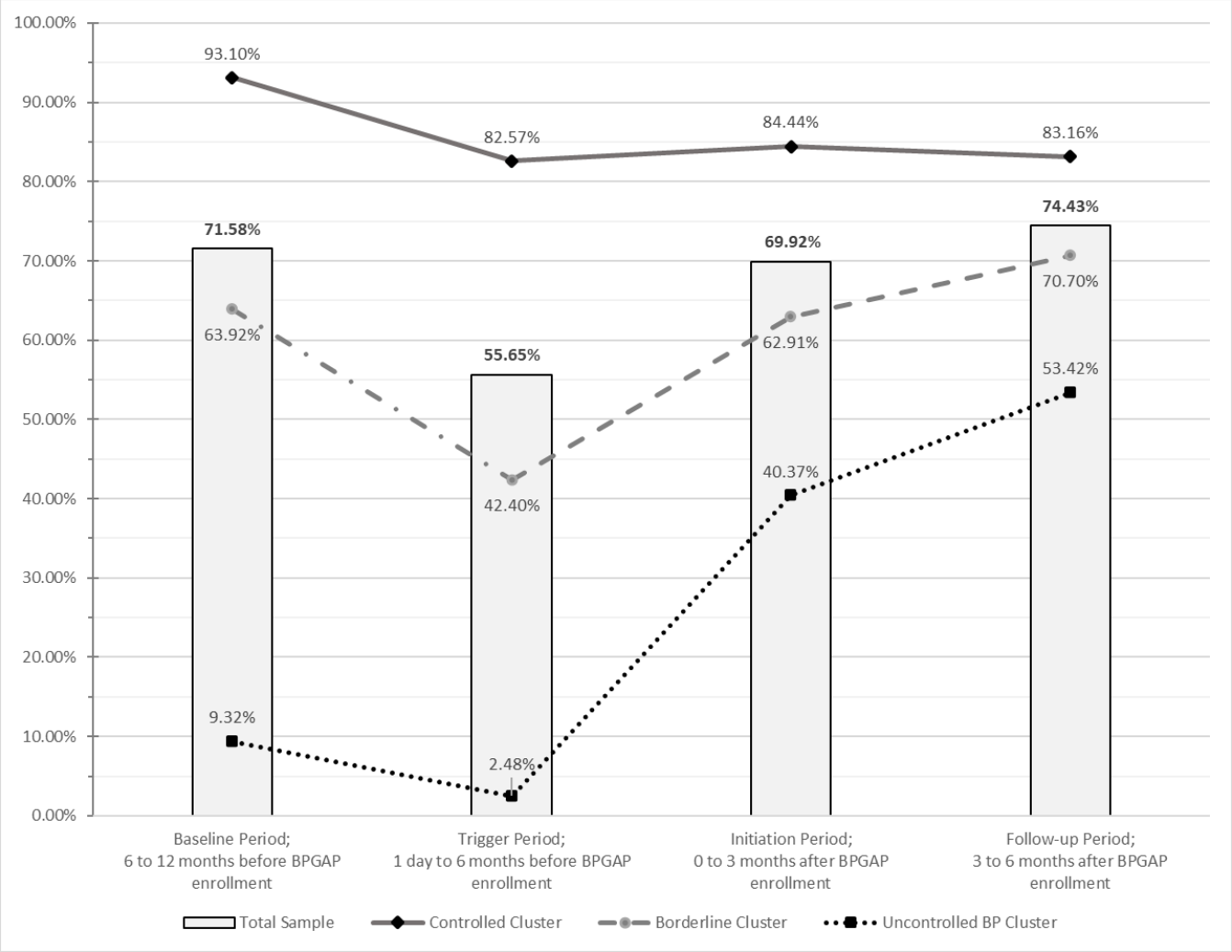
Figure 1. 90-day moving average blood pressure measurements among participants of the Blood Pressure Goals Achievement Program by blood pressure cluster; N= 5,182 patients; 68,413 blood pressure measurements between 1 year before and 1 year after BPGAP enrollment. The accompanying table denotes associated average decreases by group across each time period.



		Total average mmHg change over time			
		Baseline Period	**Trigger Period**	**Initiation Period**	**Follow-up Period**
Systolic	Uncontrolled	-2.41*	5.34*	-10.40*	-1.67*
	Borderline	0.32*	4.32*	-4.17*	-1.04*
	Controlled	0.81*	1.84*	0.20*	0.21*
Diastolic	Uncontrolled	-2.07*	3.20*	-6.62*	-0.35*
	Borderline	0.28*	2.04*	-2.57*	-0.49*
	Controlled	0.47*	0.55*	-0.04	0.04

* significant at Bonferroni correction for p<0.05 (p<0.017)

Figure 2. Percent of program participants with average blood pressures in control range (<140/90 mmHg) during the Blood Pressure Goals Achievement Program, by blood pressure cluster and overall sample; N=2,108.



Supplementary Table 1. Sensitivity analysis comparing patients with blood pressure readings spanning all four BPGAP periods and those with fewer blood pressure readings.

		Total Population	Patients without blood pressure readings across all study periods	Patients with blood pressure readings across all study periods	p-value
Total Population, N (%)		5125 (100)	3017 (58.87)	2108 (41.13)	
Age, years; median (IQR)		58 (50, 68)	57 (48, 66)	61 (51.5, 71)	<.0001
Female sex; N (%)		2646 (51.63)	1421 (47.10)	1225 (58.11)	<.0001
Race; N (%)	**White**	4370 (85.27)	2559 (84.82)	1811 (85.91)	
	Black or African American	352 (6.87)	194 (6.43)	158 (7.50)	
	Asian	174 (3.40)	112 (3.71)	62 (2.94)	
	Other/Unknown	229 (4.47)	152 (5.04)	77 (3.65)	0.021
Ethnicity; N (%)	**Hispanic / Latino**	64 (1.25)	40 (1.33)	24 (1.14)	0.55
Insurance; N (%)	**Commercial**	2250 (43.90)	1489 (49.35)	761 (36.10)	
	Medicare	2115 (41.27)	1059 (35.10)	1056 (50.09)	
	Medicaid	455 (8.88)	273 (9.05)	182 (8.63)	
	CHAMPUS/CHAMPVA	21 (0.41)	12 (0.40)	9 (0.43)	
	Self-Pay/Unknown	284 (5.54)	184 (6.10)	100 (4.74)	<.0001
Primary language; N (%)	**Non-English**	162 (3.16)	114 (3.78)	48 (2.28)	0.0025
Blood pressure cluster; N (%)	**Controlled**	1719 (33.54)	864 (28.64)	855 (40.56)	
	Borderline	2620 (51.12)	1528 (50.65)	1092 (51.80)	
	Uncontrolled	786 (15.34)	625 (20.72)	161 (7.64)	<.0001
Diabetes diagnosis before BPGAP enrollment; N (%)		972 (18.97)	451 (14.95)	521 (24.72)	<.0001
Antihypertensive medications filled in 1-year prior to BPGAP enrollment; N (%)	**Angiotensin receptor blockers**	896 (17.48)	485 (16.08)	411 (19.50)	0.0015
	Beta blocker	1442 (28.14)	757 (25.09)	685 (32.50)	<.0001
	Angiotensin-converting enzyme Inhibitor	2199 (42.91)	1364 (45.21)	835 (39.61)	<.0001
	Calcium channel blocker	1067 (20.82)	574 (19.03)	493 (23.39)	0.0002
	Diuretic	1146 (22.36)	643 (21.31)	503 (23.86)	0.03
	Alpha blocker	263 (5.13)	123 (4.08)	140 (6.64)	<.0001
	Carbonic anhydrase inhibitor	18 (0.35)	8 (0.27)	10 (0.47)	0.21
	None	1067 (20.82)	589 (19.52)	478 (22.68)	0.0062
Total antihypertensive medications types before starting BPGAP; N (%)	**0**	1067 (20.82)	589 (19.52)	478 (22.68)	
	1	2128 (41.52)	1387 (45.97)	741 (35.15)	
	2	1183 (23.08)	674 (22.34)	509 (24.15)	
	3	502 (9.80)	268 (8.88)	234 (11.10)	
	4	199 (3.88)	83 (2.75)	116 (5.50)	
	5	41 (0.80)	13 (0.43)	28 (1.33)	
	6	5 (0.10)	3 (0.10)	2 (0.09)	<.0001
Timing of first antihypertensive medication; N (%)	**> 1-year before index**	2413 (47.08)	1344 (44.55)	1069 (50.71)	
	Between 1 year and 30 days prior to index	1463 (28.55)	869 (28.80)	594 (28.18)	
	Within 30 days surrounding index	820 (16.00)	582 (19.29)	238 (11.29)	
	30 days to 1-year following index	250 (4.88)	126 (4.18)	124 (5.88)	
	No medications	179 (3.49)	96 (3.18)	83 (3.94)	<.0001

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