Machine Learning-driven Risk Factor Identification on Post-2013 Blood Pressure Control Decline in Hypertensive Populations

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Summary:

Addressing the escalating concern over hypertension prevalence and the recent decline in blood pressure control (BPC) among US adults since 2013, this study investigates key factors influencing this trend utilizing NHANES data from 2003 to 2020. The retrospective analysis of 26,147 adults reveals age, medication usage, obesity/mobility, and immune system/personal health as significant contributors to BPC decline. Notably, impact of age increased post-2013, echoing challenges prevalent in an aging population. Reduced medication usage, including issues of adherence and specific drug classes, underscores the need for interventions promoting medication adherence. Obesity, high Body Mass Index (BMI), and mobility-related factors, along with immune system indicators, were also linked to BPC decline, emphasizing the importance of lifestyle and holistic health in hypertension management. The study's sophisticated analytical approaches provide comprehensive insights, informing evidence-based interventions to mitigate cardiovascular risks among US adults.

Key words: Machine learning; NHANES; blood pressure control; feature selection; survey design and analysis

1. Introduction

Controlling blood pressure (BP) is crucial in mitigating the risk of cardiovascular disease (CVD) (SPRINT Research Group et al., 2015). Despite the established benefits, the prevalence of blood pressure control (BPC), clinically defined as systolic BP < 140 and diastolic BP < 90, (Chobanian et al., 2003; Crim et al., 2012) has experienced a concerning decline among US adults with hypertension since 2013(Egan, 2022; Muntner et al., 2022). This trend necessitates a detailed analysis of publicly available data from US adults, with the aim of identifying potential causes or correlates contributing to the deterioration of BP control over the past decade. Such insights are crucial for developing targeted interventions to effectively manage BP and prevent cardiovascular diseases (Antonakoudis et al., 2007). The urgency of our investigation is underscored by hypertension's significant impact on morbidity and mortality associated with CVD (Gu et al., 2010; Zhou et al., 2018). This concern is supported by numerous studies that consistently emphasize the critical link between blood pressure (BP) levels and adverse cardiovascular outcomes (MacMahon et al., 1990; Wang et al., 2006; Fuchs and Whelton, 2020). Our study focuses on unraveling the intricate dynamics of BPC among US adults using data spanning 2003 to 2020 from the National Health and Nutrition Examination Survey (NHANES).

The primary aim of this research is to identify key factors influencing the observed decline in BPC and contribute insights that inform targeted interventions. Leveraging sophisticated analytical approaches, we examine the relationship between demographics, medication usage, and comorbidities, unraveling the complexities surrounding hypertension trends. To achieve these objectives, we conducted a retrospective analysis of 8 cycles of NHANES data, encompassing 26,147 non-institutionalized US adults aged 18 and above. The dataset covers the period from 2003 to 2020, providing a comprehensive representation of the US civilian population. Our study evaluates BPC based on the guidelines outlined in the Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC7) and the 2017 American College of Cardiology/American Heart Association guidelines (ACC/AHA). Utilizing advanced statistical and machine learning models, we aim to discern temporal changes and feature importance in understanding the decline in BPC.

2. Materials and Methods

2.1 *Data Preprocessing*

We utilized all Continuous National Health and Nutrition Examination Survey (NHANES) datasets in addition to the provided data from the cardioStats package containing information about BPC, demographics, blood pressure levels, hypertension status, antihypertensive medication usage, and co-morbidities. We dedicated significant effort to comprehensively include all NHANES data from 1999 to 2020, which contain demographics, dietary, examination, laboratory, and questionnaire information. Figure 1 shows the complete pipeline of our data analysis.

First, datasets with complete tests across more than four cycles, spanning both pre and post-2013, were downloaded, yielding a total of 749 covariates distributed as follows: cardioStats (111), examination (107), laboratory (225), dietary (134), and questionnaire (172). The 1999-2003 cycles were excluded due to the substantial changes in the conducted tests compared to that of post-2003. The number of subjects with hypertension left for analysis based on the 2017 ACC/AHA guidelines versus the JNC7 guidelines was 26,147 and 19,245 respectively. Outcomes based on both guidelines were analyzed in Section 2.2 as their thresholds differed. Moreover, adopting a more inclusive threshold such as the 2017 ACC/AHA guideline allowed us to include subjects with pre-hypertension (Svetkey, 2005), thereby enriching our data representation and scope.

Features with 50% or more missing data were removed, and imputation was performed using Multiple Imputation by Chained Equations (MICE) method with Classification and Regression Trees (CART) as the classifier. MICE + CART yielded the most optimal imputed dataset for our study, outperforming Random Forest (MICE + RF), Predictive Mean Matching, and mean/mode method. The final dataset comprised 26,147 samples and 180 covariates. It included four binary categorical outcomes delineating BPC as per the JNC7 guideline, the 2017 ACC/AHA guideline, (systolic blood pressure $<$ 140 mm Hg and diastolic blood pressure $<$ 90 mm Hg), and (systolic blood pressure $<$ 130 mm Hg and diastolic blood pressure $<$ 80 mm Hg). Table 1 provides detailed uni- and bi-variate statistics of select features for the 180 covariates, grouped by BPC statuses and pre- versus post-2013. p_w and p_{rs} indicate the p-values from the Wilcoxon rank-sum test for complex survey samples and chi-squared test with Rao and Scott's second-order correction. The complete

table of uni- and bi-variate analyses can be accessed at https://github.com/rubychan299/ENAR-Risk-Factors-Analyses/uni_bivariate.csv [3]

2.2 *Data Analysis Steps*

We evaluated a suite of four widely used, interpretable machine learning models to perform feature selection: logistic regression with lasso regularization (LR), random forest (RF), XGBoost, and TabNet. LRSun et al. (2018) applies an L1 penalty to reduce overfitting and promotes sparsity adequate for feature selection, where non-zero coefficients indicate significant predictors. Random forest is a set of decision trees that uses mean decrease impurity (Louppe et al., 2013) to calculate the feature importance. XGBoost(Dinh et al., 2019) builds an ensemble of decision trees in a sequential manner by utilizing gradient boosting. It utilizes gain, the improvement in accuracy in a branch brought by a feature, to calculate the feature importance. TabNet(Arik and Pfister, 2021) employs a sequential attention mechanism, using the output from each decision step to update feature masks, thus creating a decision tree-like mapping with sparse, instance-wise feature selection. At each step, it focuses on a subset of features determined by a learned mask. The feature importance is then derived by aggregating these masks across all steps, providing a measure of each feature's impact on the model's predictions.

R implementations of *glmnet, randomForest,* and *xgboost* package and Python package *pytorch-tabnet* were utilzed. We originally planned to use software implementations that supported complex survey design - *svyglm* for logistic regression and *rpms* package for random forest and gradient boosted models. However, the rpms code failed internally, and there were no existing TabNet implementations that supported complex survey design. Thus, we made this preliminary feature selection step consistent by only accounting for the survey weights. All code used for data preprocessing and analysis is available at

https://github.com/rubychan299/ENAR-Risk-Factors-Analyses. Each model was calibrated to predict four distinct BPC outcomes across ten iterations. The analysis spanned three temporal segments: 2003-2013, 2013-2020, and an extended period from 2003-2020. For each time frame, we calculated the mean and standard deviation of feature importance across the ten replications. Subsequently, we identified commonalities by extracting features that appeared among the top 50 in

importance with non-zero values across at least two different time segments. Only features selected by a minimum of two out of the four models were retained for further analysis. This process allowed for a comprehensive temporal synthesis, effectively aggregating insights from various interpretable models to discern patterns influencing BPC outcomes over time.

In our final analysis, we utilized logistic spline regression with the final feature sets detailed in Table 2. This technique employs piecewise polynomials, or splines, to model data segments at critical points, called knots, to identify potential shifts in the predictor-outcome relationship, thereby enhancing model interpretability. We strategically placed a knot at 2013 to explore significant changes in the dynamics around this period. To optimize the feature set, we conducted stepwise forward elimination and assessed the variation inflation factor, pinpointing the most informative features for predicting blood pressure control (BPC). The models were tailored to two distinct outcomes based on the JNC7 and 2017 ACC/AHA guidelines. We employed the *svydesign* and *svyglm* R packages for accurate adjustment for primary sampling unit, strata, and mobile examination center (MEC) weights. Additionally, we analyzed the shift in the relationship between the feature set and BP controls by applying Elastic Net penalty regressions to the 2003-2013 and 2013-2020 datasets. 10-fold cross-validation was used for parameter tuning, and p-values were calculated using a sampling-splitting approach based on implementations available in *glmnet* and *hdi* packages.

3. Results

Our research identified four primary factors contributing to the decline in BPC: age, medication usage, obesity/mobility, and immune system/personal health. Notably, the influence of age on BPC has grown post-2013, consistent with Egan et al. (2021), who found managing blood pressure becomes more challenging as the population ages. Additionally, we observed a significant decrease in medication usage, contributing to the BPC decline. This decrease encompasses aspects such as prescription adherence and the utilization of specific drug classes, including angiotensin converting enzyme inhibitors, aldosterone antagonists, angiotensin receptor blockers, and thiazide diuretics. This trend underscores the necessity for improved strategies to encourage medication adherence in hypertensive patients.

Obesity and mobility issues also exhibited a strong correlation with the deterioration of BPC.

Influential factors include high Body Mass Index (BMI), overweight status, and arthritis presence, indicating the importance of personal health and mobility in hypertension management (Choi et al., 2023). This relationship emphasizes the critical role of lifestyle and physical activity in hypertension care. Furthermore, we identified variables linked to the immune system and overall health, such as Direct HDL-Cholesterol levels, monocyte number, lymphocyte percentage, and platelet count, as influential to BPC. These findings suggest that an inclusive view of patient health, integrating immune function and metabolic health, is vital for effective hypertension management (He et al., 2002). Table 2 reveals that age is a significant predictor of BPC, in line with the JNC7 guideline. The negative coefficient indicates that increasing age slightly reduces the likelihood of BPC, although the effect size is minimal, as reflected by an odds ratio (OR) close to zero. The statistical significance of this relationship is confirmed by a p-value ($p < 0.05$).

Additionally, the percentage of eosinophils in the blood is a meaningful predictor for BPC under the ACC/AHA guideline. Higher eosinophil percentages correlate with lower odds of controlling blood pressure. The first spline term indicates that the likelihood of achieving BPC increased as years progressed towards 2013, demonstrating a reliable trend during this period. The second spline term post-2013 shows a continued increase in the odds of achieving BPC, albeit at a reduced magnitude compared to the pre-2013 period, signifying a decline in prevalence.

4. Conclusion

In addressing the post-2013 decline in BPC among hypertensive populations in the United States, our study identifies age, medication usage, obesity/mobility, and immune system/personal health as pivotal factors contributing to this trend. Our study reveals increasing challenges in BPC due to aging, with a notable decline in medication usage highlighting the need for improved adherence strategies. Obesity, high BMI, and mobility issues emphasize lifestyle's role in hypertension management. Immune system and overall health factors are key influencers, supporting a holistic approach to patient health. Statistical analysis confirms age and eosinophil percentage as significant predictors of BPC. Our findings offer a nuanced, comprehensive understanding, guiding evidence-based interventions to enhance BPC and mitigate cardiovascular risks among US adults.

5. Tables and Figures

The figures and tables used in this paper are placed at the end of the document.

[Figure 1 about here.]

[Figure 2 about here.]

References

Antonakoudis, G., Poulimenos, L., Kifnidis, K., Zouras, C., and Antonakoudis, H. (2007). Blood pressure control and cardiovascular risk reduction. *Hippokratia* **11,** 114–119.

Arik, S. and Pfister, T. (2021). TabNet: Attentive Interpretable Tabular Learning. *Proceedings of the AAAI Conference on Artificial Intelligence* **35,** 6679–6687. Number: 8.

Chobanian, A. V., B. G. L. B. H. R. C. W. C. G. L. A. I. J. L. J. J. D. W. M. B. J. O. S. W. J. T. J., Roccella, E. J., and Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (2003). Seventh report of the joint national committee on prevention, detection, evaluation, and treatment of high blood pressure. *Hypertension* **42,** 1206–1252. Epub 2003 Dec 1.

Crim, M. T., Yoon, S. S., Ortiz, E., Wall, H. K., Schober, S., Gillespie, C., Sorlie, P., Keenan, N., Labarthe, D., and Hong, Y. (2012). National surveillance definitions for hypertension prevalence and control among adults. *Circulation. Cardiovascular Quality and Outcomes* **5,** 343–351.

Dinh, A., Miertschin, S., Young, A., and Mohanty, S. D. (2019). A data-driven approach to predicting diabetes and cardiovascular disease with machine learning. *BMC Med Inform Decis Mak* **19,** 211.

Egan, B. M. (2022). Hypertension control among us adults, 2009 to 2012 through 2017 to 2020, and the impact of covid-19. *Hypertension (Dallas, Tex. : 1979)* **79,** 1981–1983.

Fuchs, F. D. and Whelton, P. K. (2020). High blood pressure and cardiovascular disease. *Hypertension* **75,** 285–292.

Gu, Q., Dillon, C. F., Burt, V. L., and Gillum, R. F. (2010). Association of hypertension

treatment and control with all-cause and cardiovascular disease mortality among us adults with hypertension. *American Journal of Hypertension* **23,** 38–45.

Louppe, G., Wehenkel, L., Sutera, A., and Geurts, P. (2013). Understanding variable importances in forests of randomized trees. In *Advances in Neural Information Processing Systems*, volume 26. Curran Associates, Inc.

MacMahon, S., Peto, R., Collins, R., Godwin, J., Cutler, J., Sorlie, P., and Stamler, J. (1990). Blood pressure, stroke, and coronary heart disease: part 1, prolonged differences in blood pressure: prospective observational studies corrected for the regression dilution bias. *The Lancet* **335,** 765–774.

Muntner, P., Miles, M. A., Jaeger, B. C., Hannon Iii, L., Hardy, S. T., Ostchega, Y., Wozniak, G., and Schwartz, J. E. (2022). Blood pressure control among us adults, 2009 to 2012 through 2017 to 2020. *Hypertension (Dallas, Tex. : 1979)* **79,** 1971–1980.

SPRINT Research Group et al. (2015). A randomized trial of intensive versus standard blood-pressure control. *New England Journal of Medicine* **373,** 2103–2116. Erratum in: N Engl J Med. 2017;377:2506.

Sun, B., Shi, X., Wang, T., and Zhang, D. (2018). Exploration of the Association between Dietary Fiber Intake and Hypertension among U.S. Adults Using 2017 American College of Cardiology/American Heart Association Blood Pressure Guidelines: NHANES 2007–2014. *Nutrients* **10,** 1091.

Svetkey, L. P. (2005). Management of prehypertension. *Hypertension* **45,** 1056–1061.

Wang, W., Lee, E. T., Fabsitz, R. R., Devereux, R., Best, L., Welty, T. K., and Howard, B. V. (2006). A longitudinal study of hypertension risk factors and their relation to cardiovascular disease: the strong heart study. *Hypertension* **47,** 403–409.

Zhou, D., Xi, B., Zhao, M., Wang, L., and Veeranki, S. P. (2018). Uncontrolled hypertension increases risk of all-cause and cardiovascular disease mortality in us adults: the nhanes iii linked mortality study. *Scientific reports* **8,** 9418.

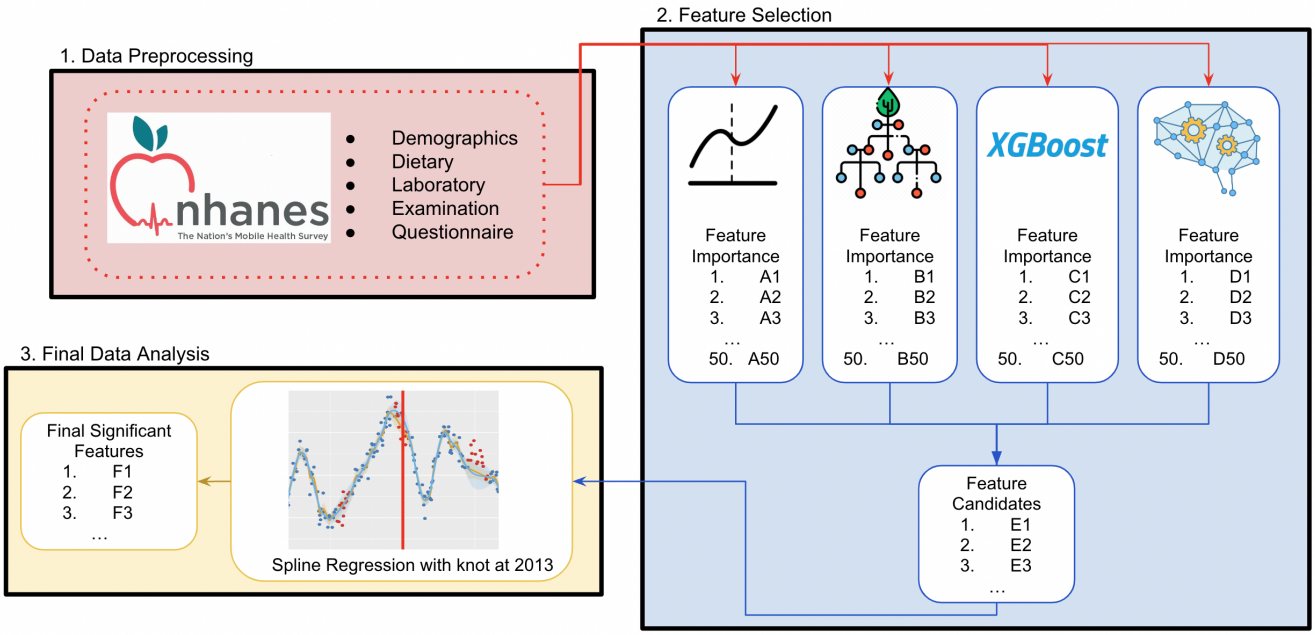

Figure 1. Data analysis pipeline for complete NHANES dataset

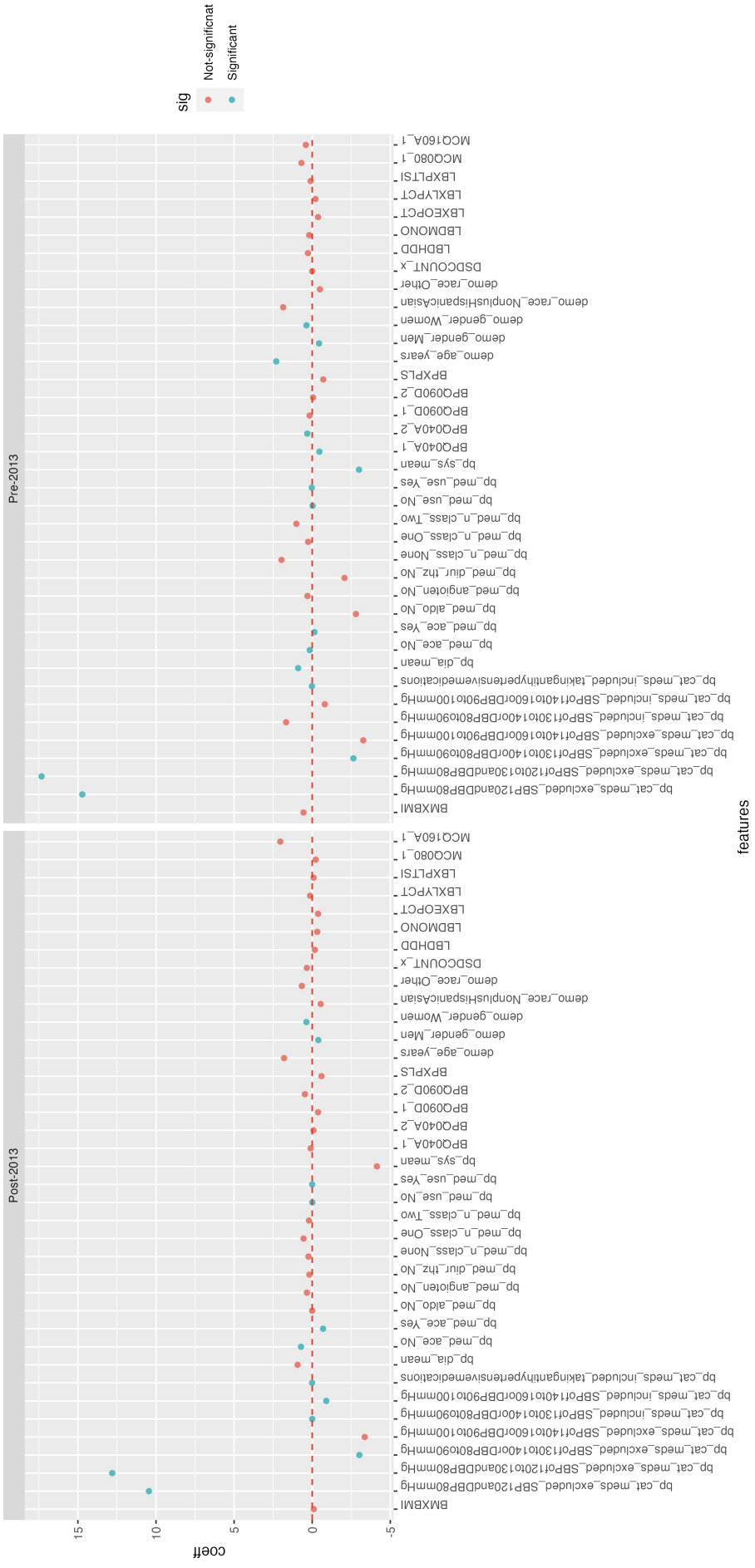

Figure 2. Elastic-Net Coefficients and Significance for Pre/Post 2013 BP Control by ACC/AHA Guideline

Table 1. Uni-/Bi-variate statistics for model-selected features

Feature		n (%) or μ	n (%) or μ ACC/AHA		p_w or p_{rs}	n (%) or μ Time		p_w or p_{rs}
			BPC = Yes	BPC = No		Before 2013	After 2013	
Race/ethnicity					<0.001			<0.001
	Non-Hispanic White	697,427,831 (73%)	540,497,054 (72%)	156,930,777 (77%)		206,750,821 (66%, 0.02)	490,677,010 (76%, 0.02)	
	Non-Hispanic Black	113,942,402 (12%)	90,954,637 (12%)	22,987,764 (11%)		42,266,295 (14%, 0.01)	71,676,107 (11%, 0.01)	
	Non-Hispanic Asian	19,182,096 (2.0%)	16,152,344 (2.1%)	3,029,753 (1.5%)		15,136,108 (4.8%, 0.00)	4,045,988 (0.6%, 0.00)	
	Hispanic	89,218,728 (9.3%)	75,690,975 (10%)	13,527,753 (6.7%)		37,984,433 (12%, 0.01)	51,234,295 (7.9%, 0.01)	
	Other	37,871,487 (4.0%)	31,041,724 (4.1%)	6,829,763 (3.4%)		10,898,499 (3.5%, 0.00)	26,972,987 (4.2%, 0.00)	
Gender					<0.001			0.032
	Men	478,607,290 (50%)	387,429,967 (51%)	91,177,323 (45%)		161,039,685 (51%, 0.01)	317,567,606 (49%, 0.01)	
	Women	479,035,254 (50%)	366,906,766 (49%)	112,128,487 (55%)		151,996,472 (49%, 0.01)	327,038,781 (51%, 0.01)	
Age (years)					<0.001			0.3
	18 to 44	217,153,854 (23%)	195,647,526 (26%)	21,506,328 (11%)		72,888,214 (23%, 0.01)	144,265,640 (22%, 0.01)	
	45 to 64	426,225,515 (45%)	328,241,619 (44%)	97,983,896 (48%)		137,381,426 (44%, 0.01)	288,844,089 (45%, 0.01)	
	65 to 74	177,484,886 (19%)	123,229,253 (16%)	54,255,632 (27%)		60,432,149 (19%, 0.01)	117,052,736 (18%, 0.01)	
	75+	136,778,290 (14%)	107,218,335 (14%)	29,559,954 (15%)		42,334,368 (14%, 0.01)	94,443,921 (15%, 0.01)	
Body Mass Index		30(7)	30(7)	32(7)	<0.001	31(7, 0)	30(7, 0)	<0.001
Blood pressure category (BPC)					< 0.001			0.013
	SBP <120 and DBP <80 mm Hg	117,566,295 (12%)	0 (0%)	117,566,295 (58%)		40,780,684 (13%, 0.01)	76,785,611 (12%, 0.01)	
	SBP of 120 to <130 and DBP <80 mm Hg	83,867,362 (8.8%)	0 (0%)	83,867,362 (41%)		31,417,928 (10%, 0.01)	52,449,434 (8.1%, 0.00)	
	SBP of 130 to <140 or DBP 80 to <90 mm Hg	408,472,847 (43%)	406,600,694 (54%)	1,872,153 (0.9%)		130,818,002 (42%, 0.01)	277,654,845 (43%, 0.01)	
	SBP of 140 to <160 or DBP 90 to <100 mm Hg	256,234,649 (27%)	256,234,649 (34%)	0 (0%)		83,634,876 (27%, 0.01)	172,599,773 (27%, 0.01)	
	SBP 160+ or DBP 100+ mm Hg	91,501,391 (9.6%)	91,501,391 (12%)	0 (0%)		26,384,667 (8.4%, 0.00)	65,116,724 (10%, 0.00)	

Table 1 continued

Feature		n (%) or μ	n (%) or μ ACC/AHA		p_w or p_{rs}	n (%) or μ Time		p_w or p_{rs}
			BPC = Yes	BPC = No		Before 2013	After 2013	
BPC including anti hypertensive medication use as a group								
	SBP <120 and DBP <80 mm Hg	0 (0%)	0 (0%)	0 (0%)		0 (0%, 0.00)	0 (0%, 0.00)	
	SBP of 120 to <130 and DBP < 80 mm Hg	0 (0%)	0 (0%)	0 (0%)		0 (0%, 0.00)	0 (0%, 0.00)	
	SBP of 130 to <140 or DBP 80 to <90 mm Hg	292,344,049 (31%)	290,834,139 (39%)	1,509,910 (0.7%)		91,742,641 (29%, 0.01)	200,601,408 (31%, 0.01)	
	SBP of 140 to <160 or DBP 90 to <100 mm Hg	146,352,995 (15%)	146,352,995 (19%)	0 (0%)		45,968,057 (15%, 0.01)	100,384,938 (16%, 0.01)	
	SBP 160+ or DBP 100+ mm Hg	41,883,488 (4.4%)	41,883,488 (5.6%)	0 (0%)		12,502,384 (4.0%, 0.00)	29,381,104 (4.6%, 0.00)	
Diastolic blood pressure (mmHg)		75(13)	78(12)	66(10)	<0.001	76(12, 0)	75(13, 0)	0.4
Systolic blood pressure (mmHg)		135(18)	139(16)	116(10)	<0.001	135(17, 0)	134(18, 0)	0.3
Taking ACE inhibitors	212,178,293 (22%)		119,217,639 (16%)	92,960,654 (46%)	<0.001	76,380,814 (25%, 0.01)	135,797,480 (21%, 0.01)	0.001
Taking an aldosterone antagonist		12,230,046 (1.3%)	5,574,116 (0.7%)	6,655,930 (3.3%)	<0.001	4,562,903 (1.5%, 0.00)	7,667,143 (1.2%, 0.00)	0.4
Taking an angiotensin receptor blocker		126,045,016 (13%)	76,437,269 (10%)	49,607,747 (25%)	<0.001	46,409,873 (15%, 0.01)	79,635,143 (12%, 0.01)	0.010
Taking a thiazide diuretic		181,066,851 (19%)	105,072,189 (14%)	75,994,662 (38%)	<0.001	54,892,802 (18%, 0.01)	126,174,048 (20%, 0.01)	0.052
Taking prescription for hypertension					<0.001			0.001
	Yes	525,105,968 (90%)	323,208,765 (85%)	201,897,203 (100%)		181,572,923 (92%, 0.00)	343,533,045 (89%, 0.01)	
	No	56,415,325 (9.7%)	56,323,327 (15%)	91,999 (<0.1%)	(	15,626,697 (7.9%, 0.00)	40,788,628 (11%, 0.01)	
Told to take prescription for cholesterol					<0.001			<0.001
	Yes	321,647,160 (54%)	216,226,496 (48%)	105,420,663 (70%)		125,260,278 (45%, 0.01)	196,386,882 (61%, 0.01)	
	No	274,970,058 (46%)	229,680,802 (51%)	45,289,257 (30%)		149,621,883 (54%, 0.01)	125,348,176 (39%, 0.01)	

Table 1 continued

Feature		n (%) or μ	n (%) or μ ACC/AHA		p_w or p_{rs}	n (%) or μ Time		p_w or p_{rs}
			BPC = Yes	BPC = No		Before 2013	After 2013	
Total of dietary supplements taken		1.60(2.87)	1.50(2.39)	1.92(4.07)	<0.001	1.81(3.39, 0.08)	1.37(2.15, 0.05)	<0.001
60 second Pulse		73(13)	73(13)	72(12)	<0.001	73(12, 0)	73(13, 0)	0.2
Depression					0.5			0.3
	Not at all	564,762,041 (77%)	438,649,251 (77%)	126,112,790 (76%)		226,275,820 (77%, 0.01)	338,486,221 (78%, 0.01)	
	Several days	118,956,474 (16%)	91,323,980 (16%)	27,632,493 (17%)		49,391,972 (17%, 0.01)	69,564,502 (16%, 0.01)	
	More than half the days	25,569,348 (3.5%)	19,342,309 (3.4%)	6,227,039 (3.8%)		9,718,671 (3.3%, 0.00)	15,850,676 (3.6%, 0.00)	
	Nearly every day	21,571,048 (2.9%)	16,233,445 (2.9%)	5,337,603 (3.2%)		9,595,602 (3.3%, 0.00)	11,975,447 (2.7%, 0.00)	
Trouble concentrating					0.6			0.027
	Not at all	615,241,415 (84%)	476,704,163 (84%)	138,537,252 (84%)		245,031,867 (83%, 0.01)	370,209,548 (85%, 0.01)	
	Several days	74,807,269 (10%)	57,863,644 (10%)	16,943,625 (10%)		30,172,298 (10%, 0.01)	44,634,971 (10%, 0.01)	
	More than half the days	20,214,029 (2.8%)	15,478,348 (2.7%)	4,735,682 (2.9%)		9,541,615 (3.2%, 0.00)	10,672,415 (2.4%, 0.00)	
	Nearly every day	20,282,978 (2.8%)	15,235,341 (2.7%)	5,047,637 (3.1%)		10,046,653 (3.4%, 0.00)	10,236,325 (2.3%, 0.00)	
Moving or speaking slowly or too fast					0.2			0.062
	Not at all	660,786,650 (90%)	513,157,321 (91%)	147,629,329 (89%)		264,647,296 (90%, 0.01)	396,139,354 (91%, 0.01)	
	Several days	45,343,801 (6.2%)	34,168,654 (6.0%)	11,175,147 (6.8%)		18,726,962 (6.3%, 0.00)	26,616,839 (6.1%, 0.00)	
	More than half the days	13,718,320 (1.9%)	10,147,728 (1.8%)	3,570,592 (2.2%)		6,372,605 (2.2%, 0.00)	7,345,715 (1.7%, 0.00)	
	Nearly every day	10,575,895 (1.4%)	7,714,173 (1.4%)	2,861,722 (1.7%)		5,152,174 (1.7%, 0.00)	5,423,721 (1.2%, 0.00)	
Number of Rooms in Home		7.77(35.37)	7.58(32.85)	8.49(43.50)	0.2	8.72(43.60, 1.37)	7.47(32.31, 0.40)	0.4
Blood ever tested for HIV					0.077			<0.001
	Yes	278,569,220 (31%)	222,348,130 (31%)	56,221,090 (29%)		94,026,028 (32%, 0.01)	184,543,192 (30%, 0.01)	
	No	598,494,955 (66%)	465,316,574 (66%)	133,178,381 (68%)		186,970,062 (63%, 0.01)	411,524,893 (68%, 0.01)	

Table 1 continued

Feature		n (%) or μ	n (%) or μ ACC/AHA		p_w or p_{rs}	n (%) or μ Time		p_w or p_{rs}
			BPC = Yes	BPC = No		Before 2013	After 2013	
Direct HDL-Cholesterol		53(17)	53(17)	51(16)	<0.001	53(18, 0)	53(16, 0)	>0.9
Monocyte count		0.59(0.22)	0.58(0.21)	0.60(0.25)	0.018	0.61(0.22, 0.00)	0.57(0.22, 0.01)	<0.001
Segmented neutrophils count		4.40(1.69)	4.38(1.64)	4.46(1.84)	0.13	4.48(1.71, 0.03)	4.34(1.67, 0.04)	0.015
Eosinophils percent		2.91(2.01)	2.87(1.98)	3.06(2.08)	0.001	2.84(1.99, 0.03)	2.96(2.02, 0.03)	<0.001
Hepatitis A antibody					0.5			0.007
	Positive	263,311,426 (36%)	206,498,723 (36%)	56,812,702 (34%)		105,413,556 (36%, 0.01)	157,897,870 (36%, 0.01)	
	Negative	473,805,172 (64%)	365,847,568 (64%)	107,957,604 (65%)		190,322,830 (64%, 0.01)	283,482,343 (64%, 0.01)	
	Indeterminate	799,915 (0.1%)	600,109 (0.1%)	199,806 (0.1%)		763,772 (0.3%, 0.00)	36,143 (<0.1%, 0.00)	
Lymphocyte percent		29(8)	30(8)	29(8)	<0.001	29(8, 0)	29(8, 0)	0.9
Platelet count		251(69)	252(68)	246(71)	<0.001	239(63, 1)	259(71, 2)	<0.001
Overweight					<0.001			<0.001
	Yes	351,645,182 (45%)	253,828,161 (42%)	97,817,021 (56%)		152,506,063 (49%, 0.01)	199,139,119 (43%, 0.01)	
	No	428,428,602 (55%)	353,020,743 (58%)	75,407,860 (44%)		160,333,524 (51%, 0.01)	268,095,079 (57%, 0.01)	
Arthritis					<0.001			0.2
	Yes	361,359,961 (38%)	255,589,473 (34%)	105,770,488 (52%)		122,092,154 (39%, 0.01)	239,267,807 (37%, 0.01)	
	No	588,912,719 (62%)	491,870,301 (66%)	97,042,418 (48%)		189,047,443 (61%, 0.01)	399,865,276 (62%, 0.01)	
Osteoporosis					0.016			0.2
	Yes		69,168,400 (9.9%)	51,939,218 (9.5%)	17,229,182 (11%)		17,838,872 (11%, 0.01)	51,329,528 (9.5%, 0.01)
	No		625,316,739 (90%)	493,493,167 (90%)	131,823,572 (88%)		139,210,441 (88%, 0.01)	486,106,297 (90%, 0.01)
Creatinine, urine		116(75)	115(76)	116(74)	0.2	119(78, 1)	114(74, 1)	0.052
Self-reported weight		394(1,515)	396(1,521)	390(1,494)	0.13	463(1,703, 25)	361(1,413, 17)	<0.001

Table 2. Linear Spline Logistic Regression Model on BP control by JNC7 and ACC/AHA Guideline

Features	JNC7			ACC/AHA		
	OR[1]	95% CI[1]	p-value	OR[1]	95% CI[1]	p-value
Race/ethnicity						
Non-Hispanic White		—			—	
Non-Hispanic Black	0.942	-0.19, 0.07	0.3	0.247	-3.5, 0.77	0.2
Non-Hispanic Asian	0.942	-0.24, 0.12	0.5	1.020	-1.6, 1.6	> 0.9
Gender						
Men		—			—	
Women	0.914	-0.22, 0.03	0.14	6.050	-0.18,3.8	0.074
Age at Screening Adjudicated	0.990	-0.01, 0.00	0.012	1.271	0.19,0.30	<0.001
Blood pressure category						
SBP $<$ 120 and DBP $<$ 80 mm Hg		—			—	
SBP of 120 to $<$ 130 and DBP $<$ 80 mm Hg	1.094	-0.23, 0.41	0.6	0.961	-3.4, 3.3	> 0.9
SBP of 130 to $<$ 140 or DBP 80 to $<$ 90 mm Hg	2.82077E-53	-121, -121	< 0.001	1.60381E-28	-70, -58	< 0.001
SBP of 140 to $<$ 160 or DBP 90 to $<$ 100 mm Hg	9.08666E-80	-183, -182	< 0.001	8.98583E-37	-90, -76	< 0.001
SBP 160+ or DBP 100+ mm Hg	9.08666E-80	-183, -181	< 0.001	6.63968E-36	-89, -74	< 0.001
Blood pressure category including antihypertensive medication use as a group						
SBP of 130 to $<$ 140 or DBP 80 to $<$ 90 mm Hg		—			—	
SBP of 130 to $<$ 140 or DBP 80 to $<$ 90 mm Hg		—			—	
SBP of 130 to $<$ 140 or DBP 80 to ¡90 mm Hg		—			—	
SBP of 130 to $<$ 140 or DBP 80 to $<$ 90 mm Hg		—			—	
SBP of 140 to $<$ 160 or DBP 90 to $<$ 100 mm Hg	3.004	0.83, 1.3	< 0.001	0.427	-4.0, 2.3	0.6
SBP 160+ or DBP 100+ mm Hg	12.182	2.2, 2.7	< 0.001	0.463	-4.0, 2.4	0.6
taking antihypertensive medications	22.198	2.9, 3.2	< 0.001	0.657	-2.1, 1.2	0.6
Diastolic blood pressure (DBP) mm Hg	1.000	0.00, 0.01	0.5	1.336	0.21, 0.37	< 0.001
Antihypertensive medication use recommended by the JNC7 guideline						
No		—				
Yes	0.003	-6.1, -5.6	< 0.001			
Systolic blood pressure (SBP) mm Hg	1.000	-0.01, 0.01	0.5	0.795	-0.28, -0.18	< 0.001
Prevalent chronic kidney disease						
No		—				
Yes	3.22134E-27	-61, -60	< 0.001			
Prevalent diabetes						
No		—				
Yes	3.22134E-27	-61, -61	< 0.001			
Apparent resistant hypertension defined by the JNC7 guideline						
No		—				
Yes	0.607	-0.66, -0.34	< 0.001			

[1] OR = Odds Ratio

CI = Confidence Interval (log(OR) Level)

Table 2 continued

Features		JNC7		ACC/AHA		
	OR[1]	95% CI[1]	p-value	OR[1]	95% CI[1]	p-value
Body Mass Index (kg/m^2)				1.020	-0.05, 0.09	0.6
ACE inhibitors						
No					—	
Yes				0.009	-7.4, -2.1	< 0.001
Aldosterone antagonists						
No					—	
Yes				6.050	-1.6, 5.2	0.3
Angiotensin receptor blockers						
No					—	
Yes				1.584	-1.8, 2.7	0.7
Thiazide or thiazide-type diuretics						No
				—		
Yes				6.050	-0.29, 3.9	0.09
Number of antihypertensive medication classes						
None					—	
One				0.301	-3.5, 1.2	0.3
Two				0.517	-3.1, 1.8	0.6
Three				7.58256E-10	-25, -17	< 0.001
Four or more				2.06115E-09	-24, -15	< 0.001
Taking prescription for hypertension						
Yes					—	
No				2.138	-0.87, 2.4	0.4
Told to take prescription for cholesterol						
Yes					—	
No				1.462	-1.5, 2.2	0.7
Pulse regular or irregular?						
Regular						
Irregular				0.905	-0.16, -0.04	< 0.001
Total of Dietary Supplements Taken				1.127	0.08, 0.16	< 0.001
Direct HDL-Cholesterol (mg/dL)				1.010	-0.03, 0.04	0.6
Monocyte number (1000 cells/uL)				1.259	-2.1, 2.5	0.8
Eosinophils percent (%)				0.651	-0.72, -0.14	0.004
Lymphocyte percent (%)					-0.05, 0.04	0.9
Platelet count (1000 cells/uL)					-0.01, 0.01	0.5
Doctor ever said you were overweight						
Yes					—	
No				0.795	-1.6, 1.1	0.7
Doctor ever said you had arthritis						
Yes					—	
No				0.202	-3.1, -0.08	0.039
Linear spline term						
knot: Pre-2013	0.878	-0.28, 0.03	0.1	12.182	0.44, 4.5	0.018
knot: Post-2013	0.86	-0.30, 0.01	0.062	8.166	0.22, 3.9	0.028

[1] OR = Odds Ratio CI = Confidence Interval (log(OR) Level)