RACIAL DISPARITIES IN BLOOD PRESSURE CONTROL AND IMPLICATIONS OF HYPERTENSION GUIDELINES

by
Kathryn Foti

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Abstract

This dissertation examines key issues for improving hypertension management and the implications of recent guidelines for cardiovascular health and disparities. We used multiple data sources and study designs to inform our public health recommendations.

First, we examined trends in hypertension awareness, treatment, and control from 1999 to 2016 using National Health and Nutrition Examination Survey (NHANES) data. Awareness, treatment, and control increased overall, but primarily between 1999 and 2010. Hypertension treatment to control was lower among Blacks than whites. There were gaps at all stages of care among younger Hispanics.

Second, clinical guidelines emphasize accurate blood pressure (BP) measurement for hypertension diagnosis and treatment. Rounding measurements to zero is a common source of error. We used National Disease and Therapeutic Index data from 2014 to 2018 to examine BP measurements at physician office visits by adults aged ≥18 with treated hypertension. The proportion of measurements ending in zero remains high, despite modest decreases among systolic (43.0% to 38.1%) and diastolic (44.3% to 39.4%) BP measurements.

Third, we examined changes in hypertension control from 2011-2013 to 2016-2017 among white and Black older adults with treated hypertension in the Atherosclerosis Risk in Communities Study. At baseline, 75.4% of whites and 66.0% of Blacks had controlled hypertension. While changes were similar by race, Blacks with diabetes or reduced kidney function were less likely to be controlled at follow up. Higher BP goals recommended in 2014 for older adults and those with diabetes and chronic kidney disease may contribute to these findings and differences by race.

Finally, we calculated the proportion of cardiovascular events which could be prevented if hypertension was treated to the 2017 guideline target (<130/80 mmHg). Using NHANES data and parameters from the literature, we estimated 29.0% of events among Blacks and 21.0% of

events among whites could be prevented. However, intensive efforts may be required to achieve this BP goal.

Our findings highlight implementation considerations. Recommended BP measurement procedures can be difficult to incorporate into the clinical workflow. Controversy and confusion regarding conflicting guidelines may have unintended consequences for patients at increased cardiovascular risk and contribute to cardiovascular health disparities.

Dissertation Readers

Elizabeth Selvin, PhD, MPH; Co-Adviser
Professor of Epidemiology and Medicine

Lawrence J. Appel, MD, MPH; Co-Adviser
C. David Molina, MD, MPH Professor of Medicine
with Joint Appointments in Epidemiology, International Health and Nursing

Josef Coresh, MD, PhD
George W. Comstock Professor of Epidemiology
with Joint Appointments in Biostatistics and Medicine

Joanna Cohen, PhD
Bloomberg Professor of Disease Prevention
Professor of Health, Behavior and Society and Medicine

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Kathryn Foti
Baltimore, Maryland

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List of Acronyms

ACC	American College of Cardiology
AHA	American Heart Association
ARIC	Atherosclerosis Risk in Communities Study
BMI	Body mass index
BP	Blood pressure
CES-D	Center for Epidemiologic Studies Depression scale
CI	Confidence interval
CKD	Chronic kidney disease
CKD-EPI	Chronic Kidney Disease Epidemiology Collaboration
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
eGFR	Estimated glomerular filtration rate
JNC7	Seventh Joint National Committee
JNC8	Eighth Joint National Committee
MCI	Mild Cognitive Impairment
NDTI	National Disease and Therapeutic Index
NHANES	National Health and Nutrition Examination Survey
OR	Odds ratio
PAF	Population attributable fraction
PIF	Population impact fraction
SBP	Systolic blood pressure
SPPB	Short Physical Performance Battery
SPRINT	Systolic Blood Pressure Reduction Intervention Trial
US	United States

Introduction

Improving the prevention and management of high blood pressure is a leading public health challenge and an issue for health equity. Hypertension has been described as one of the most important risks to the cardiovascular health of African Americans and also one of the greatest opportunities for disease prevention if effectively managed and prevented.[1] This dissertation focuses on understanding trends in hypertension management by population subgroup and the implications of recent hypertension guidelines for racial disparities in cardiovascular health.

Disparities in the burden of hypertension in the U.S.

High blood pressure is a leading modifiable risk factor for cardiovascular disease, the top cause of death in the U.S. and around the world.[2] Hypertension (blood pressure >140/90 mmHg) affects nearly one-third of all U.S. adults. The prevalence of hypertension is significantly and persistently higher among non-Hispanic Blacks in the U.S. than other racial/ethnic groups. In 2015-2016, 40.6% of non-Hispanic Black adults ages 18 and older had hypertension as compared with 27.8% of non-Hispanic whites.[3]

Among U.S. adults with hypertension, only about half have their blood pressure controlled (<140/90 mmHg), a proportion which has not changed since 2010.[3] Hypertension control is significantly lower among non-Hispanic Blacks than non-Hispanic whites (44.6% vs 50.8% in 2015-2016).[3]

Racial disparities in hypertension prevention and control contribute to longstanding disparities in cardiovascular health outcomes, such as coronary heart disease, stroke, heart failure, chronic kidney disease, and deaths from these conditions.[4–7]

The role of health care in health equity

Racial disparities in hypertension emerge at a young age, highlighting the importance of primordial prevention to reduce disparities in the incidence of hypertension.[1,8] Racial disparities in hypertension control and blood pressure-related outcomes, despite comparable levels of awareness and treatment of hypertension among whites and blacks, suggests a role for health care in addressing disparities,[1] which is the focus of this dissertation, recognizing it is necessary to address the underlying historical, political, and social determinants of health to truly achieve equity.[1,9]

Health care systems with racially and ethnically diverse patient populations and in diverse practice settings have demonstrated it is possible to increase hypertension control to 70% and higher.[10–13] Certain health systems have implemented interventions which resulted in comparable increases in hypertension control across racial/ethnic groups, which we would expect to have greater benefits for those at higher risk of cardiovascular disease, though identifying interventions which effectively eliminate disparities in hypertension control is an area of current investigation.[10]

Common elements of interventions which have improved blood pressure control include standardizing blood pressure measurement procedures and implementing guideline-driven protocols for hypertension treatment. We focus on blood pressure measurement and clinical practice guidelines, and their implications for equity, in the discussion which follows.

Blood pressure measurement

Accurate blood pressure measurement is central to the diagnosis and management of hypertension and its importance is emphasized universally in clinical practice guidelines. However, accurate and reliable assessment of an individual's blood pressure is challenging. Blood pressure is inherently variable and variability is further increased when health care providers do not follow standardized measurement procedures,[14] which can be difficult to implement in routine clinical practice.[15,16] Inaccurate measurement may result in under- or overtreatment of patients with hypertension, and may be an overlooked barrier to improving control of hypertension as providers are more likely to take action on credible high blood pressure measurements.[17,18]

Therefore, it is important to quantify blood pressure measurement error. One common form of systematic measurement error which can easily be assessed in clinical quality improvement programs is terminal digit bias, or a preference by the observer to round measurements to a specific end digit, most commonly zero.[19] It is possible terminal digit preference has been reduced in recent years as a result of increased use of automated blood pressure devices, which eliminate certain sources of error which can occur during auscultatory blood pressure measurement, and national initiatives to improve hypertension control which have included a focus on measurement. We examined trends in terminal digit preference as an indicator of blood pressure measurement quality in the U.S.

Hypertension treatment recommendations in recent guidelines

Evidence-based guidelines promote consistency, objectivity, and accountability, which also affects equity of care.[20] However, physician do not always adhere to clinical practice guidelines.[21] Thus, while there is the potential for guideline-driven care to reduce disparities, there is also the potential to perpetuate or exacerbate disparities if clinical practice guidelines are not implemented consistently.

There have been three guidelines published in the past two decades with different recommendations for the management of hypertension (**Table 1**). The Seventh Joint National Committee (JNC) on the Prevention, Detection, Evaluation, and Management of Hypertension published a comprehensive guideline in 2003, which was the standard of care for many years.[22] The JNC7 guideline recommended a treatment goal of <140/90 mmHg for patients with hypertension and <130/80 mmHg for those with diabetes or chronic kidney disease.[22] In February 2014, panel members of the eighth JNC published a report which recommended treatment goals of <140/90 mmHg for patients <60 years of age and <150/90 mmHg for patients ≥60 years of age, as well as those patients with diabetes or CKD.[23]

In 2017, the American College of Cardiology (ACC) and the American Heart Association (AHA) published a new guideline which redefined hypertension as blood pressure ≥130/80 mmHg and recommended treatment to <130/80 mmHg for all patients on medication.[16]

Potential impact of recent hypertension guidelines on racial/ethnic disparities

The potential impact of recent hypertension guidelines on racial/ethnic disparities has been the subject of debate. Following the release of the 2014 guideline, a minority of the Association of Black Cardiologists and several of the guideline authors expressed concern about raising the threshold for treatment initiation and treatment goal from 140/90 to 150/90 mmHg among those aged ≥60 without diabetes or chronic kidney disease. In addition to concerns about the standard of evidence used to inform this recommendation, they cited concerns about potential harms among individuals at increased risk for cardiovascular disease, including African Americans, individuals with a history of cardiovascular disease, and those with risk factors for cardiovascular disease other than diabetes and chronic kidney disease.[24,25]

The 2017 ACC/AHA guideline, which recommends a lower blood pressure treatment goal regardless of age or comorbidity status could have a large impact on overall cardiovascular health in the population. One recent modeling study found achieving the 2017 ACC/AHA guideline systolic blood pressure treatment goal could avert 610,000 cardiovascular events (340,000 more than the 2014 guideline) and 334,000 all-cause deaths (156,000 more than the 2014 guideline) among US adults aged 40 years and older.[26]

Implementation of the 2017 ACC/AHA guideline recommendations would be expected to result in greater benefit for subgroups, including African Americans, with higher blood pressures. However, the guideline has not been endorsed by certain primary care societies and there are concerns about feasibility of implementation.[27] The extent to which the guideline is currently being followed is unknown. There is the potential to exacerbate disparities if lower blood pressure treatment goals are implemented differentially, such as more complete implementation among those with greater access to care or who are already better managed.

To increase understanding of the implications of recent guideline changes for racial disparities in hypertension control and cardiovascular disease outcomes, we used observational data to examine changes in hypertension control before and after publication of the 2014 guideline and conducted a modeling study to assess the potential impact of the 2017 guideline.

Study aims

This dissertation was intended to address key issues related to improving hypertension management in the population and reducing racial disparities through the following specific aims:

Aim 1. To examine national trends in hypertension prevalence, awareness, treatment, and control from 1999-2016 among U.S. adults by age, sex, and race/ethnicity.

Aim 2. To evaluate terminal digit preference in blood pressure measurement and its trends among a nationally representative sample of office-based hypertension treatment visits for adults.

Aim 3. To examine changes in hypertension control before and after publication of the 2014 hypertension guideline among a community-based cohort of Black and white older adults with treated hypertension.

Aim 4. To investigate the theoretical impact of the 2017 ACC/AHA guideline on racial disparities in cardiovascular health outcomes using a simulation study.

Dissertation structure

This dissertation includes four chapters dedicated to the study aims and an overarching conclusion section. Each of the chapters is formatted as a publishable manuscript. Chapter 1 describes trends in hypertension prevalence, awareness, treatment, and control and was published in the *American Journal of Epidemiology.*[28] Chapter 2 quantifies terminal digit preference in blood pressure measurements obtained at office visits for hypertension treatment. Chapter 3 examines changes in hypertension control before and after the 2014 hypertension guideline among Black and white older adults with treated hypertension. Chapter 4 examines the potential impact of implementing the 2017 ACC/AHA guideline recommendations for hypertension treatment on cardiovascular events by race. Additional methodologic detail for each aim can be found the Supplement. Finally, the Conclusion provides a synthesis of our findings and proposes next steps for further research and public health action.

Table 1. Guideline-recommended blood pressure levels for initiation of pharmacotherapy and goal blood pressure among those treated with pharmacotherapy.

	JNC7 (2003)		JNC8 (2014)		ACC/AHA (2017)	
Population	**Initiation**	**Goal**	**Initiation**	**Goal**	**Initiation**	**Goal**
General population	≥140/90	<140/90	≥140/90	<140/90	≥140/90	<130/80
Diabetes or CKD	≥130/80	<130/80	≥140/90	<140/90	≥130/80	<130/80
Age ≥60 yrs without diabetes or CKD	*	*	≥150/90	<150/90	*	*
Age ≥65 yrs	*	*	*	*	≥130	<130
High CVD risk[†]	*	*	*	*	≥130/80	<130/80

*Not addressed. [†]10-year CVD risk ≥10% by the Pooled Cohort Equations. CVD = Cardiovascular Disease. CKD= Chronic Kidney Disease. JNC7= Seventh Joint National Committee. JNC8 = Eight Joint National Committee. Not addressed indicates other thresholds listed from the pertinent guideline should be applied as appropriate. Adapted from Muntner et al. *Circulation*. 2018;137:109-118.[29]

Chapter 1. Hypertension awareness, treatment and control in US adults: Trends in the hypertension control cascade by population subgroup (NHANES 1999–2016)

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Co-authors: Dan Wang, Lawrence J. Appel, Elizabeth Selvin

ABSTRACT

Examining changes in the hypertension awareness, treatment and control (i.e., the hypertension control cascade) by population subgroup can inform targeted efforts to improve hypertension control and reduce disparities. We analyzed data from the 1999-2016 National Health and Nutrition Examination Survey and examined trends across 6-year periods in hypertension awareness, treatment, and control by age, sex and race/ethnicity. We included 39,589 participants (16,141 with hypertension). Hypertension awareness, treatment, and control increased from 1999 to 2016 among all age groups. However, there were few changes after 2010. Across all time periods, awareness, treatment, and control were higher among younger women (versus younger men), while control was higher among older men (versus older women). Hypertension control was persistently lower for blacks than whites of all ages, and awareness, treatment, and control were lower among younger Hispanics. There have been few changes in hypertension awareness, treatment, and control since 2010. Disparities in hypertension control by sex highlight the need for effective interventions among younger men and older women. Concerted efforts are also needed to reduce persistent racial/ethnic disparities, particularly to improve treatment to control among blacks and further address gaps at all stages among younger Hispanics.

INTRODUCTION

Hypertension (blood pressure ≥140/90 mm Hg) is a leading modifiable risk factor for cardiovascular disease, the leading cause of death in the United States and globally.[1] Further, there are longstanding racial/ethnic disparities in cardiovascular risk factors, particularly hypertension.[2]

The hypertension control cascade, which includes hypertension awareness, treatment, control, has been proposed as a framework for improving blood pressure control in the population.[3] The proportion of adults with hypertension who have their blood pressure controlled (<140/90 mmHg) increased from the late 1990s through 2010 due to both increases in awareness of hypertension and treatment to control among those treated.[4,5]

However, national data show there has been no change since, and currently, less than less than half of all US adults with hypertension have their blood pressure controlled.[6] This plateau has occurred despite increased knowledge of effective strategies at the organization, provider, and patient levels to improve control of hypertension.[7] Communities[5] and health systems[8] around the country have demonstrated it is possible to achieve much higher rates of blood pressure control and with concerted efforts, it should be possible to reach 70% hypertension control in the population.[9]

It is unclear whether the recent lack of progress in hypertension control is attributable to a lack of progress at a particular stage in the cascade, nor whether patterns are uniform across major demographic groups. Previous research has shown that barriers to hypertension control differ age, sex, and race/ethnicity.[3,10] Additionally, there are a number of contextual changes which may have influenced approaches to hypertension management for different patient subgroups in recent years. Such changes include increases in the prevalence of obesity and diabetes, expanded insurance coverage, and the publication of multiple clinical practice guidelines for hypertension.[11–14]

Understanding changes over time in hypertension awareness, treatment, and control overall and among different subpopulations can inform targeted efforts to improve hypertension management and reduce disparities. We conducted serial cross-sectional analyses among participants in the 1999–2016 National Health and Nutrition Examination Survey (NHANES), the most recent national data available, to better understand changes in the hypertension control cascade over time overall and by subgroup.

METHODS

Data source

NHANES is a population-based survey which uses stratified, multistage probability sampling to produce nationally representative estimates for the civilian, noninstitutionalized population in the US. The survey includes interview and examination components. Since 1999, NHANES data have been released in 2-year data cycles. We analyzed data from 1999–2016.

Study population

There were 41,511 non-pregnant adults aged ≥25 years who completed the examination component of the survey. Participants who did not have at least one blood pressure measurement or for whom hypertension status could not be determined (N=2,096) were excluded from all analyses. Those with missing data for hypertension status were more likely to be aged 25–44 or ≥65 (versus in the middle age category), female (versus male), and non-Hispanic black, Hispanic, or Other race/ethnicity (versus non-Hispanic white) compared with those for whom hypertension status could be determined. The final analytic sample included 39,589 participants.

Primary exposure

Blood pressure measurements were obtained during the NHANES examination by trained physicians using a standard study protocol.[15] After the participant rested in a seated position for 5 minutes, 3 consecutive auscultatory blood pressure readings were obtained using a mercury sphygmomanometer and appropriately sized blood pressure cuff. If a blood pressure measurement was interrupted or incomplete, a fourth attempt was made. All available blood pressure readings (i.e., up to three measurements) were used to calculate mean systolic and diastolic blood pressures.[16] Hypertension was defined as mean systolic blood pressure ≥140 mmHg, or mean diastolic blood pressure ≥90 mmHg, or currently taking antihypertensive medication.

Outcome assessment

Among those with hypertension, hypertension awareness was defined based on response to the question, *"Have you ever been told by a doctor or health professional that you had hypertension, also called high blood pressure?"* Hypertension treatment was defined as self-reported current antihypertensive medication use based on responses to the questions, *"Because of your high blood pressure/hypertension, have you ever been told to take prescribed medicine?"* and *"Are you now taking prescribed medicine for high blood pressure?"* Hypertension control was defined as blood pressure <140/90 mmHg; we assessed hypertension control among all those with hypertension and among those who reported antihypertensive medication use. We also examined blood pressure levels over time among those with hypertension and those with treated hypertension in mutually exclusive categories: <130/80 mmHg, 130/80 to <140/90 mmHg, 140/90 to <150/90 mmHg, or ≥150/90 mmHg.

Statistical analyses

Because hypertension prevalence varies by age, analyses were stratified by age, categorized as: 25–44, 45–64, or ≥65 years. We combined data into 6-year periods to obtain more statistically stable estimates within subpopulations defined by age, sex, and/or race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic). We estimated the prevalence of hypertension, and among those with hypertension, the prevalence of awareness, treatment, and control, as well as control among those treated. All analyses were weighted to account for the complex survey design and produce results generalizable to the U.S. population aged 25 or older. We obtained standard errors using the Taylor series (linearization) method.

Within age groups, we used linear regression models with an indicator variable for survey cycle to assess absolute changes in prevalence in the periods 2005–2010 or 2011–2016 compared to 1999–2004. We used a linear combination of regression coefficients to compare estimates for 2005–2010 to the 2011–2016 period. We included interaction terms to assess whether differences by sex or race/ethnicity changed over time. In supplemental analyses, we also examined trends by 2-year survey cycles. We used chi-square tests to examine changes across periods by age group in the proportion of those with hypertension and those with treated hypertension with blood pressure <130/80 mmHg, 130/80-<140/90 mmHg, 140/90-<150/90 mmHg, or ≥150/90 mmHg. Participant blood pressure was categorized using the highest category of systolic or diastolic blood pressure.

To examine trends in hypertension control before and after adjustment for other individual characteristics, we used logistic regression to obtain predictive margins. Within age groups, we calculated the unadjusted prevalence of hypertension control and compared the prevalence of hypertension control across time periods using prevalence ratios. We sequentially adjusted for demographic characteristics (sex, race/ethnicity, age within age group), clinical characteristics (body mass index (BMI) and self-reported diabetes), access to care (insurance coverage and having a usual source of care), and hypertension awareness. Additionally, among those who were aware of their hypertension, we adjusted for duration of hypertension. Duration of hypertension was calculated based on the participant's current age and the age at which they were told they had hypertension. Information on duration of hypertension is available for 2007 onward; for this analysis, we compared hypertension control in 2011–2016 to 2007–2010.

All analyses were conducted in Stata version 15.1 (StataCorp, College Station, TX) using the *svy* command package to account for the complex survey design. We used a 2-sided p-value of 0.05 to define statistical significance. NHANES was approved by the National Center for Health Statistics Institutional Review Board and informed consent was obtained from all participants.

RESULTS

There were 39,589 participants (16,141 with hypertension) included in our analysis. During the study period, there was no significant change in hypertension prevalence in any age group (**Figure 1, Web Table 1**).

From 1999–2004 to 2011–2016, hypertension awareness, treatment, and control increased significantly among all age groups. However, changes primarily occurred between 1999–2004 and 2005–2010. Hypertension awareness, treatment, and control significantly increased from 1999–2004 to 2005–2010 among those ages 45–64 and ≥65. The only significant changes from 2005–2010 to 2011–2016 were increases in awareness among those aged 25–44 and ≥65. Meanwhile, supplemental analyses examining data in 2-year survey cycles showed that there was a significant decrease in hypertension control among those aged ≥65 from 2013–2014 to 2015–2016 (-8.2%). There were also significant decreases in hypertension control among those treated from 2013–2014 to 2015–2016, for those aged 25–44 (-10.3%) and aged ≥65 (-8.1%) (**Web Table 2**).

Hypertension control cascade by age group and sex

Among those aged 25–44, hypertension prevalence was significantly lower among women than men in all time periods, though this difference was attenuated in the last survey period (**Web Table 3, Figure 2**). However, across all survey periods, hypertension awareness, treatment, and control were higher among women than men aged 25-44. Hypertension control among those treated was also higher among women than men but this difference was not statistically significant.

For those aged 45–64, hypertension prevalence was lower among women than men in 2011–2016 (38.2% vs. 43.3%), a significant change from 1999–2004 when there was no difference in hypertension prevalence. Hypertension awareness, treatment, and control increased among both men and women during the full study period among those aged 45–64. Nonetheless, women had higher levels of awareness, treatment, and control in 2005–2010 and 2011–2016. Among women aged 45–64, hypertension control and control among those treated significantly increased in both survey periods, and the sex difference in hypertension control and treatment to control was larger in 2011–2016 versus 1999–2004.

Among those aged ≥65, the prevalence of hypertension was higher among women than men in all periods, though the sex differences were smaller in 2005–2010 and 2011–2016 than in 1999–2004. Hypertension awareness, treatment, and control increased among both men and women aged ≥65 from 1999–2004 to 2011–2016; however, changes primarily occurred from 1999–2004 to 2005–2010. There were no sex differences in awareness or treatment, but hypertension control and control among those treated were lower among women than men aged ≥65 in all time periods.

Hypertension control cascade by age group and race/ethnicity

Hypertension prevalence was significantly and consistently higher among blacks than whites in all age groups and across all survey cycles (**Web Table 4, Figure 3**). Awareness and treatment were also higher among blacks than whites aged 45–64 and ≥65 at the start of the study period, but there were greater increases in awareness and treatment among whites. By 2011–2016, differences in awareness and treatment by race were no longer statistically significant despite the overall higher prevalence of hypertension in blacks.

Hypertension control and control among those treated were generally lower for blacks than whites aged 25–44 and 45–64 for the duration of the study period. Among those aged ≥65, hypertension control was significantly lower among blacks than whites in 2011–2016, while control among those treated was generally lower throughout the study.

Meanwhile, hypertension prevalence was generally similar among Hispanic and white adults. Hypertension awareness, treatment, and control were lower among Hispanics than whites aged 25–44, though there were increases among younger Hispanics between 2005–2010 and 2011–2016. Hypertension control and control among those treated were generally lower for Hispanics than whites of all ages.

Blood pressure levels by age group

In all age groups, there were differences in the distribution of blood pressure levels among those with hypertension and treated hypertension during the overall study period (**Table 1**). Among those aged 25–44 and 45–64, there were favorable changes from 1999-2004 to 2005–2010. The only statistically significant change between 2005–2010 and 2011–2016 was among those aged 45–64 with treated hypertension.

Trends in hypertension control before and after adjustment for participant characteristics

Within age groups, there was little change in the prevalence ratios for hypertension control comparing 2005–2010 to 1999–2004, 2011–2016 to 1999–2004, or 2011–2016 to 2005–2010 after adjusting for demographic factors, clinical characteristics, access to care, or hypertension awareness (**Web Table 5**). Among those who were aware of their hypertension, additionally adjusting for duration of hypertension did not change the prevalence ratios for hypertension control comparing 2011–2016 to 2007–2010 (**Web Table 6**).

DISCUSSION

Our investigation of the hypertension cascade by population subgroup showed hypertension awareness, treatment, and control increased during the study period, but improvements at each stage of the cascade primarily occurred from 1999–2004 to 2005–2010. There were few changes at any stage of the cascade after 2010 for any population subgroup. Meanwhile, hypertension prevalence remained stable over time across age groups. However, we observed persistent disparities among certain population subgroups. Namely, the prevalence of hypertension was higher among blacks than whites, among younger men than women, and among older women than men.

Although the proportion of those with hypertension who are aware and treated has increased and there is less room for improvement, the lack of recent change highlights the need to implement strategies to detect and initiate treatment among those with hypertension. Consistent with previous studies, we found awareness of hypertension is lower among younger than middle or older age populations, and particularly low among younger men, which may due to lower healthcare utilization.[17] Additionally, among those with self-reported hypertension, black and Hispanic adults are more likely than whites to be uninsured, lack a regular doctor or health care provider, and to report being unable to visit a doctor because of cost[18] which may account for the lower prevalence of awareness in these groups.

Treatment to control remains a major barrier at the population-level and indeed, there is a substantial drop off in the hypertension cascade at this stage. In particular, treatment to control is a major barrier among adults aged ≥65. Additionally, we observed non-significant decreases in control and control among those treated from 2005–2010 to 2011–2016 among blacks and women aged ≥65. Based on the distribution of blood pressure levels, there is a suggestion of potential deintensification of treatment among adults aged ≥65 in the 2011–2016 period, which may reflect 2014 guideline recommendations that adults aged 60 and older without comorbidities be treated to <150/90 mmHg rather than <140/90 mmHg (see **Web Table 7** for guideline-recommended hypertension treatment goals over time). As NHANES data are cross-sectional, we cannot determine whether any change in the proportion of people with blood pressure between 140/90 and 150/90 mmHg is the result of treatment deintensification among those with previously lower blood pressure values or improved treatment among those with higher blood pressure values. Our findings warrant further investigation as there is limited research to date on changes in clinical practice before and after the 2014 guideline[19] and the potential implications for disparities.

Sex differences in hypertension control at younger ages (more favorable for women vs. men) and older ages (more favorable for men vs. women) persisted during the study period. However, we found that sex differences in hypertension prevalence changed over time. The difference in hypertension prevalence narrowed during the study period among those aged 25–44 (higher prevalence among men than women) and among those aged ≥65 (higher prevalence among women than men). Among those 45–64, we found that hypertension prevalence increased among men, but not among women. Additionally, we observed a greater increase in hypertension control and control among those treated for women aged 45–64 than men. To our knowledge, these changes by sex have not been reported previously. Additional studies are needed to understand sex differences in treatment patterns and facilitators and barriers to hypertension control by age and sex.

The only narrowing of black-white disparities we observed was whites catching up to blacks in terms of awareness and treatment of hypertension among those aged 45–64 and ≥65. In addition, despite some progress from 2005–2010 to 2011–2016, younger Hispanics had persistently lower rates of hypertension treatment, control, and control among those treated. Among Hispanic adults, the hypertension control cascade may vary by Hispanic/Latino background.[20] Increased understanding of the hypertension cascade by origin, level of acculturation, preferred language, and other factors are needed to inform culturally-appropriate interventions to improve blood pressure control.

Despite population-level changes during the study timeframe, we did not find that factors such as obesity, diabetes, insurance coverage, or duration of hypertension explained the stall in improving hypertension control. Additionally, education campaigns to warn about the dangers of high blood pressure have not led to improvements in hypertension control in the population. In the setting of health disparities, it is well-known that targeted efforts are required to achieve health equity.[21] Targeted efforts in clinical care will be required to reduce observed differences in hypertension control by population subgroups.[22] Special efforts will be needed to reach younger men and younger non-white individuals who access care less often than their respective counterparts, but most patients with uncontrolled hypertension have insurance and access the health care system.

In 2017, the American College of Cardiology (ACC) and American Heart Association (AHA) released an updated guideline for the prevention, detection, evaluation, and management of high blood pressure among adults.[23] This guideline redefines hypertension at a lower level of blood pressure (≥130/80 mmHg) and recommends treatment to a lower level of blood pressure (<130/80 mmHg) for all population subgroups. If clinical and public health efforts actually achieve the lower threshold of <130/80 mmHg, the guideline will also increase hypertension awareness, treatment, and control to the surveillance definition of <140/90 mmHg. Although some professional societies have not endorsed the more stringent treatment goal,[24,25] it is important to highlight that even by the higher threshold of <140/90 mmHg, many adults have uncontrolled hypertension. It is also important that the new guideline is broadly implemented across population subgroups to reduce rather than exacerbate disparities in hypertension control.

Our study has several limitations. First, because we combined data into 6-year periods to improve the stability of prevalence estimates by population subgroup, there may have been contextual changes that led to changes in hypertension management on a smaller timescale than was our focus. Our supplemental analyses using 2-year data cycles provide some information on changes which occurred within the broader 6-year periods used in the main analysis. Second, information on awareness and treatment of hypertension is based on self-report, and there may be reporting biases. Third, we are not able to ascertain hypertension treatment with lifestyle modification, which may be recommended prior to pharmacotherapy. Fourth, we were unable to report data for other racial/ethnic groups due to limited sample sizes, nor were we able to report data by Hispanic/Latino origin. Our study also has a number of strengths including the large study population, standardized blood pressure measurements, and nationally representative study design.

Conclusion

There has been no change in hypertension control overall since 2010, and since then, there have been few changes at any stage of the hypertension cascade overall or by age group. Thus, barriers to achieving hypertension control and reducing disparities remain. Among younger populations, particularly among men and Hispanics, there are gaps in awareness and treatment. For most subpopulations, however, the largest drop off in the hypertension cascade is from treatment to control. Further, there are disparities in treatment to control by sex and race/ethnicity, including for older women as compared to older men and for black and Hispanic adults of all ages as compared to their white counterparts. Persistent disparities illustrate hypertension remains a priority health equity issue. Targeted, culturally-appropriate approaches to address barriers at specific stages of the hypertension cascade by population subgroup, as well as broader efforts to prioritize hypertension control in clinical practice, are needed to resume improvements in hypertension control and reduce disparities in cardiovascular health in the US.

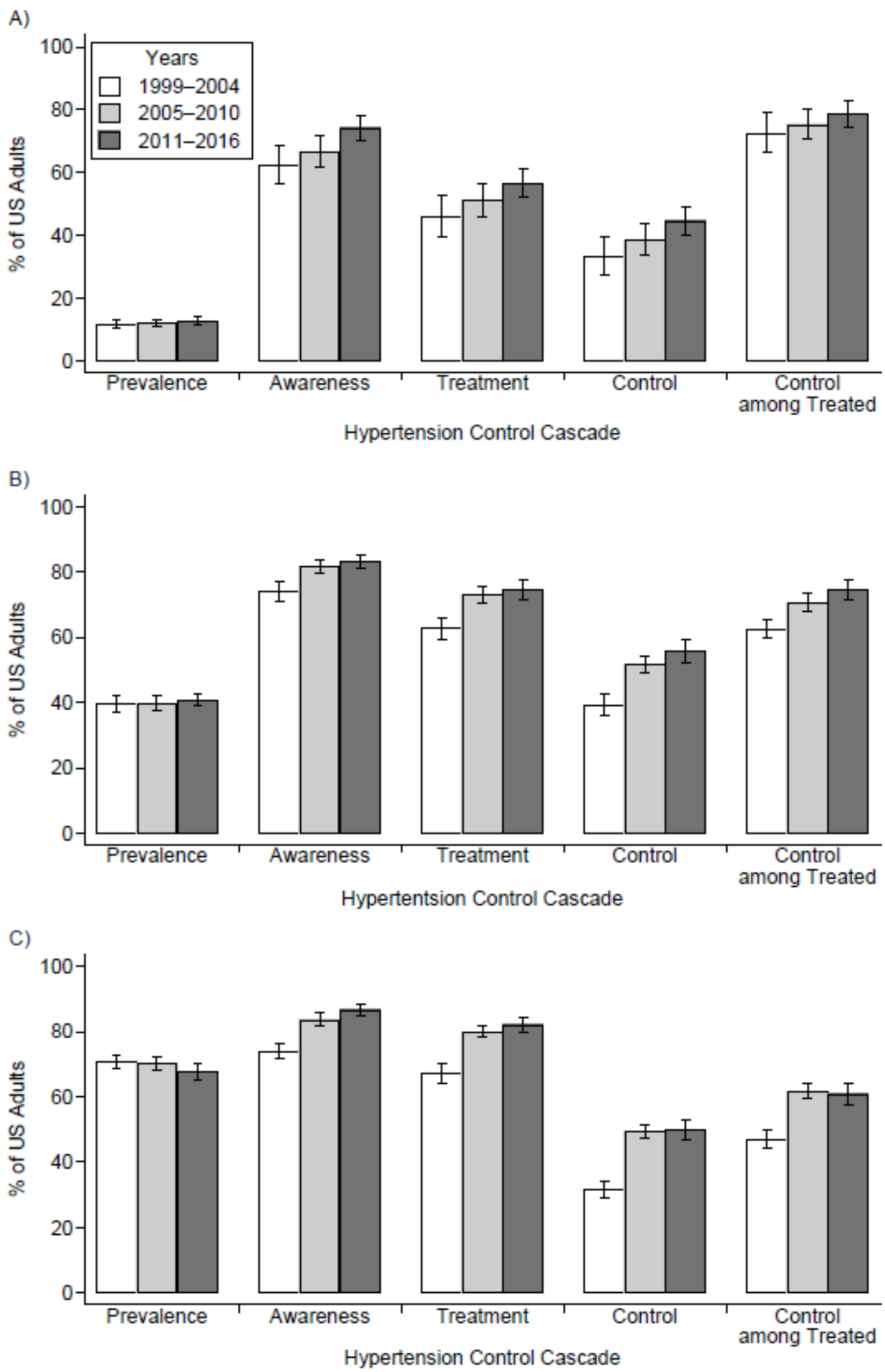
TABLES

Table 1. Blood Pressure Levels Among All Those With Hypertension and Treated Hypertension by Age Group – US Adults Aged ≥25, National Health and Nutrition Examination Survey 1999–2016.

	1999–2004	2005–2010	2011–2016	*P* value for χ^2		
	(1)	(2)	(3)	(2) vs (1)	(3) vs (2)	(3) vs (1)
Age and Blood Pressure	**Among Those with Hypertension, % (SE)**					
25–44				0.23	0.14	<0.001
<130/80	15.3 (1.8)	21.2 (1.9)	28.4 (2.2)			
140/90	18.2 (2.2)	17.4 (1.9)	16.2 (1.8)			
150/90	18.2 (2.2)	18.8 (2.2)	16.8 (1.8)			
≥150/90	48.2 (3.3)	42.7 (2.9)	38.6 (2.3)			
45–64				<0.001	0.13	<0.001
<130/80	22.2 (1.2)	32.3 (1.4)	37.2 (1.8)			
140/90	17.1 (1.1)	19.5 (1.1)	18.4 (1.3)			
150/90	19.4 (1.4)	19.5 (1.2)	17.1 (1.4)			
≥150/90	41.3 (1.8)	28.8 (1.2)	27.2 (1.4)			
≥65				<0.001	0.65	<0.001
<130/80	17.2 (1.1)	31.3 (1.1)	31.6 (1.5)			
140/90	14.3 (0.8)	18.0 (0.9)	18.3 (1.1)			
150/90	21.1 (0.9)	20.0 (1.0)	21.4 (1.1)			
≥150/90	47.2 (1.5)	30.7 (1.0)	28.7 (1.4)			
	Among Those with Treated Hypertension, % (SE)					
25–44				0.34	0.14	0.002
<130/80	33.1 (3.2)	41.3 (2.7)	50.2 (3.3)			
140/90	39.5 (3.4)	34.0 (3.1)	28.6 (2.9)			
150/90	7.3 (1.8)	6.7 (1.6)	4.1 (1.1)			
≥150/90	20.0 (2.9)	18.0 (2.1)	17.1 (1.9)			
45–64				<0.001	0.03	<0.001
<130/80	35.3 (1.6)	44.1 (1.6)	49.9 (2.0)			
140/90	27.2 (1.4)	26.6 (1.5)	24.7 (1.6)			
150/90	11.1 (1.1)	13.0 (0.8)	9.3 (1.1)			
≥150/90	26.3 (1.5)	16.3 (1.2)	16.1 (1.1)			
≥65				<0.001	0.83	<0.001
<130/80	25.8 (1.5)	39.2 (1.3)	38.5 (1.7)			
140/90	21.4 (1.1)	22.5 (1.1)	22.3 (1.3)			
150/90	15.6 (0.9)	14.7 (0.8)	16.1 (1.1)			
≥150/90	37.2 (1.4)	23.6 (0.9)	23.1 (1.3)			

FIGURES

Figure 1. Hypertension Prevalence, Awareness, Treatment, Control and Control Among Those Treated by Age Group – US Adults Aged ≥25, National Health and Nutrition Examination Survey 1999–2016.

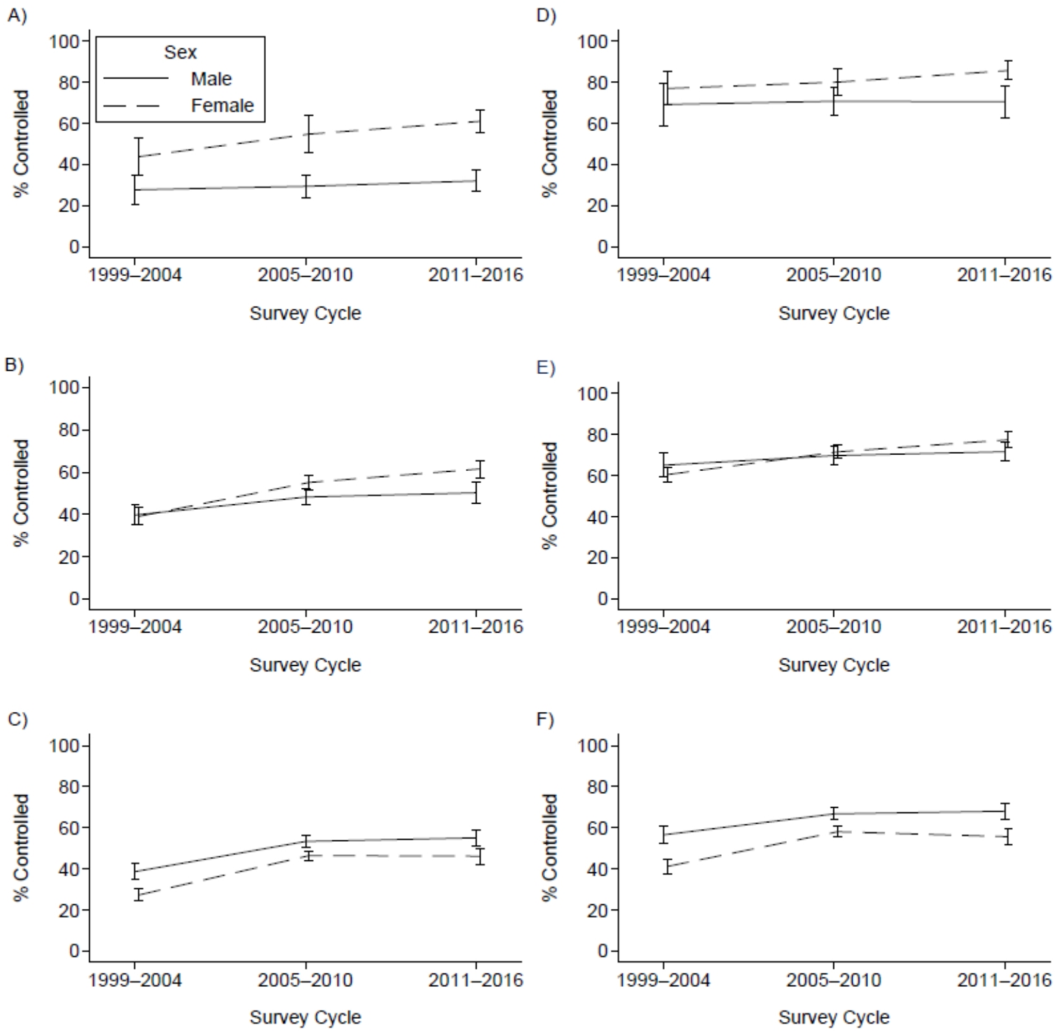


A) US Adults Aged 25–44. Among those with hypertension, hypertension awareness was significantly higher ($P<0.05$) in 2011–2016 as compared to 1999–2004 and 2005–2010. Hypertension treatment was significantly higher in 2011–2016 as compared to 2005–2010. Hypertension control was significantly higher in 2011–2016 as compared to 2005–2010.

B) US Adults Aged 45–64. Among those with hypertension, hypertension awareness, treatment, control, and control among those treated were significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004.

C) US Adults Aged ≥65. Among those with hypertension, hypertension awareness was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004, and higher in 2011–2016 as compared to 2005–2010. Hypertension treatment, control, and control among those treated were significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004.

Figure 2. Hypertension Control (Left) and Control Among Those Treated (Right) by Age Group and Sex – US Adults Aged ≥25, National Health and Nutrition Examination Survey 1999–2016.



A) Hypertension Control Among US Adults Aged 25–44 with Hypertension. Among females, hypertension control was significantly higher (*P*<0.05) in 2011–2016 as compared to 1999–2004. Hypertension control was significantly higher among females than males in 1999–2004, 2005–2010, and 2011–2016.

B) Hypertension Control Among US Adults Aged 45–64 with Hypertension. Among females, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004, and in 2011–2016 as compared to 2005–2010. Among males, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004. Hypertension control was significantly higher among females than males in 2005–2010 and 2011–2016. There was a larger difference in hypertension control by sex in 2011–2016 as compared to 1999–2004.

C) Hypertension Control Among US Adults Aged ≥65 with Hypertension. Among males, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to

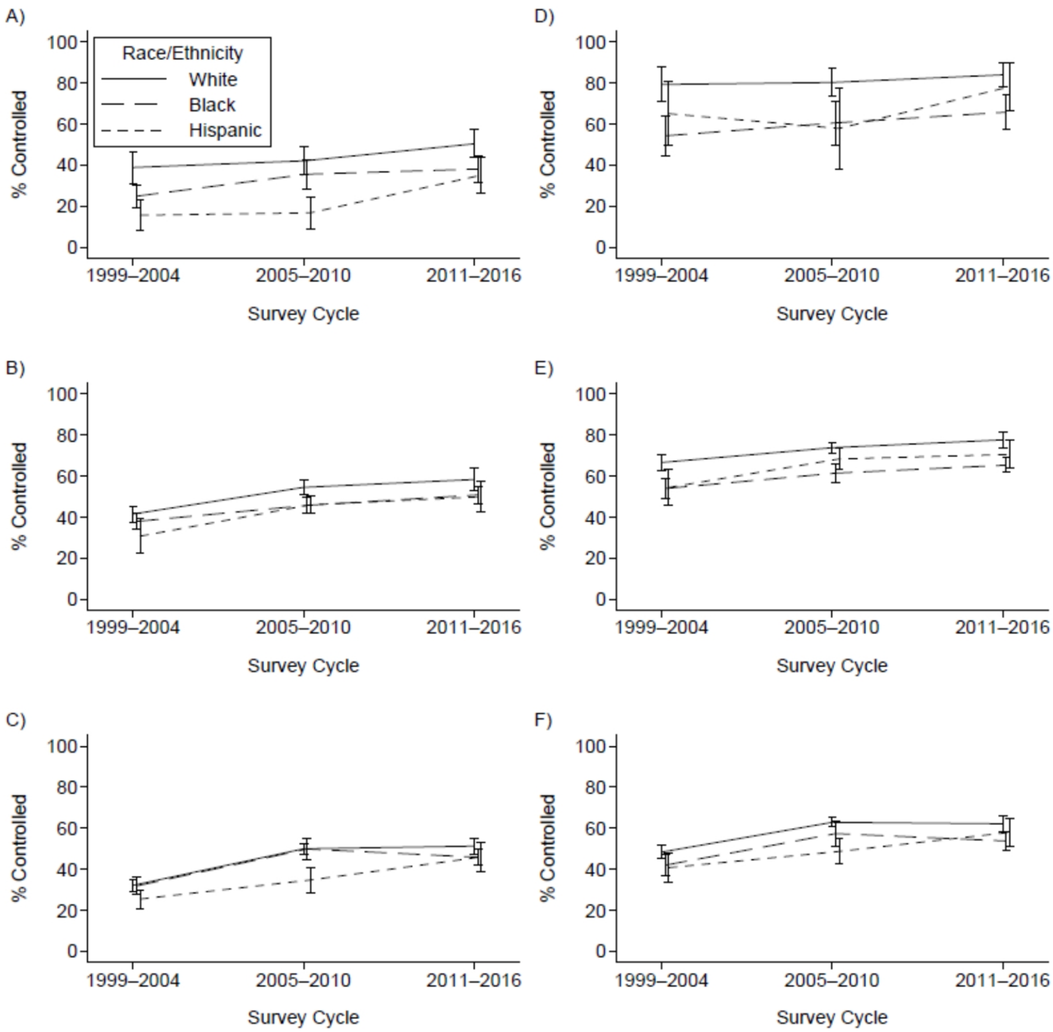
1999–2004. Among females, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004. Hypertension control was significantly higher among males than females in 1999–2004, 2005–2010, and 2011–2016.

D) Hypertension Control Among US Adults Aged 25–44 with Treated Hypertension.

E) Hypertension Control Among US Adults Aged 45–64 with Treated Hypertension. Among females with treated hypertension, hypertension control was significantly higher in 2011–2016 as compared to 1999–2004 and 2005–2010. Among males with treated hypertension, hypertension control was significantly higher in 2011–2016 as compared to 1999–2004. Among those treated, hypertension control was significantly higher among females than males in 2011–2016 and the sex difference in hypertension control was significantly different in 2011–2016 as compared to 1999–2004.

F) Hypertension Control Among US Adults Aged ≥65 with Treated Hypertension. Among males and females with treated hypertension, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004. Among those treated, hypertension control was significantly higher among males than females in 2005–2010 and 2011–2016. The male-female sex difference in hypertension control among those treated was significantly smaller in 2005–2010 as compared to 1999–2004.

Figure 3. Hypertension Control (Left) and Control Among Those Treated (Right) by Age Group and Race/Ethnicity – US Adults Aged ≥25, National Health and Nutrition Examination Survey 1999–2016.



A) Hypertension Control Among US Adults Aged 25–44 with Hypertension. Among whites, hypertension control was significantly higher (P<0.05) in 2011–2016 as compared to 1999–2004. Among blacks, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004. Among Hispanics, hypertension control was significantly higher in 2011–2016 as compared to 1999–2004 and 2005–2010. Hypertension control was significantly higher among whites than blacks in 1999–2004 and 2011–2016. Hypertension control was significantly higher among whites than Hispanics in 1999–2004, 2005–2010, and 2011–2016.

B) Hypertension Control Among US Adults Aged 45–64 with Hypertension. Among whites, blacks, and Hispanics, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004. Hypertension control was significantly higher among whites than blacks in 1999–2004, 2005–2010, and 2011–2016. Hypertension control was significantly higher among whites than Hispanics in 1999–2004 and 2005–2010.

C) Hypertension Control Among US Adults Aged ≥65 with Hypertension. Among whites, blacks, and Hispanics, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004; among Hispanics, hypertension control was also significantly higher in 2011–2016 as compared to 2005–2010. Hypertension control was significantly higher among whites than blacks in 2011–2016. Hypertension control was significantly higher among whites than Hispanics in 1999–2004 and 2005–2010, with a larger difference in 2005–2010 than in 1999–2004.

D) Hypertension Control Among US Adults Aged 25-44 with Treated Hypertension. Among those with treated hypertension, hypertension control was significantly higher among whites than blacks in 1999–2004, 2005–2010, and 2011–2016, and significantly higher among whites than Hispanics in 1999–2004 and 2005–2010.

E) Hypertension Control Among US Adults Aged 45–64 with Treated Hypertension. Among whites, blacks, and Hispanics with treated hypertension, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004. Among those treated, hypertension control was significantly higher among whites than blacks in 1999–2004, 2005–2010, and 2011–2016. Among those treated, hypertension control was significantly higher among whites than Hispanics in 1999–2004.

F) Hypertension Control Among US Adults Aged ≥65 with Treated Hypertension. Among whites, blacks, and Hispanics with treated hypertension, hypertension control was significantly higher in 2005–2010 and 2011–2016 as compared to 1999–2004. Among those treated, hypertension control was significantly higher among whites than blacks in 1999–2004 and 2011–2016. Among those treated, hypertension control was significantly higher among whites than Hispanics in 2005–2010.

Chapter 2. Digit preference in office blood pressure measurements, United States 2014–2018

Co-authors: Lawrence J. Appel, Kunihiro Matsushita, Josef Coresh, G. Caleb Alexander, Elizabeth Selvin

ABSTRACT

Importance: Accurate blood pressure (BP) measurement is essential for the diagnosis and treatment of hypertension, but BP measurement is prone to error. One common source of systematic error is terminal digit preference, most often a terminal digit of '0'. The increasing use of automated BP devices and initiatives to improve hypertension management may have reduced terminal digit preference in recent year.

Objective: To evaluate trends in terminal digit preference among a nationally representative sample of office BP measurements among adults with treated hypertension. We hypothesized digit preference would decrease over time.

Design: We conducted a serial cross-sectional study using data 2014 to 2018 from IQVIA's National Disease and Therapeutic Index, a nationally-representative audit of office-based physicians.

Setting: Office-based physicians in the U.S.

Participants: Patients visits were the unit of analysis. We included all office visits among adults aged ≥18 years receiving antihypertensive treatment.

Exposures: We examined trends by patient sex, age, and race/ethnicity, by physician specialty, and by first or subsequent hypertension treatment visit.

Main Outcome: Proportion of systolic and diastolic BP measurements ending in zero.

Results: In the absence of bias, the expected percent of BPs with a terminal zero is 10% for automated and 20% for manual readings. From 2014 to 2018, there was a decrease in the percent of visits with systolic (43.0% to 38.1%) or diastolic (44.3% to 39.4%) BP recordings ending in zero. Trends were similar by patient demographic characteristics. However, there was less reduction in terminal digit preference among first (vs subsequent) treatment visits, visits to cardiologists (vs primary care physicians), and among visits with systolic BP ≥140 mmHg or diastolic BP ≥90 mmHg (vs <140/90 mmHg).

Conclusions and Relevance: Terminal digit preference remains a common problem, despite modest improvement over time. Systematic error contributes to both under- and overtreatment of individuals with hypertension. Reducing digit preference is feasible and can improve the accuracy of BP measurement and management of hypertension in the U.S.

INTRODUCTION

Accurate blood pressure (BP) measurement is central to the diagnosis and treatment of hypertension.[1] Although BP is measured at nearly every clinical encounter, accurate and reliable assessment of an individual's BP is challenging. Blood pressure is inherently variable and variability is further increased when health care providers do not follow standardized measurement procedures.[1] Recommended procedures for accurate BP measurement can be difficult to implement in routine clinical practice resulting in inaccurate assessment of BP.[2,3] Measurement error may result in the under- or overtreatment of patients with hypertension.[4]

One common form of measurement error is terminal digit bias, or a preference by the observer to round measurements to a specific end digit, most commonly zero.[5] In ambulatory care, BP is assessed with either a manual device using an auscultatory approach or an electronic device using an oscillometric approach.[1] Without terminal digit bias, approximately 20% of measurements with manual and 10% of measurements with automated devices are expected to end in zero. However, previous studies report an absolute excess of 1-79% in end-digit zeroes.[5] Prior research shows patients at practices with higher terminal digit preference are less likely to have an antihypertensive prescription[6] and are more likely to experience an adverse cardiovascular event.[7]

Terminal digit preference may have decreased in recent years. The restricted use of mercury devices, concerns about measurement error with manual BP measurement, and discrepancies between in- and out-of-office BPs[1] has led to increased use of automated BP devices in the past two decades. Though automated BP devices do not eliminate measurement error, they may reduce terminal digit preference. Several clinic-based studies have documented a reduction in terminal digit preference after the introduction of automated BP devices.[7,8] Additionally, national and global cardiovascular health initiatives emphasize proper BP measurement technique, including the U.S. Department of Health and Human Services' Million

Hearts initiative,[9] the American Heart Association and American Medical Association's Target: BP,[10] the World Health Organization's Global Hearts initiative,[11] Vital Strategies' Resolve to Save Lives,[12] and the Accuracy in Measurement of Blood Pressure (AIM-BP) collaborative from the World Hypertension League.[13]

In this context, we evaluated trends in terminal digit preference among a nationally representative sample of office BP measurements among adults with treated hypertension. We hypothesized digit preference would be reduced over time.

METHODS

Data source

We used data from IQVIA's National Disease and Therapeutic Index (NDTI), which provides nationally representative data on the patterns and treatment of disease encountered by office-based physicians in the continental U.S. Data from the NDTI have been used in other studies examining ambulatory care.[14,15] The NDTI uses the American Medical Association and American Osteopathic Association master lists to sample approximately 4,000 physicians quarterly, stratified by geographic region and specialty. For each participating physician, two random consecutive workdays are sampled. For each patient seen on those workdays, the physician reports all diagnoses and all prescription and non-prescription medications newly ordered or previously ordered and continued. Data are weighted to estimate all patient contacts on all workdays for all U.S. office-based physicians.

We identified all office visits from January 1, 2014 to December 31, 2018 among adults aged ≥18 years with a recorded diagnosis of hypertension and at which hypertension treatment occurred (i.e., adult hypertension treatment visits). Hypertension diagnoses were identified using survey-specific diagnostic codes. Each record of new or continued drug therapy is linked to the relevant diagnosis.

Blood pressure measurement and recording

The BP measurements used in our study are based on the information recorded on the survey form for each patient visit. The NDTI survey procedures do not instruct the physician or individual taking the BP measurement to use a specific protocol.

Patient and physician characteristics

Physicians record patient demographic characteristics for each encounter on the survey form, including sex, age, and race/ethnicity. Each visit is also characterized by the physician as a first or subsequent treatment visit, based on whether the physician has seen the patient previously for this episode of the diagnosis. Physician specialty is obtained from the American Medical Association and American Osteopathic Association master lists.

Statistical Analyses

We examined annual trends from 2014 to 2018 in the number of hypertension treatment visits and the proportion of such visits with recorded systolic and diastolic BP measurements with a terminal digit '0.' We examined trends overall and by patient characteristics and physician specialty. We categorized patient sex as male or female, age as 18-59 or ≥60 years, and race/ethnicity as white, Black, Hispanic, Asian, or other (race/ethnicity categories used are based on those available to physicians on the survey form). We categorized visits as first or subsequent treatment visits. We categorized physician-reported specialty as primary care (family practice, general practice, or internal medicine), cardiology, or other.

We examined the frequency of specific BP values in the dataset and plotted histograms to characterize the extent of terminal digit preference across the full range of BP values. We present the distributions of systolic and diastolic BP from 2018 as examples of the patterns we observed.

Then, we examined the proportion of BP values with a terminal zero by BP level. We considered the measurement ending in 0 as the midpoint of the interval including all possible end digits; for 0 to represent the middle of the interval we used one half of the measurements ending in 5 at the lower and upper bound of the interval.[16] For example, we calculated the proportion of systolic BP measurements of 140 mmHg in the interval from 135 to 145 mmHg, using half of the number of 135 and 145 mmHg measurements.

Next, we examined trends in the proportion of systolic and diastolic BP measurements with other end digits. We also calculated the proportion of measurements ending in 1, 3, 7, and 9 in each year. While there is some evidence observers round measurements to 5,[17] measurements ending in 1, 3, 7, or 9, are likely only obtained using automated devices.

In supplemental analyses, we examined trends in the proportion of BP values immediately above and below thresholds for hypertension control recommended by clinical practice guidelines in use during the study period.[3,18,19] Some previous studies have found evidence of a preference for values just below target BPs.[16,20] We examined trends in the proportion of measurements within ± 2-units of 130, 140, and 150 mmHg systolic BP, and within ± 2-units of 80 and 90 mmHg diastolic BP.[16]

All analyses were weighted to generate estimates nationally representative of office visits among US adults aged ≥18 with hypertension treatment in the years 2014 to 2018.

RESULTS

Between 2014 and 2018, there were approximately 60 million hypertension treatment visits annually (**Table 1**). The majority of hypertension treatment visits occurred among adults aged ≥60 years, were for subsequent hypertension treatment, and among primary care physicians. In all study years, approximately 60% of visits had a systolic BP measurement <140 mmHg and nearly 80% of visits had a diastolic BP measurement <90 mmHg.

Trends in terminal digit preference overall and by subgroup

In 2014, the proportion of visits with systolic (43.0%) and diastolic (44.3%) BP measurements with a terminal zero was higher than expected based on chance alone (**Table 2**). In 2018, 38.1% of systolic and 39.4% of diastolic recordings ended in zero.

Trends in the proportion of systolic and diastolic BP measurements were similar by sex, age, and race/ethnicity. The proportion of visits with a systolic or diastolic BP measurement ending in zero was generally higher at first (vs subsequent) treatment visits, visits to cardiologists (vs primary care and other physicians), and at systolic BP ≥140 mmHg or diastolic BP ≥90 mmHg. There were also smaller decreases in the proportion of visits with terminal digit zeroes in these groups.

Distribution of BP values

Histograms of systolic and diastolic BP measurements from 2018 are shown in **Figure 1**. Terminal digit zeroes were common across the full range of BP values. The most frequently recorded systolic BP value was 130 mmHg, followed by 140 mmHg, and the most frequently recorded diastolic BP value was 90 mmHg.

Trends in terminal digit preference by BP level

Although systolic BP of 140 mmHg and diastolic BP of 90 mmHg were reported frequently, the proportion of BP measurements ending in 0 was lowest around those values (**Figure 2**). Further, the proportion of measurements with a terminal zero generally decreased in those intervals during the study period. The proportion measurements with a terminal zero was somewhat higher at higher levels of systolic and diastolic BP.

Trends in other terminal digits

Throughout the study period, even terminal digits were more frequently reported than odd (**Figure 3**). Eight was the second most common end digit after zero. Throughout the study period, approximately 14% of systolic BP measurements ended in eight. There was an increase from 12.3% to 15.2% in the proportion of diastolic BP measurements ending in eight.

Five was the most common odd terminal digit. The proportion of systolic BP measurements ending in five increased from 4.4% to 6.9%, while the proportion of diastolic BP measurements ending in five remained around 4%. There was little change from 2014 to 2018 in the proportion of systolic (6.3% to 7.1%) or diastolic (6.4% to 7.2%) BP measurements ending in 1, 3, 7, or 9.

Trends in blood pressure values around treatment thresholds

The percentage of systolic BP measurements of 138-139 mmHg was 1.5 times higher than the percentage of systolic BP measurements of 141-142 mmHg (**Supplemental Table**). However, these percentages remained relatively stable over time. The proportions of systolic BP measurements 2-units below and 2-units above 130 mmHg were similar and remained stable; a similar pattern was observed around 150 mmHg.

Among diastolic BP measurements, the proportion of measurements within 2-units below and 2-units above 80 mmHg were similar and there was little change over time. The proportion of diastolic BP measurements of 88-89 mmHg meanwhile was approximately two-fold higher than the proportion of diastolic BP measurements of 91-92 mmHg, and the proportion of diastolic BP measurements of 88-89 mmHg increased from 3.9% to 5.7% from 2014 to 2018.

DISCUSSION

In this serial, cross-sectional analysis of a nationally-representative audit of ambulatory care physicians, we identified approximately 60 million office visits for hypertension treatment annually between 2014 and 2018. In 2018, 38.1% of systolic and 39.4% of diastolic BP measurements recorded at such visits ended in zero. Terminal digit preference remains commo, despite an absolute decrease by 5-percentage points from 2014 to 2018 in the percent of systolic and diastolic BP measurements with a terminal zero. Additionally, we observed less progress and a higher proportion of measurements with a terminal zero among first treatment visits, visits to cardiologists, and at higher levels of systolic and diastolic BP.

There are several factors which may have contributed to the decrease in terminal digit preference in our study. First is the increased use of automated BP devices, though we do not have information on the devices used. In recent decades, as mercury has been eliminated from medical devices and in recognition of the potential for error with auscultatory technique, semi-automated and automated oscillometric BP devices have become increasingly used in clinical practice.[1,21] Second is discussion and debate in the field about BP measurement, for example, in the context of the 2015 Systolic Blood Pressure Intervention Trial (SPRINT).[22] The SPRINT trial demonstrated a reduction in cardiovascular events and deaths treating adults with hypertension at increased cardiovascular risk to a systolic BP of <120 mmHg versus <140 mmHg.[22] The SPRINT protocol used automated BP measurement, including unattended automated BP measurement at some study sites.[23] The trial results subsequently informed hypertension treatment goals in the 2017 ACC/AHA high blood pressure guideline.[3] While it is acknowledged the BPs achieved in SPRINT measured with automated BP devices using standardized procedures correspond to higher casual measurement values, discussion about the trial's measurement protocol may have influenced BP measurement procedures in practice.[21] Third is increased awareness of the importance of proper BP measurement technique as a result of global, national, and local initiatives to improve hypertension control.[9–13]

Terminal digit preference has implications for patient care across BP levels. Consistent with previous studies, we found greater terminal digit preference at higher BPs for patients with hypertension.[24] One could argue rounding at BPs above guideline-recommended treatment goals is not particularly problematic because such patients would be treated regardless of their exact BP. However, rounding typically occurs down which could affect the intensity of pharmacologic treatment or use of other patient engagement strategies.[6,7] The lowest levels of terminal digit preference occurred near guideline-recommended thresholds for BP control (eg, systolic BP <140 mmHg or diastolic BP <90 mmHg) and decreased over time in such intervals. It is possible providers obtain higher quality measurements when the BP value is likely to affect treatment decisions. However, it is unclear whether this is the case, and misclassification of hypertension control may negatively impact patient outcomes. In a prior study conducted in the UK, researchers documented an excess of diastolic BP measurements of '88', as well as end digit zeroes, and found women with recorded diastolic BP 88-89 mmHg had subsequently higher rates of mortality than those with diastolic BP 90-99.[20] It appeared observers rounded down or re-measured BP until they obtained a more favorable value if they thought the patient did not need treatment.[20] In other studies in the UK, there is evidence of increased preference for the digits just below pay-for-performance targets after their introduction (i.e., threshold bias).[16,24] While we found an increase in the proportion of diastolic BP measurements of 88-89 mmHg in our study, we did not otherwise find strong evidence of preference for values immediately below certain thresholds. It will be important to continue to monitor preference for terminal zeroes and values just below specific thresholds, as well as the resulting impact on patient treatment and outcomes.[16]

Our results showing higher terminal digit preference among visits to cardiologists warrant further exploration. A limitation of our study is we do not know who measured the BP that was recorded. We are not aware of other studies comparing terminal digit preference by specialty. However, terminal digit preference has been documented across a range of health care settings, including hypertension specialty clinics.[25]

In addition to factors related to BP measurement devices and procedures, our study also highlights the importance of accurate BP recording. While we believe the use of automated devices increased during this time, the proportion of measurements ending in an odd digit other than 5 did not change substantially. It is possible observers maintain a preference for even digits or intentionally round measurements from automated devices to zero. It is important to better understand and address inaccuracies in BP recording.

The 2017 ACC/AHA high blood pressure guideline issues a strong recommendation for use of proper methods for accurate measurement and documentation of BP.[3] The guideline also notes there is a growing evidence base supporting the use of automated office BP measurements.[3] Automated office BP is similar to mean awake ambulatory BP and home BP, which are more predictive of cardiovascular events than casual office BP measurements.[26] The guideline stops short of formally recommending the use of automated devices in the office setting. Meanwhile, the Canadian Hypertension Education Program recommends automated BP measurement as the preferred method of office measurement.[27] Indeed, there has been a decrease in terminal digit preference across Canadian primary care clinics following the adoption of automated office BP devices.[7] However, terminal digit preference has not been eliminated, possibly due to continued use of manual devices even when automated devices are available,[7,28] or rounding of automated measurements, highlighting implementation considerations for automated office BP measurement.[21] Regardless of the type of device used, it is important to train and retrain current and future health professionals in proper BP measurement technique and to ensure procedures can be incorporated into the clinical workflow.[2,29]

There are several limitations of our study. First, there is no agreed upon "acceptable" percentage of terminal digit zeroes. While we expect 10-20% of measurements to end in zero without bias, some have considered 10-29% acceptable.[30] However, the percentage of BP measurements with a terminal zero in our study was still in excess of this range. Second, we do not know the type of BP device or the measurement procedures used, including whether multiple readings were obtained. Thus, we cannot determine the contribution of increased use of automated devices to the overall decrease in terminal digit preference during the study period. Additionally, without knowing the type of device, we cannot determine whether a terminal digit of 8 reflects the use of a manual device which is marked with only even numbers or a "preference" by the observer for a particular value. Third, we also do not know if the BP readings recorded on the NDTI survey are the same as those recorded in the patient's medical record and used to inform decisions about patient care; in field settings, the co-authors have observed transcript errors related to intentional rounding. Finally, we cannot account for the clustering in measurement (or measurement error) which occurs when the same physician reports data for multiple patients.

Our study has several strengths. To our knowledge, this is the first study to document the extent of terminal digit preference nationally and trends over time. The data are nationally representative of all visits to office-based physicians in the U.S. Additionally, NDTI data are available with a short lag time, which enables use of the data to monitor changes in near real-time.

Conclusion

Our work highlights the need to improve the quality of BP measurement in ambulatory settings. To better understand the determinants of terminal digit preference, it would be useful to understand the BP devices currently used in practice for screening and diagnosis of hypertension, and to monitor the response to hypertension treatment.[28] It is possible to reduce terminal digit preference through the use of automated devices, clinical training, and support.[2] U.S. guidelines could more strongly recommend the use of automated BP devices in the office setting. Regardless of the type of device used, accurate BP recording and reporting is critical to patient care. Finally, it will be important to continue to monitor trends in terminal digit preference as clinical quality measures and pay-for-performance programs are implemented to ensure other biases do not occur. Terminal digit preference remains pervasive, but can feasibly be reduced to improve the accuracy of BP measurement and management of hypertension in the U.S.

TABLES

Table 1. Characteristics of office-based hypertension treatment visits – National Disease and Therapeutic Index, 2014–2018.

	2014	2015	2016	2017	2018
Total visits (N, millions)	64.5	60.7	58.7	63.7	67.7
Sex, %					
Male	50.4	51.9	52.7	53.3	54.0
Female	49.6	48.1	47.3	46.7	46.0
Age, %					
Age <60	41.5	41.2	40.4	38.5	38.0
Age ≥60	58.5	58.8	59.6	61.5	62.0
Race/ethnicity, %					
White	70.8	71.2	69.9	68.4	68.8
Black	17.5	17.2	17.5	17.4	16.7
Hispanic	6.1	5.7	6.0	6.3	6.7
Asian	4.9	5.2	5.5	5.5	6.1
Other	0.8	0.6	1.1	2.4	1.6
Visit type, %					
First treatment visit	16.1	16.9	17.3	18.0	20.3
Subsequent treatment visit	83.9	83.1	82.7	82.0	79.7
Physician specialty, %					
Cardiology	9.4	9.8	10.2	10.0	10.0
Primary care	75.3	74.3	72.3	71.6	71.2
Other	15.3	15.9	17.6	18.4	18.8
Blood pressure level, %					
SBP <140 mmHg	60.3	61.6	59.6	58.8	59.4
SBP ≥140 mmHg	39.7	38.4	40.4	41.2	40.6
DBP <90 mmHg	78.2	78.5	77.4	78.4	77.5
DBP ≥90 mmHg	21.8	21.5	22.6	21.6	22.5

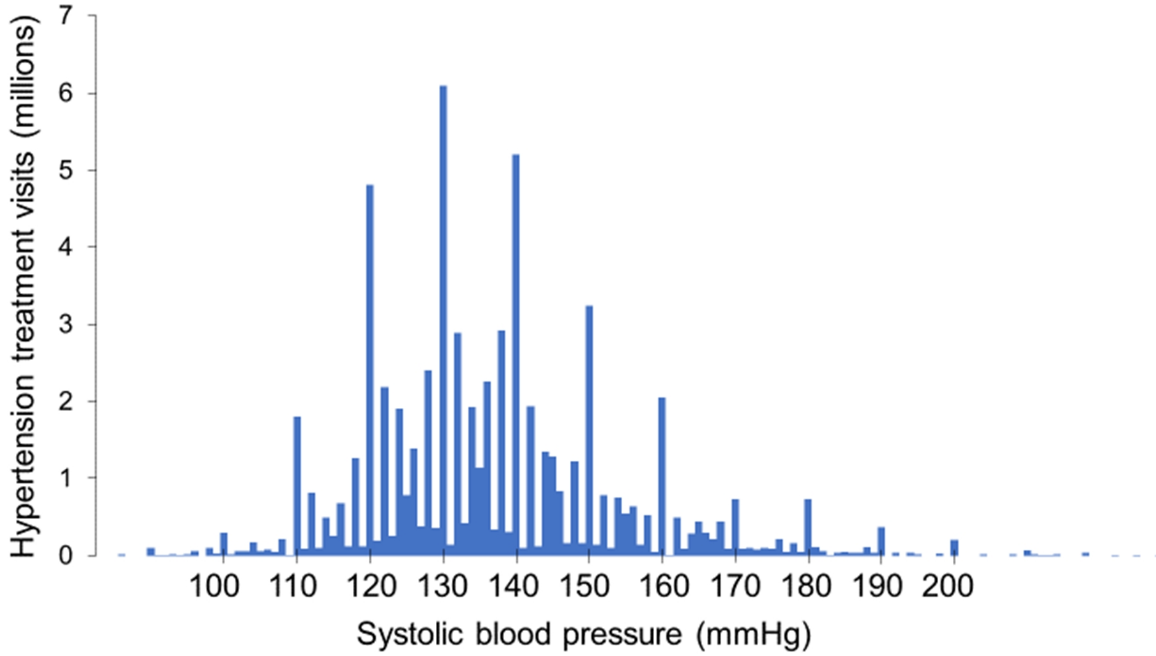
Table 2. Percentage of office-based hypertension treatment visits with blood pressure measurements with a terminal digit of zero – National Disease and Therapeutic Index, 2014–2018.

	Systolic Blood Pressure					Diastolic Blood Pressure				
	2014	**2015**	**2016**	**2017**	**2018**	**2014**	**2015**	**2016**	**2017**	**2018**
Overall, %	43.0	41.7	39.0	38.0	38.1	44.3	42.7	40.9	38.5	39.4
Sex, %										
Male	43.6	42.2	39.1	37.3	39.1	43.5	41.5	40.8	37.4	39.5
Female	42.2	41.0	38.9	38.8	36.8	45.0	43.7	41.0	39.8	39.3
Age, %										
Age <60	40.7	41.0	39.3	37.0	38.5	41.9	41.7	39.0	36.8	37.5
Age ≥60	44.6	42.2	38.8	38.6	37.8	46.0	43.4	42.3	39.6	40.6
Race/ethnicity, %										
White	43.2	42.1	39.5	38.5	39.4	45.0	42.5	41.1	38.9	40.2
Black	43.5	39.6	36.2	37.4	33.9	41.9	41.1	37.6	37.0	37.1
Hispanic	40.7	42.1	39.5	38.7	35.9	44.0	44.2	44.0	39.1	37.8
Asian	44.3	41.7	38.7	37.3	36.7	46.1	46.4	44.4	40.5	40.3
Other	38.9	36.1	44.8	27.8	36.8	36.3	47.2	44.5	33.6	33.7
Visit type, %										
First treatment visit	44.7	45.2	39.9	42.1	42.9	46.2	45.4	39.5	40.2	42.3
Subsequent treatment visit	42.7	41.5	38.9	37.1	36.8	44.2	42.6	41.2	38.2	38.7
Physician specialty, %										
Cardiology	48.6	45.5	44.2	43.2	44.5	49.7	49.4	50.9	50.3	51.0
Primary care	42.6	42.1	38.5	37.4	38.4	44.3	42.8	41.1	37.0	39.0
Other	41.2	37.6	37.9	37.5	33.5	41.0	38.1	34.6	38.1	34.7
Blood pressure level, %										
SBP <140 mmHg	37.4	36.6	33.7	33.0	32.6	—	—	—	—	—
SBP ≥140 mmHg	51.5	49.8	46.8	45.0	46.1	—	—	—	—	—
DBP <90 mmHg	—	—	—	—	—	41.1	39.4	36.9	33.5	34.7
DBP ≥90 mmHg	—	—	—	—	—	56.1	54.7	54.8	56.7	55.6

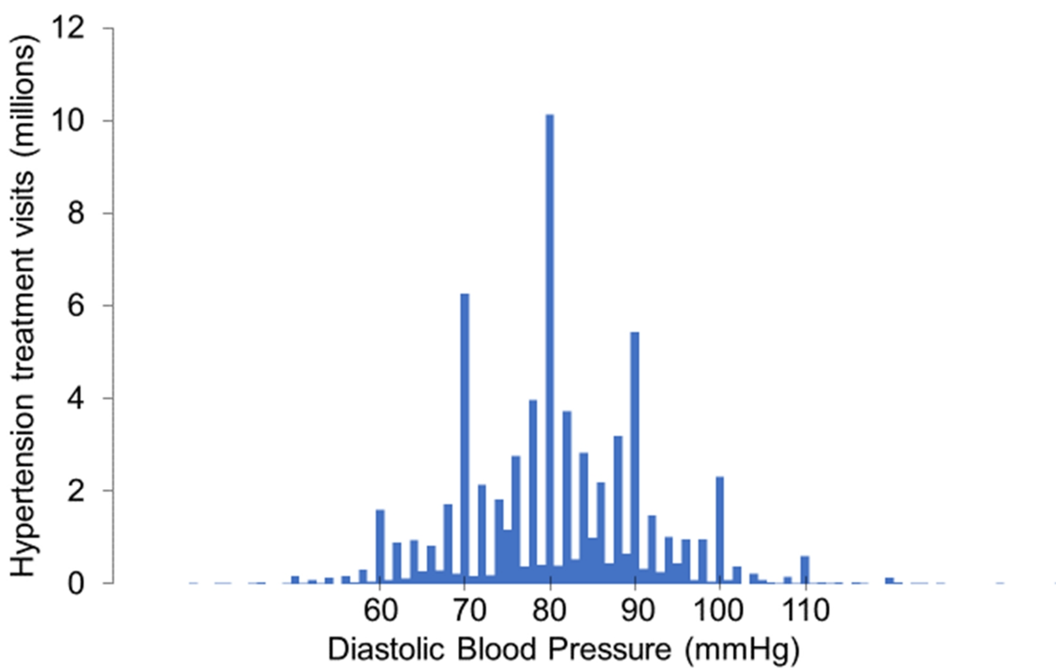
Primary care defined as family practice, general practice, or internal medicine.

FIGURES

Figure 1. Distribution of systolic (top) and diastolic (bottom) blood pressure measurements – Hypertension treatment visits 2018.

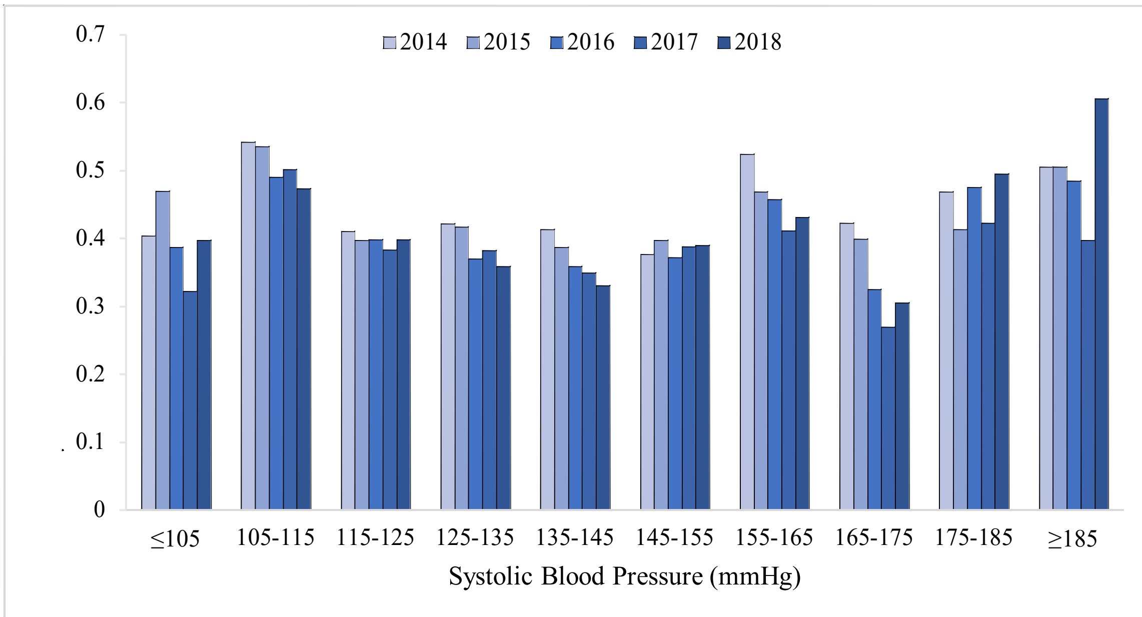


Source: IQVIA National Disease and Therapeutic Index

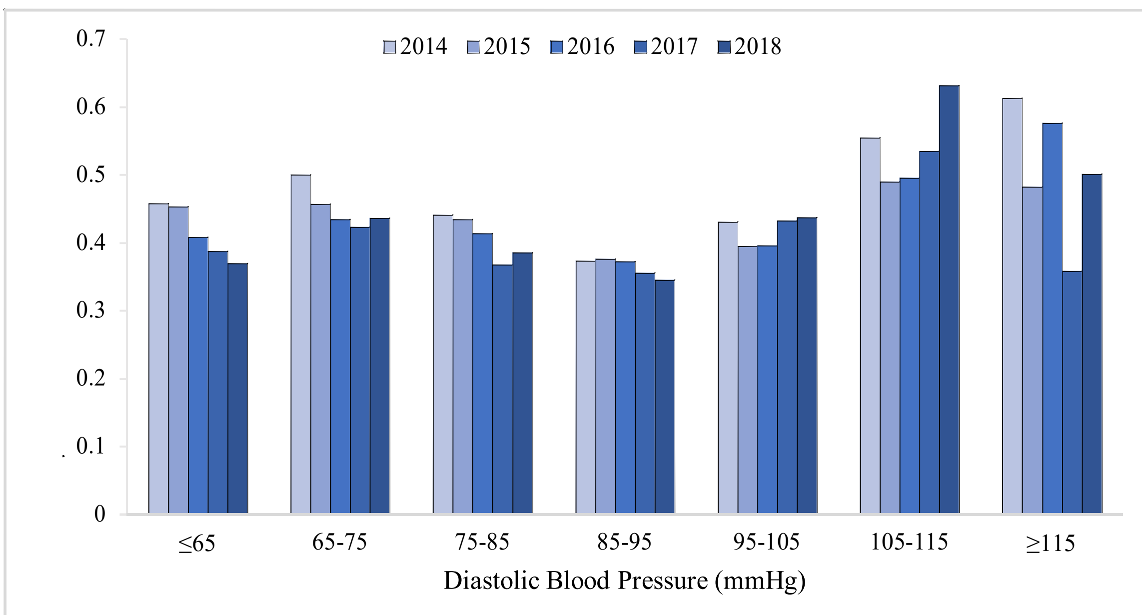


Source: IQVIA National Disease and Therapeutic Index

Figure 2. Proportion of systolic (top) and diastolic (bottom) blood pressure measurements with an end-digit zero, by blood pressure level – Hypertension treatment visits 2014–2018.



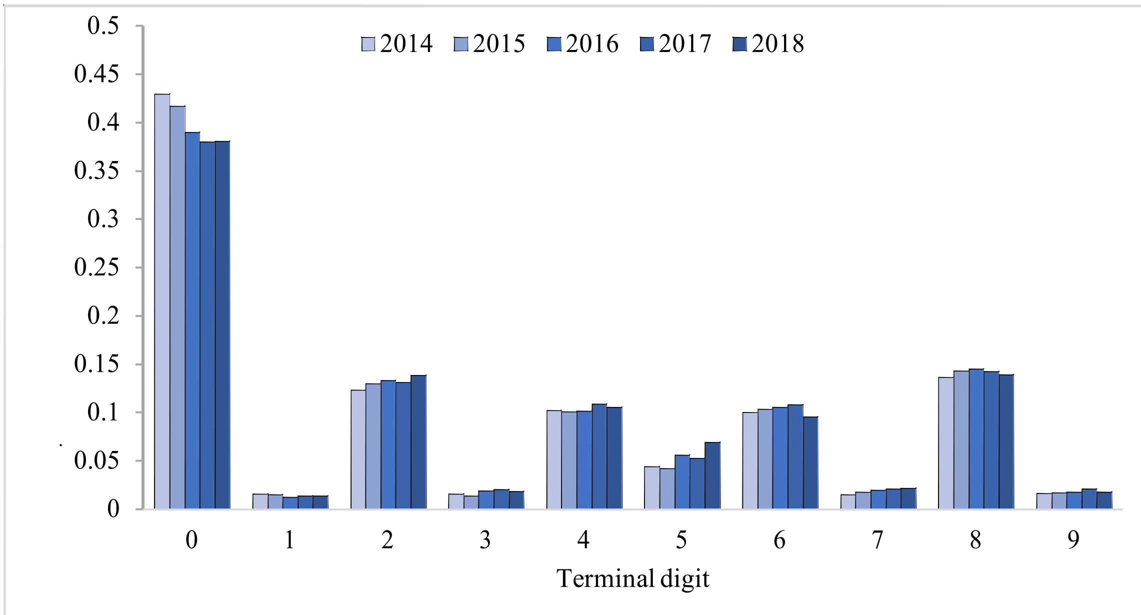
SBP = systolic blood pressure.



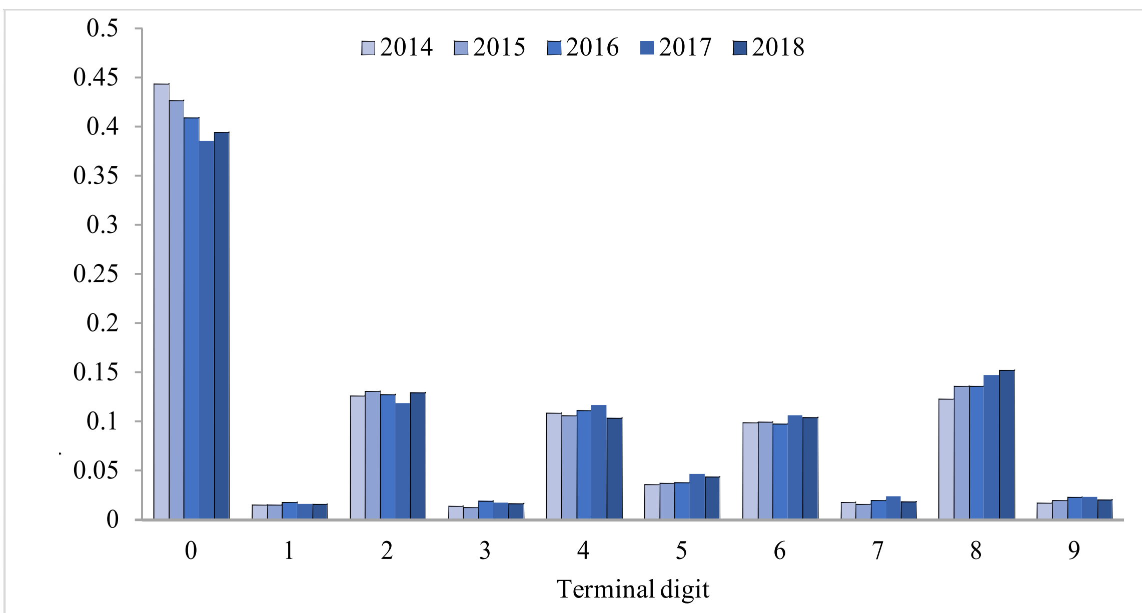
DBP = diastolic blood pressure.

Figures report the proportion of measurements ending in zero in the specified interval. Each interval includes one half of the measures ending in five at the upper and lower bounds.

Figure 3. Trends in systolic (top) and diastolic (bottom) blood pressure measurement end digits – Hypertension treatment visits 2014–2018.



SBP = systolic blood pressure.



DBP = diastolic blood pressure.

Chapter 3: Changes in hypertension control in a community-based population of older adults, 2011-2013 to 2016-2017

Co-authors: Kunihiro Matsushita, Silvia Koton, Keenan Walker, Josef Coresh, Lawrence J. Appel, Elizabeth Selvin

ABSTRACT

Background: Hypertension guidelines published in 2014 raised treatment goals in older adults.

Objectives: To examine and compare changes in hypertension control (systolic blood pressure <140 mmHg) among Black and white older adults with treated hypertension.

Methods: We included 2,250 participants aged 71-90 in the Atherosclerosis Risk in Communities (ARIC) Study with treated hypertension in 2011-2013 (baseline), present in 2016-2017 (follow up). We assessed predictors of change in hypertension control using logistic regression.

Results: Among whites, 75.4% at baseline and 59.4% at follow up had controlled hypertension. Among Blacks, 66.0% at baseline and 56.5% at follow up had controlled hypertension. One-third of whites and Blacks with controlled hypertension at baseline developed uncontrolled hypertension. Predictors included older age [odds ratio (OR) 1.30 per 5 years, 95% confidence interval (CI) 1.14-1.48], female sex (OR 1.60, 95% CI 1.25-2.06), and reduced kidney function among whites (OR 1.32, 95% CI 1.00-1.75), and hypertension duration (OR 1.23 per 5 years, 95% CI 1.05-1.44) and diabetes among Blacks (OR 1.92, 95% CI 1.27-2.92). Among those uncontrolled at baseline, ~40% were controlled at follow up. White females (OR 0.45, 95% CI 0.29-0.68) and Blacks with reduced kidney function (OR 0.44, 95% CI 0.22-0.87) had lower odds of control.

Conclusions: Changes in hypertension control were similar in whites and Blacks. However, Blacks with diabetes or reduced kidney function were less likely to have hypertension control at

follow up. Higher treatment goals may have contributed to these findings and unintended differences by race.

INTRODUCTION

Hypertension is common in older persons, but treatment goals in this population are widely debated. Clinical practice guidelines for hypertension management seek to balance the benefits of blood pressure-lowering therapy with the potential for adverse events. However, recent recommendations from leading professional societies are conflicting. The JNC7 guideline published in 2003 recommended treating hypertension to a goal of <140/90 mmHg among the general population and to <130/80 mmHg for those with diabetes or chronic kidney disease.[1] In 2014, panel members of the JNC8 committee recommended treatment to <150/90 mmHg for adults aged 60 years or older without diabetes or chronic kidney disease and to <140/90 mmHg for all other patients.[2] However, not all of the panel members agreed with the higher treatment goals.[2,3] Several panel members expressed concern that raising the systolic blood pressure (SBP) threshold for older adults could undo progress to reduce cardiovascular disease and could have a disproportionate negative impact on patients at highest cardiovascular risk, such as African Americans, those with a history of cardiovascular disease, and those with multiple risk factors.[2,3] The Association of Black Cardiologists echoed these concerns and cautioned that an unintended consequence may be to worsen Black-white disparities in cardiovascular outcomes and life expectancy.[4]

In 2015, the Systolic Blood Pressure Intervention Trial (SPRINT) demonstrated treating high-risk adults without diabetes to SBP to <120 mmHg as compared with <140 mmHg resulted in lower rates of cardiovascular events and deaths.[5] An analysis restricted to trial participants ages 75 and older found similar results, including benefit among those who were frail.[6] There was no difference across trial arms in the rate of serious adverse events.[6]

Influenced by the results of SPRINT, the American College of Cardiology (ACC), American Heart Association (AHA) and 9 other professional societies recommended in 2017 that adults aged ≥65 be treated to SBP <130 mmHg.[7] Meanwhile, the American College of Physicians and American Academy of Family Physicians continue to endorse a treatment goal of <150/90 mmHg among adults aged ≥60 and have published their own clinical practice guideline.[8]

Racial disparities in hypertension and blood pressure control in the US are present at all ages, including older ages, despite comparable or higher levels of awareness and treatment among blacks and whites.[9] In the context of conflicting guidelines, it is critical to characterize those factors that influence hypertension control and changes in control across subgroups, as these may contribute to disparities in the population.[10]

There are few community-based cohorts of older adults with contemporary, repeat blood pressure measurements that provide an opportunity to evaluate recent changes in the management of hypertension. The Atherosclerosis Risk in Communities (ARIC) Study, which enrolled Black and white adults from four U.S. communities, conducted examination visits in 2011-2013 and 2016-2017 when participants were aged 71-90 and 75-94, respectively. Our objectives were to examine and compare changes in hypertension control in older Black and white adults, and to assess sociodemographic and clinical factors associated with these changes.

METHODS

Study population

The ARIC Study included 15,792 participants from Forsyth County, North Carolina, Jackson, Mississippi, Minneapolis, Minnesota, and Washington County, Maryland aged 45-64 at the first study visit in 1987-1989.[11] Follow up visits have been conducted in 1990-1992, 1993-1995, 1996-1998, 2011-2013, and 2016-2017. An institutional review board at all study sites and the University of North Carolina (ARIC coordinating center) approved all procedures. All participants provided written informed consent.

For the present analysis, the 2011-2013 study visit (visit 5) served as the baseline. Our primary analysis included those participants with treated hypertension in 2011-2013 who also attended the 2016-2017 study visit (visit 6) (**Supplemental Figure 1**). There were 6,538 total participants who attended visit 5. We excluded participants who were nonwhite or nonblack (n=18); missing hypertension status, SBP measurements, or self-reported antihypertensive medication use (additional n=146); and missing covariates of interest (additional n=837). Among this population, we identified those with a doctor's diagnosis of hypertension and who self-reported antihypertensive medication use in the past 4 weeks. Among Black and white participants in 2011-2013, 74.6% had hypertension, and among those, 90.9% reported antihypertensive medication treatment. Of the 3,752 participants with treated hypertension in 2011-2013, 2,250 were present in 2016-2017 and comprised our study sample.

In secondary analyses, we examined antihypertensive medication use among those participants who brought all of their medications to the 2011-2013 and 2016-2017 study visits (n=37 without medications at both visits).

Outcome

At the study visits in 2011-2013 and 2016-2017, blood pressure measurements were obtained using the same, standardized procedures. In brief, each participant had their blood pressure measured using an automated sphygmomanometer, the Omron HEM 907 XL, with an appropriately-sized cuff. After five minutes of rest, the device took three serial measurements. The mean of the second and third SBP readings was used for all analyses. We focused on SBP given the independent association with cardiovascular disease outcomes and the emphasis on SBP thresholds for older adults.[6,7] We defined controlled hypertension at baseline as SBP <140 mmHg and uncontrolled hypertension as SBP ≥140 mmHg.

We classified individuals as having controlled or uncontrolled hypertension at baseline and then ascertained hypertension control status at the follow-up visit. Those with SBP <140 mmHg at baseline could be classified as having controlled (SBP <140 mmHg) or uncontrolled hypertension (SBP ≥140 mmHg) at follow up. Similarly, those with SBP ≥140 mmHg at baseline could be classified as having uncontrolled hypertension (SBP ≥140 mmHg) or controlled hypertension (SBP <140 mmHg) at follow up.

In secondary analyses, we assessed antihypertensive medication use based on medications brought to the visits and corresponding scanned UPC codes. We calculated the total number of antihypertensive medications at baseline and follow-up, and change in the total number of antihypertensive medications, for each participant. For combination therapies, each drug in the combination was counted as a unique medication (i.e., two-drug single pill combinations were counted as two medications).

Participant characteristics of interest

Participant characteristics were assessed at the 2011-2013 study visit unless otherwise noted. We included factors associated with hypertension control or which we hypothesized could influence clinical-decision making about hypertension treatment goals. Age, sex, and race were self-reported. Years of education were self-reported at the initial ARIC visit in 1987-1989 and categorized as less than high school graduate; high school graduate or vocational school; college, graduate or professional school.

The Short Physical Performance Battery (SPPB) was used to assess physical functioning. The SPPB includes three components, chair stands, standing balance, and gait speed. Each component is scored from 0-4 with a possible range of composite scores from 0-12. We defined poor physical function as an SPPB score ≤6.[12] Frailty was assessed using a previously validated measure and defined as ≥3 of the following criteria: low strength, low energy, slow walking speed, low physical activity, or unintentional weight loss.[13] Those who met 1-2 criteria were considered pre-frail. In all analyses, we compared participants who were frail or pre-frail with those who were not frail.

Cognitive status was determined by expert committee review according to procedures established by the ARIC Neurocognitive Study, which added dementia surveillance and a comprehensive cognitive exam to the ARIC Study beginning in 2011.[14] Participants were categorized as having normal cognition, mild cognitive impairment (MCI) or dementia. We grouped participants with MCI or dementia into one category for analysis due to the low prevalence of dementia in our sample and compared such individuals to those with normal cognitive status. We defined current depressive symptoms based on a score ≥9 on the 11-item Center for Epidemiologic Studies Depression (CES-D) scale.[15,16]

Medication adherence was assessed using the Morisky scale and scores were categorized as "low," "intermediate," or "high" based on established cut points.[17] Questions on the Morisky scale were not asked in the context of antihypertensive medications specifically, rather about adherence to all medications. Hypertension duration was determined based on the time elapsed between the date of doctor's diagnosis, medication use, or elevated blood pressure and the 2016-2017 study visit date. If a participant had prevalent hypertension at the first ARIC study visit in 1987-1989, we considered the first study visit as the time of hypertension onset as we did not have prior information.

Body mass index (BMI) was calculated as weight in kilograms (kg) divided by height in meters squared (m^2). BMI was then categorized as <25 kg/m^2 (normal BMI), 25 to <30 kg/m^2 (overweight), or ≥30 kg/m^2 (obese). Diabetes was defined as hemoglobin A1c ≥6.5 %, or using medication for diabetes, or self-reported diagnosis of diabetes. Reduced kidney function was defined as creatinine-based estimated glomerular filtration rate (eGFR) <60 mL/min/1.73 m^2. Prevalent coronary heart disease, stroke, and heart failure were defined based on self-report of an event prior to the first ARIC study visit or an adjudicated event prior to the 2011-2013 visit.

Statistical analysis

We compared baseline characteristics of participants with treated hypertension by race using t-tests for continuous variables and chi-square tests for categorical variables. In a supplemental analysis to better understand losses to follow up among those with treated hypertension in 2011-2013, we compared the characteristics of those who were present and absent in 2016-2017 using t-tests and chi-square tests.

Next, we examined the distribution of SBP values among Black and white participants; we compared mean SBP values and the proportion with SBP <140 mmHg among Black and white participants. Given the 2017 ACC/AHA guideline recommends SBP <130 mmHg, we also examined the proportion of white and Black participants with treated hypertension who had achieved this more stringent SBP goal.

We calculated prevalence ratios for participant characteristics associated with SBP <140 mmHg and SBP <130 mmHg at baseline, stratified by race and adjusted for age and sex, using Poisson regression with robust variance estimates. *A priori*, we stratified regression models by race as we hypothesized there may be racial differences in associations between participant characteristics and hypertension control. We tested for differences in associations among Blacks and whites using models which included an interaction term between race and the characteristic of interest.

Among individuals with SBP <140 mmHg at baseline, we examined the percentage who remained controlled at follow up and the percentage who developed uncontrolled hypertension, stratified by race. Among Blacks and whites, we compared participant characteristics for those who remained controlled and those who developed uncontrolled hypertension at follow up. Among those with SBP ≥140 mmHg at baseline, we examined the percentage of individuals who had controlled hypertension at follow-up and the percentage who remained uncontrolled, and compared participant characteristics by race.

Next, we used logistic regression to evaluate the associations of each participant characteristic of interest with change in hypertension control status from baseline. For those with SBP <140 mmHg at baseline, we calculated odds ratios for the development of uncontrolled hypertension at follow up. For those with SBP ≥140 mmHg at baseline, we calculated odds ratios for controlled hypertension at follow up. We stratified our models by race and controlled for age, sex, and baseline SBP. We again tested for differences in associations by race by including interaction terms between race and the characteristic of interest.

Finally, among participants with available data on antihypertensive medications brought to the study visits, we examined the mean number of medications at baseline and follow up. We tested differences in means using paired t-tests. All analyses were conducted using Stata version 15.1 (College Station, TX). P-values <0.05 were considered statistically significant.

RESULTS

At baseline, Black participants were younger, but had a longer mean duration of hypertension than whites (**Table 1**). Blacks were more likely than whites to be female, have less education, poor physical functioning, depressive symptoms, lower medication adherence, and generally had a higher prevalence of cardiovascular disease and its risk factors. White participants were more likely than blacks to have reduced kidney function. Characteristics of participants who did and did not attend the 2016-2017 visit are found in **Supplemental Table 1**.

Baseline Results

At baseline, mean SBP was lower among whites than Blacks (129.0 vs 134.3 mmHg, p <0.001) (**Figure 1**). At baseline, 75.4% of whites and 66.0% of Blacks had SBP <140 mmHg (p <0.001), while 53.3% and 43.4% of whites and Blacks, respectively, had SBP <130 mmHg (p <0.001). Black participants were, on average, taking more antihypertensive medications than whites (2.53 vs 2.18, p <0.001).

Among white participants at baseline, women, older participants, and those with longer hypertension duration were less likely to have SBP controlled to <140 mmHg (as indicated by prevalence ratios <1.00; **Table 2**). Among Black participants, women and those with longer hypertension duration were less likely to have SBP controlled to <140 mmHg, while those with obesity were more likely to have SBP <140 mmHg. Associations were generally similar for more intensive SBP control (ie, SBP <130 mmHg), though whites with coronary heart disease or heart failure had a higher prevalence of SBP <130 mmHg.

Follow-up Results

At follow up (**Figure 1**), mean SBP was 136.0 mmHg among whites and 137.9 mmHg among blacks (p = 0.04). At follow up, 59.4% of all white participants and 56.5% of all Black participants had SBP <140 mmHg (p=0.20). Among those with controlled hypertension at baseline, approximately one-third of both whites and Blacks had uncontrolled hypertension at follow up (**Figure 2**). Among those with uncontrolled hypertension at baseline, 36.1% of whites and 38.9% of Blacks subsequently had their hypertension controlled at follow up. Descriptive characteristics of Black and white participants by change in hypertension control status from baseline to follow up are presented in **Supplemental Tables 2 and 3**.

Among whites with SBP <140 mmHg at baseline, older age, female sex, and reduced kidney function were associated with higher odds of uncontrolled SBP at follow-up (indicated by odds ratios >1.00; **Table 3**). Among blacks, longer hypertension duration and diabetes were associated with higher odds of uncontrolled SBP at follow-up. There was a significant interaction between diabetes and race, indicating Blacks with diabetes were significantly more likely than whites to have uncontrolled hypertension at follow-up (p-value for interaction = 0.009).

Among those with SBP ≥140 mmHg at baseline, white females and Blacks with reduced kidney function had lower odds of SBP control at follow up (indicated by odds ratios <1.00; **Table 4**). Blacks with reduced kidney function were significantly less likely than whites to have controlled hypertension at follow up (p-value value for interaction = 0.004).

From 2011-2013 to 2016-2017, the mean number of antihypertensive medications per participant decreased from 2.18 to 2.11 (mean difference = -0.07, p = 0.004) among whites; there was no change among Blacks, from 2.53 to 2.55 (mean difference = 0.02, p = 0.64).

DISCUSSION

Among older adults with treated hypertension at baseline, SBP was lower for whites than Blacks, and a greater proportion of whites than Blacks had SBP controlled to <140 mmHg or to a more stringent target of <130 mmHg. While there was greater cumulative exposure to uncontrolled hypertension among blacks during the study period, conditional on baseline hypertension control status, we found similar changes in control among whites and Blacks. Approximately one-third of both whites and Blacks with controlled hypertension at baseline developed uncontrolled hypertension at follow up, and just under 40% of whites and Blacks with uncontrolled hypertension at baseline had controlled hypertension at follow up. However, there were several important differences by race in clinical characteristics associated with subsequent controlled and uncontrolled hypertension which may contribute to disparities in cardiovascular outcomes among older adults.

Among those controlled at baseline, whites and Blacks with reduced kidney function were more likely to have uncontrolled hypertension at follow-up, though the association was not statistically significant among Blacks. Additionally, Blacks with diabetes had two-fold higher odds of incident uncontrolled hypertension as compared to those without diabetes; meanwhile, there was no association with diabetes among whites. Among those who were uncontrolled at baseline, Blacks with reduced kidney function had lower odds of incident control compared to those with normal kidney function; the association was significantly different from that among whites. Given the high burden of diabetes and chronic kidney disease among older Black adults in the population, combined with the less favorable trends in hypertension management for older blacks with such comorbidities, inadequate blood pressure control is an important and potentially increasing source of disparities in cardiovascular health.

During the time between the two study visits, a new clinical guideline was issued by members of the JNC 8 panel recommending higher blood pressure goals for adults aged ≥60 (an increase from <140/90 to <150/90 mmHg) and those with diabetes or chronic kidney disease (an increase from <130/80 to <140/90 mmHg). Of note, the guideline included a corollary recommendation for patients on pharmacologic treatment with lower blood pressures (e.g., <140 mmHg) without adverse effects, that treatment does not necessarily need to be adjusted. It is unclear whether our findings with respect to changes in hypertension control among those with diabetes or reduced kidney function can be attributed to changes in guidelines or whether they reflect changes in provider attitudes and practices towards treatment goals as patients with comorbidities age. For some patients with a high burden of comorbidities or limited life expectancy, higher blood pressure goals may be appropriate based on clinical judgement and patient preferences.[7] However, the less favorable changes in SBP among Blacks with diabetes and chronic kidney diseases are concerning.

Moving forward, as lower blood pressure treatment goals recommended by the 2017 ACC/AHA guideline (i.e., SBP <130 mmHg) are implemented in practice, it will be important to monitor how hypertension is managed among population subgroups. In our study, we examined the proportion of individuals with treated SBP <130 mmHg and cross-sectional associations of participant characteristics with SBP treatment to <130 mmHg at the 2011-2013 study visit. More than half of white participants had their SBP controlled to <130 mmHg at the baseline visit compared with ~40% of black participants. Among both whites and blacks with diabetes or chronic kidney disease, we found no difference in the prevalence of SBP <130 mmHg by diabetes or chronic kidney disease, despite that the JNC7 guideline recommended a target of <130/80 mmHg for such patients at the time. While our findings illustrate blood pressure can be managed to lower levels among older adults, it will be important to ensure lower treatment goals are implemented equitably. This will require targeted efforts to address barriers to hypertension control among African Americans, including those which occur in health care (e.g., provider mistrust, cultural competence) and as a result of historical, social, and economic factors.[18,19] Additionally, it will be important individuals at increased cardiovascular risk, such as those with diabetes or chronic kidney disease, discuss treatment goals with their physicians.

We found that Blacks were using more antihypertensive medications than whites at baseline, though there was little change in the mean number of medications per person among either group at follow-up. It is difficult to determine from our data whether there were additional medication adjustments or intensifications that would have been clinically appropriate, especially if the BP goal remained <140 mmHg. Further examination of treatment practices among older adults using clinic-based information could provide additional insight regarding treatment decisions relative to blood pressure levels and patient health status. Although adherence scores were lower among Blacks than whites at baseline, a small proportion of participants had low adherence scores and this does not appear to be the major driver of differences in blood pressure levels by race.

There are several limitations to our study. First, blood pressure measurements obtained in a research setting may differ from those in the clinical setting used to guide treatment decisions. There is greater variability in blood pressure measurements obtained in the clinical setting than in research studies with standardized measurement protocols.[20] Second, the majority of Black participants in our study are from one study site in Jackson, Mississippi. Differences by race identified in our study may therefore reflect geographic differences in care practices or social determinants of health. Third, changes in blood pressure may reflect heterogeneous processes. Some decreases in blood pressure could be due to worsening health status as opposed to improved hypertension control. Fourth, we were not able to assess whether participants received or adhered to lifestyle modifications to reduce blood pressure. Finally, because of the age of participants in the cohort, there is substantial loss to follow-up between the two study visits. However, study retention is considered high for a cohort of older adults. Additionally, our aim was to describe blood pressures among those who were followed.

Our study also has a number of strengths. The ARIC Study is a large, community-based cohort which includes both Black and white older adults whose health status is well-characterized over time. Risk factors were assessed by trained personnel using rigorous, standardized measurements including a consistent, high-quality blood pressure measurement protocol across the two study visits. Additionally, we were able to leverage ARIC study visits before and after the publication of a major hypertension guideline in 2014.

Conclusion

Our study highlights that Black older adults have a higher cumulative burden of uncontrolled hypertension as compared with whites. While prevention at younger ages is critical, improving hypertension management in older age is also important for reducing cardiovascular disease. We found that blacks with diabetes or chronic kidney disease were less likely to have improvements in hypertension management from 2011-2013 to 2016-2017. Higher treatment goals recommended in 2014 may have contributed to these findings and unintended differences by race. To reduce disparities in cardiovascular disease it is necessary to improve hypertension care among such subgroups, including efforts to address clinical and social factors which influence hypertension control. The lower level of SBP recommended by the 2017 ACC/AHA guideline affords an opportunity to focus on reducing blood pressure for populations at high risk to reduce disparities in cardiovascular disease.

TABLES

Table 1. Characteristics of older adults with treated hypertension in 2011–2013, by race.

	White	Black	p-value
N (%)	1600 (71.1%)	650 (28.9%)	
Age, mean years (SD)	75.1 (4.7)	74.0 (4.7)	<0.001
Female sex	54.4%	71.4%	<0.001
Education			
Less than high school	9.5%	22.8%	<0.001
High school or vocational school	45.6%	32.2%	
College or higher	44.9%	45.1%	
Poor physical function	7.4%	22.3%	<0.001
Pre-frail or frail	50.2%	53.8%	0.12
Mild cognitive impairment or dementia	19.1%	17.7%	0.45
Depressive symptoms	5.1%	9.4%	<0.001
Medication adherence			
High	61.1%	56.2%	<0.001
Intermediate	37.6%	39.2%	
Low	1.3%	4.6%	
Hypertension duration, mean years (SD)	16.3 (7.3)	19.2 (6.5)	<0.001
BMI category (kg/m^2)			
<25	20.1%	11.7%	<0.001
25-<30	41.2%	37.1%	
≥30	38.7%	51.2%	
Diabetes	27.8%	42.9%	<0.001
eGFR <60 mL/min/1.73 m^2	30.1%	24.9%	0.013
Prevalent coronary heart disease	18.9%	9.2%	<0.001
Prevalent stroke	3.1%	5.2%	0.017
Prevalent heart failure	11.6%	18.2%	<0.001

BMI = Body Mass Index. eGFR = Estimated Glomerular Filtration Rate.

Table 2. Characteristics associated with systolic blood pressure <140 mmHg and <130 mmHg among older adults with treated hypertension in 2011–2013, by race.

	SBP <140 mmHg			SBP <130 mmHg		
Prevalence ratio (95% CI)*	**White**	**Black**	***P*†**	**White**	**Black**	***P*†**
Age, per 5 years	**0.95 (0.92-0.98)**	0.95 (0.89-1.01)	0.96	**0.89 (0.84-0.93)**	**0.85 (0.76-0.94)**	0.43
Female (vs Male)	**0.91 (0.86-0.96)**	**0.86 (0.77-0.96)**	0.38	**0.88 (0.80-0.96)**	0.84 (0.70-1.00)	0.64
Education (vs Less than high school)			0.78			0.26
High school or vocational school	0.99 (0.90-1.09)	0.99 (0.85-1.16)		0.91 (0.77-1.07)	1.10 (0.86-1.41)	
College or higher	0.99 (0.90-1.09)	1.04 (0.90-1.20)		1.00 (0.85-1.17)	1.04 (0.82-1.31)	
Poor physical function (vs Normal)	0.96 (0.85-1.09)	1.06 (0.92-1.21)	0.39	0.88 (0.71-1.09)	1.14 (0.93-1.41)	0.14
Pre-frail or frail (vs Not frail)	1.01 (0.95-1.07)	1.04 (0.93-1.16)	0.75	1.00 (0.91-1.09)	**1.22 (1.02-1.45)**	0.08
Mild cognitive impairment or dementia (vs Normal)	0.95 (0.88-1.02)	0.99 (0.85-1.16)	0.66	0.97 (0.86-1.09)	0.93 (0.72-1.20)	0.90
Depressive symptoms (vs No)	1.01 (0.90-1.15)	0.84 (0.67-1.06)	0.15	1.05 (0.86-1.28)	0.74 (0.51-1.07)	0.10
Medication adherence (vs High)			0.50			0.30
Intermediate	1.01 (0.96-1.07)	0.94 (0.84-1.06)		0.99 (0.90-1.09)	0.92 (0.77-1.10)	
Low	0.93 (0.71-1.22)	0.97 (0.75-1.26)		**0.43 (0.20-0.92)**	0.77 (0.47-1.26)	
Hypertension duration, per 5 years	**0.97 (0.95-0.98)**	**0.94 (0.91-0.97)**	0.13	0.99 (0.96-1.02)	0.99 (0.93-1.05)	0.84
BMI category, kg/m^2 (vs <25)			0.40			0.73
25-<30	1.02 (0.94-1.11)	1.20 (0.97-1.49)		1.00 (0.87-1.13)	1.14 (0.83-1.57)	
≥30	1.05 (0.97-1.14)	**1.24 (1.00-1.54)**		1.06 (0.93-1.20)	1.18 (0.86-1.61)	
Diabetes (vs No)	1.01 (0.95-1.08)	1.01 (0.90-1.13)	0.99	1.01 (0.92-1.12)	1.01 (0.85-1.21)	0.95
eGFR <60 mL/min/1.73 m^2 (vs ≥60)	0.96 (0.90-1.02)	0.99 (0.87-1.13)	0.65	1.04 (0.94-1.15)	1.12 (0.92-1.37)	0.57
Prevalent coronary heart disease (vs No)	1.02 (0.95-1.10)	0.91 (0.74-1.12)	0.38	**1.16 (1.04-1.29)**	1.05 (0.78-1.41)	0.56
Prevalent stroke (vs No)	0.99 (0.84-1.16)	0.98 (0.76-1.26)	1.00	0.91 (0.68-1.23)	0.83 (0.53-1.29)	0.71
Prevalent heart failure (vs No)	0.98 (0.89-1.07)	0.97 (0.84-1.12)	0.98	**1.17 (1.02-1.33)**	1.01 (0.81-1.27)	0.26

*Prevalence ratios adjusted for age and sex. A prevalence ratio >1.00 indicates a higher prevalence of hypertension control as compared to the reference group. Bold indicates the prevalence ratio is significant at p <0.05.

†P-value for interaction. A p-value for interaction <0.05 indicates a statistically significant difference in the association by race.

BMI = Body Mass Index. CI = Confidence Interval. eGFR = Estimated Glomerular Filtration Rate.

Table 3. Odds ratios for <u>uncontrolled</u> systolic blood pressure in 2016–2017 among white and black participants with <u>controlled</u> systolic blood pressure in 2011–2013.

	Whites	**Blacks**	***P*-value for interaction**
	OR (95% CI)*	**OR (95% CI)***	
Age, per 5 years	**1.30 (1.14-1.48)**	1.14 (0.92-1.42)	0.31
Female (vs Male)	**1.60 (1.25-2.06)**	1.20 (0.77-1.86)	0.25
Education (vs Less than high school graduate)			0.24
High school or vocational school	1.13 (0.73-1.75)	0.87 (0.50-1.54)	
College or higher	0.78 (0.50-1.22)	0.96 (0.57-1.62)	
Poor physical function (vs Normal)	1.25 (0.78-2.02)	0.86 (0.52-1.42)	0.18
Pre-frail or frail (vs Not frail)	1.23 (0.95-1.58)	1.32 (0.88-2.02)	0.93
Mild cognitive impairment or dementia (vs Normal)	1.24 (0.90-1.70)	1.56 (0.91-2.65)	0.55
Depressive symptoms (vs No)	1.04 (0.59-1.82)	1.46 (0.71-3.00)	0.47
Medication adherence (vs High)			0.39
Intermediate	0.91 (0.70-1.18)	1.27 (0.83-1.96)	
Low	2.14 (0.74-6.21)	1.77 (0.68-4.61)	
Hypertension duration, per 5 years	1.03 (0.95-1.12)	**1.23 (1.05-1.44)**	0.06
BMI category, kg/m^2 (vs <25)			0.23
25-<30	0.88 (0.63-1.24)	0.90 (0.44-1.82)	
≥30	0.83 (0.58-1.17)	0.54 (0.27-1.10)	
Diabetes (vs No)	1.03 (0.78-1.36)	**1.92 (1.27-2.92)**	**0.009**
eGFR <60 mL/min/1.73 m^2 (vs ≥60)	**1.32 (1.00-1.75)**	1.47 (0.92-2.35)	0.76
Prevalent coronary heart disease (vs No)	1.37 (0.99-1.90)	0.95 (0.45-2.00)	0.45
Prevalent stroke (vs No)	1.48 (0.74-2.95)	1.82 (0.75-4.45)	0.70
Prevalent heart failure (No)	0.93 (0.62-1.40)	1.02 (0.59-1.73)	0.80
Systolic blood pressure at Visit 5	**1.04 (1.03-1.05)**	**1.04 (1.02-1.07)**	0.90

*Odds ratios adjusted for age, sex, and systolic blood pressure at Visit 5 (2011-2013). An odds ratio >1.00 indicates higher odds of <u>uncontrolled</u> systolic blood pressure in 2016-2017. Bold indicates statistically significant at p <0.05. A p-value for interaction <0.05 indicates a statistically significant difference in the association by race. BMI = Body Mass Index. CI = Confidence Interval. eGFR = Estimated Glomerular Filtration Rate. OR = Odds Ratio.

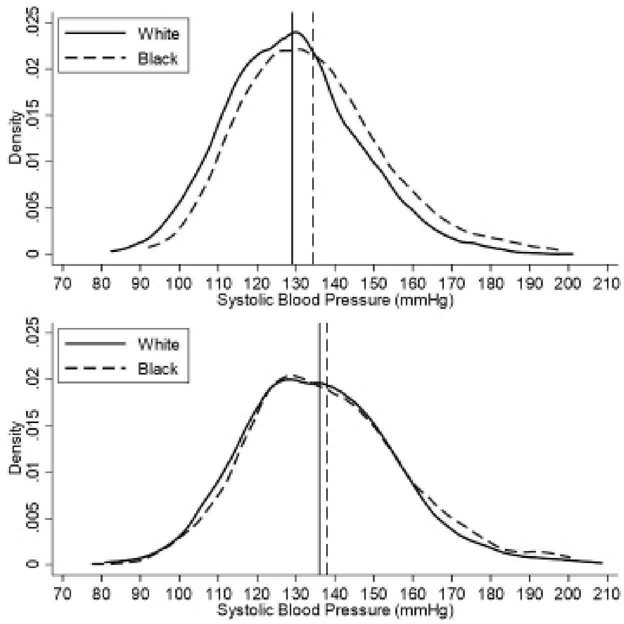
Table 4. Odds ratios for controlled systolic blood pressure in 2016–2017 among white and black participants with uncontrolled systolic blood pressure in 2011–2013.

	Whites	**Blacks**	***P*-value for interaction**
	OR (95% CI)*	**OR (95% CI)***	
Age, per 5 years	1.10 (0.97-1.38)	1.12 (0.84-1.48)	0.92
Female (vs Male)	**0.45 (0.29-0.68)**	0.83 (0.43-1.59)	0.11
Education (vs <Less than high school)			0.53
High school or vocational school	0.85 (0.40-1.83)	0.62 (0.29-1.31)	
College or higher	0.96 (0.44-2.08)	1.15 (0.57-2.29)	
Poor physical function (vs Normal)	1.49 (0.72-3.08)	1.57 (0.80-3.11)	0.78
Pre-frail or frail (vs Not frail)	0.97 (0.63-1.49)	0.83 (0.48-1.44)	0.70
Mild cognitive impairment or dementia (vs Normal)	1.15 (0.69-1.94)	0.55 (0.26-1.16)	0.12
Depressive symptoms (vs No)	0.71 (0.26-1.95)	0.53 (0.21-1.32)	0.74
Medication adherence (vs High)			0.41
Intermediate	0.93 (0.60-1.44)	0.79 (0.45-1.39)	
Low	0.41 (0.05-3.75)	1.69 (0.45-6.34)	
Hypertension, duration per 5 years	1.09 (0.93-1.28)	0.88 (0.68-1.14)	0.15
BMI category, kg/m^2 (vs <25)			0.87
25-<30	1.41 (0.80-2.50)	0.98 (0.42-2.30)	
≥30	1.52 (0.85-2.73)	1.10 (0.48-2.56)	
Diabetes (vs No)	1.16 (0.72-1.86)	0.81 (0.47-1.41)	0.38
eGFR <60 mL/min/1.73 m^2 (vs ≥60)	1.46 (0.92-2.32)	**0.44 (0.22-0.87)**	**0.004**
Prevalent coronary heart disease (vs No)	1.03 (0.58-1.82)	1.67 (0.68-4.10)	0.56
Prevalent stroke (vs No)	0.45 (0.12-1.75)	0.69 (0.20-2.42)	0.72
Prevalent heart failure (vs No)	1.26 (0.68-2.36)	0.77 (0.38-1.60)	0.29
Systolic blood pressure at Visit 5	**0.98 (0.96-1.00)**	0.99 (0.97-1.01)	0.36

*Odds ratios adjusted for age, sex, and systolic blood pressure at Visit 5 (2011-2013). An odds ratio >1.00 indicates higher odds of controlled systolic blood pressure in 2016-2017. Bold indicates statistically significant at p <0.05. A p-value for interaction <0.05 indicates a statistically significant difference in the association by race. BMI = Body Mass Index. CI = Confidence Interval. eGFR = Estimated Glomerular Filtration Rate. OR = Odds Ratio.

FIGURES

Figure 1. Systolic blood pressure among older adults with treated hypertension in 2011–2013 (top) and 2016–2017 (bottom), by race.



2011-2013

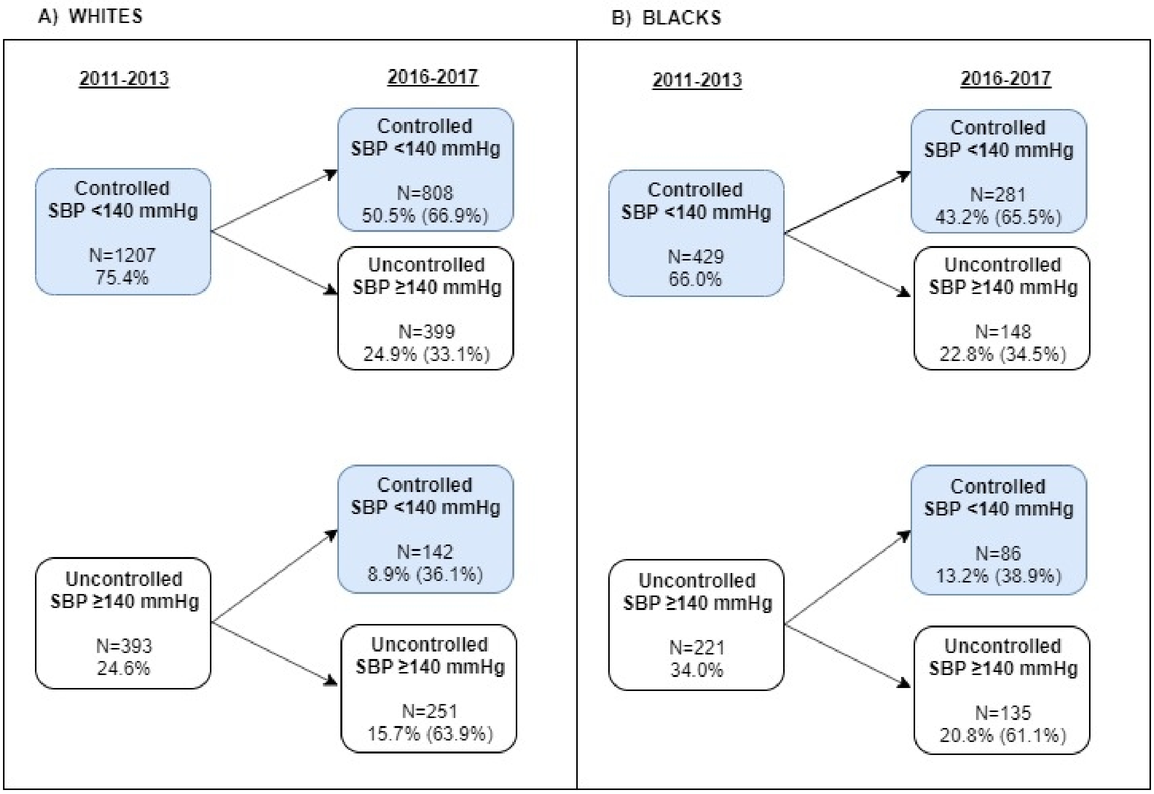
	Mean SBP (SD)	SBP <140	SBP <130
White	129.0 (17.2)	75.4%	53.3%
Black	134.3 (18.3)	66.0%	43.4%

2016-2017

	Mean SBP (SD)	SBP <140	SBP <130
White	136.0 (19.4)	59.4%	39.8%
Black	137.9 (19.4)	56.5%	37.5%

This figure shows the SBP distributions for white and black adults at Visit 5 (2011-2013) and Visit 6 (2016-2017). The mean SBP values and percentage of individuals with SBP <140 mmHg and <130 mmHg at each visit are given at right. SBP = Systolic Blood Pressure. SD = Standard Deviation.

Figure 2. Systolic blood pressure control in 2011–2013 and 2016–2017, by race.



The figure shows the percent of white and black individuals with SBP <140 mmHg and ≥140 mmHg at baseline in 2011-2013. Within baseline categories of baseline hypertension control, we show the overall percent of individuals with controlled and uncontrolled hypertension in 2016-2017. The value in parentheses refers to the percent of individuals from the baseline category.

Chapter 4. Implementation of 2017 ACC/AHA hypertension guideline: Potential effect on cardiovascular events among white and Black adults in the United States

Co-authors: Elizabeth Selvin, Josef Coresh, Lawrence J. Appel

Introduction: Treating hypertension to lower levels of blood pressure (<130/80 mmHg) recommended by the 2017 ACC/AHA hypertension guideline could promote cardiovascular health equity. Alternatively, there are concerns about differential implementation, which might increase racial disparities. The purpose of our study was to investigate the potential impact of treating hypertension according to the 2017 guideline on racial disparities in hypertension control and the proportion of cardiovascular disease events which could be prevented nationally in different implementation scenarios.

Methods: We used 2011-2016 data from the National Health and Nutrition Examination Survey for Black and white adults aged ≥40 to estimate the prevalence of hypertension, uncontrolled hypertension, and eligibility for antihypertensive treatment. We used hazard ratios for the risk associated with systolic blood pressure above the treatment goal from a network meta-analysis of hypertension treatment trials. We calculated the proportion of events prevented among Blacks and whites if all those eligible for antihypertensive treatment had their blood pressure reduced to the treatment goal and when less than 100% of individuals were treated to the goal.

Results: Overall, 74.0% of Blacks and 59.9% of whites had hypertension, 56.3% of Blacks and 43.0% of whites had uncontrolled hypertension, and 44.4% of Blacks and 31.9% of whites were eligible for pharmacologic treatment. If all individuals with hypertension eligible for pharmacologic treatment were treated to goal, 29.0% (27.3%, 30.7%) of cardiovascular events among Blacks and 21.0% (19.7, 22.3%) of cardiovascular events among whites would be prevented. With the same relative reduction in uncontrolled hypertension, the proportion of

cardiovascular events prevented is higher among Blacks than whites. However, if the reduction in the prevalence of uncontrolled hypertension is more than ~1.4 times higher among whites than Blacks, there would be a greater reduction in the proportion of events prevented among whites than Blacks, thereby exacerbating disparities.

Conclusion: Treating hypertension to the 2017 ACC/AHA goal could reduce absolute and relative racial disparities in cardiovascular events in the population. However, there is also a possibility of exacerbating disparities if implementation occurs differentially by race. Efforts are warranted to promote equitable improvements in hypertension control in practice.

INTRODUCTION

The rate of cardiovascular disease mortality in the United States has decreased dramatically from its peak in the 1950s due to advances in prevention and treatment.[1,2] While rates were comparable among Blacks and whites at the start of the decline, racial disparities in cardiovascular disease have since emerged and persisted.[3,4] The fundamental social causes of disease theory posits it is our expanded ability to prevent and control disease which leads to improved population health that also causes disparities as the benefits of public health and medical interventions are distributed according to available resources.[4]

High blood pressure is a leading modifiable risk factor for cardiovascular disease. High blood pressure is more common (40.3% vs 27.8%) and more poorly controlled (44.6% vs 50.8%) among non-Hispanic Black than non-Hispanic white adults in the U.S.[5] Hypertension has been described as one of the most important risks to the cardiovascular health of African Americans and also one of the greatest opportunities for disease prevention if effectively managed and prevented.[6] Reducing racial disparities in hypertension control is therefore a priority for cardiovascular health equity.

In 2017, the American College of Cardiology (ACC) and American Heart Association (AHA) published a new high blood pressure guideline which redefined hypertension at a lower level of blood pressure (≥130/80 mmHg) and recommended a lower blood pressure goal for those treated with antihypertensive medication (<130/80 mmHg).[7] The guideline presents opportunities and challenges for cardiovascular health and disparities in the population. One recent modeling study found achieving the 2017 ACC/AHA guideline systolic blood pressure treatment goal could avert 610,000 cardiovascular events and 334,000 all-cause deaths among US adults aged 40 years and older.[8]

Implementation of the 2017 ACC/AHA guideline recommendations would be expected to result in greater absolute and relative benefit for subgroups with higher blood pressures, including

African Americans. However, the guideline has not been endorsed by certain primary care societies and there are concerns about feasibility of implementation.[9] The extent to which the guideline has been adopted in clinical practice is unknown. There is the potential to exacerbate disparities if lower blood pressure treatment goals are implemented differentially, such as if lower treatment goals are more widely used among individuals with greater access to care, who are already better managed, or are at lower risk.[10]

The population-attributable fraction (PAF) represents the proportion of disease cases in the population attributed to a risk factor; it can also be interpreted as the proportion of cases which would be theoretically prevented in the population if the exposure was eliminated, assuming the exposure is a direct cause of the disease.[11] The PAF is determined by the prevalence of the exposure and the risk of disease it confers. When the counterfactual scenario is not elimination but a reduction of the exposure prevalence, a related concept, the potential impact fraction (PIF) can be used to estimate the proportion of cases which would be prevented.[12] The PAF and PIF are useful for prioritizing public health policy and programs to address modifiable risk factors which have the greatest impact on reducing disease.[13,14] The objective of our study was to examine the potential impact of treating hypertension according to the 2017 ACC/AHA guideline on racial disparities in cardiovascular events in U.S. adults using the PAF or PIF in multiple implementation scenarios.

METHODS

Data source

We used data from the National Health and Nutrition Examination Survey (NHANES) for the years 2011-2016. NHANES is a population-based survey which uses stratified, multistage probability sampling to produce nationally-representative estimates for the civilian, noninstitutionalized population in the U.S. The survey includes interview and examination components. NHANES was approved by the National Center for Health Statistics Institutional Review Board and informed consent was obtained from all participants.

Study population

We included Black and white adults aged 40 years and older from the NHANES 2011-2016 survey cycles who completed the examination component of the survey (N=6,912). We excluded participants who did not have at least one valid blood pressure measurement or for whom hypertension status could not be determined. We also excluded those with missing data for covariates used to determine their treatment eligibility (diabetes, chronic kidney disease, history of cardiovascular disease, and atherosclerotic cardiovascular disease (ASCVD) risk score). The final analytic sample included 6,106 participants.

Blood pressure measurement

Blood pressure measurements were obtained by trained physicians using a standard study protocol during the NHANES examination.[15] After participants rested in a seated position for five minutes, three consecutive auscultatory blood pressure readings were obtained using a mercury sphygmomanometer and appropriately sized blood pressure cuff. If a blood pressure measurement was interrupted or incomplete, a fourth attempt was made. We used all available blood pressure readings (i.e., up to three measurements) to calculate mean systolic (SBP) and diastolic (DBP) blood pressures.[16]

Hypertension and uncontrolled hypertension

Based on the ACC/AHA guideline (**Table 1**), we defined hypertension as having SBP ≥130 mmHg, or DBP ≥80 mmHg, or currently taking antihypertensive medications. Current antihypertensive medication use was based on self-report. We defined uncontrolled hypertension as having SBP ≥130 mmHg or DBP ≥80 mmHg.

Treatment eligibility

We determined eligibility for new or additional pharmacotherapy based on the 2017 ACC/AHA guideline recommendations.[7] All individuals with SBP ≥140 mmHg or DBP ≥90 mmHg were eligible for pharmacotherapy. Individuals with SBP 130-139 mmHg and/or DBP 80-89 mmHg were considered eligible for pharmacotherapy if they reported current antihypertensive medication use (ie, had hypertension) or were aged ≥65 years, had diabetes, chronic kidney disease, history of cardiovascular disease, or 10-year ASCVD risk ≥10%. Diabetes was determined based on self-reported diagnosis or diabetes medication use. Chronic kidney disease was defined based on an albumin-to-creatinine ratio ≥30 mg/g or estimated glomerular filtration rate (eGFR) <60 mL/min/1.73 m^2 based on the CKD-EPI equation. History of cardiovascular disease was assessed based on self-reported history of coronary heart disease (coronary heart disease, myocardial infarction, or angina), heart failure, or stroke. We calculated ASCVD risk score using the Pooled Cohort Equation among individuals without a history of cardiovascular disease aged 40-79.[17,18]

Descriptive characteristics

We report descriptive characteristics among whites and Blacks. Among the overall population, those with hypertension, and those with uncontrolled hypertension eligible for medication initiation or intensification, we estimated the proportion who are female, aged ≥65 years, with diagnosed diabetes, chronic kidney disease, history of cardiovascular disease, and among those without cardiovascular disease, the proportion with an ASCVD risk score ≥10%. We compared differences in proportions among whites and Blacks using chi-square tests and differences in means using t-tests. We used a 2-sided p-value <0.05 to define statistical significance. All analyses incorporated sampling weights to account for the complex survey design and generate estimates representative of the civilian U.S. population aged 40 or older.

Population attributable fraction and population impact fraction

The PAF or PIF is calculated from the prevalence of the exposure and the risk of disease associated with the exposure. We considered the exposure as a multi-category variable; we used NHANES data to estimate the prevalence of each exposure category and estimates from the literature to estimate the risk associated with each exposure category above the reference.[8,19]

We used hazard ratios for cardiovascular disease events (coronary heart disease, stroke, heart failure, or cardiovascular disease death) associated with SBP above the treatment goal from the network meta-analysis by Bundy et al,[20] which included 42 antihypertensive clinical trials with 144,220 participants. Other studies examining the population impact of treating hypertension according to the ACC/AHA guideline recommendations have also used hazard ratios associated with SBP above the treatment goal from this network meta-analysis.[8,19] We are not aware of a similar meta-analysis based on DBP.

To align with the hazard ratios available for SBP above the treatment goal, we categorized SBP values as <130 (reference), 130-134, 135-139, 140-144, 145-149, 150-154, 155-159, or ≥160 mmHg. We determined treatment eligibility as described earlier, but based only on the SBP component. We assumed that only those eligible for pharmacologic treatment would have their SBP reduced.

We used the following formula to calculate the proportion of cardiovascular events prevented under each implementation scenario:

PIF =

where *p* is the prevalence in each SBP category and *p′* is the prevalence under the counterfactual, HR is the hazard ratio of the exposed compared to the reference level of exposure, and *n* is the total number of SBP categories. The PAF is a specific case of the PIF when the counterfactual exposure prevalence is zero (i.e., the exposure is eliminated).

Hypertension treatment scenarios

First, we calculated the PAF by race, or the proportion of events which could be prevented among whites and Blacks if all individuals eligible for pharmacologic treatment were treated and achieved SBP <130 mmHg. We assumed no reduction in SBP occurred among those individuals with SBP 130-139 but not eligible for pharmacologic treatment (i.e., recommended lifestyle modification only). In a sensitivity analysis, we examined the proportion of events prevented if all individuals with systolic blood pressure ≥130 mmHg had their SBP reduced to <130 mmHg.

Second, we estimated the proportion of events prevented in scenarios when less than 100% of individuals eligible for antihypertensive medication are treated to SBP <130 mmHg. We examined the impact of 75%, 50%, 25%, 20%, 15%, 10%, and 5% reductions in uncontrolled SBP. We assumed the reduction in uncontrolled SBP occurred uniformly across SBP categories (for example, when the overall prevalence of uncontrolled SBP was reduced by 20%, we reduced the prevalence in each treatment-eligible SBP category by 20%). We also calculated the absolute reduction in uncontrolled SBP and the absolute disparity in uncontrolled SBP for each scenario.

Among the scenarios with less than complete implementation, we examined the impact of a plausible reduction in uncontrolled SBP on preventing cardiovascular events. We highlight results for a 20% reduction in uncontrolled SBP as this may be achievable in clinical settings,[21] though there is scarce evidence on real-world improvements in controlling SBP to <130 mmHg. Additionally, to understand how different the relative reductions in uncontrolled SBP would have to be among whites and Blacks to exacerbate disparities in cardiovascular events, we estimated the reduction in uncontrolled hypertension among whites which would prevent the same proportion of cardiovascular events as a 20% reduction in uncontrolled hypertension among

Blacks. Finally, we considered the impact of reducing uncontrolled SBP by 20% among whites and achieving a comparable absolute prevalence of uncontrolled SBP among Blacks (ie, a "leveling up" approach).[22]

To estimate the 95% confidence interval for the PAF, we used Monte Carlo simulations to account for the uncertainty around the estimated prevalence in each SBP category and uncertainty around the hazard ratio. We performed 10,000 repetitions and used the 2.5th and 97.5th percentiles to form the confidence interval.[8,23] Confidence intervals for the PIF are scaled from those for the PAF. All analyses were performed in Stata version 15.1 (StataCorp, College Station, TX).

RESULTS

Descriptive characteristics

Among adults aged 40 years and older, 74.0% of Blacks and 59.9% of whites had hypertension (**Table 2**). In the overall population 56.3% of Blacks and 43.0% of whites had uncontrolled hypertension, and 44.4% of Blacks and 31.9% of whites were eligible for pharmacologic treatment. The mean SBP (131.5 mmHg vs 125.7 mmHg) and DBP (73.1 mmHg vs 71.3 mmHg) were significantly higher among Blacks than whites. The prevalence of diabetes, chronic kidney disease, cardiovascular disease and ASCVD risk score ≥10% were significantly higher among Blacks than whites. A greater proportion of whites than Blacks were aged 65 and older.

Among those with hypertension and uncontrolled hypertension, the mean SBP and DBP were significantly higher among Blacks than whites. The prevalence of diabetes and ASCVD risk score ≥10% were significantly higher among Blacks than whites, but the prevalence of chronic kidney disease and cardiovascular disease were similar by race.

Population attributable fraction

The prevalence of Black and white adults in each SBP-treatment category is shown in **Table 3**. If all individuals with hypertension eligible for pharmacologic treatment were treated to SBP <130 mmHg, 29.0% (27.3%, 30.7%) of cardiovascular events among Blacks and 21.0% (19.7%, 22.3%) of cardiovascular events would be prevented (**Table 4, Figure 1**).

If SBP was reduced among all individuals with SBP ≥130 mmHg, regardless of recommendation for pharmacologic therapy (i.e., including those for whom only lifestyle modification is recommended), we estimated that 30.3% (28.5%, 32.1%) of cardiovascular events among Blacks and 22.3% (20.9%, 23.6%) of cardiovascular events among whites would be prevented (**Supplemental Table 1**).

Potential impact fraction

For the same proportional reduction in uncontrolled SBP, there would be a greater absolute reduction in uncontrolled SBP among Blacks than whites and a reduction in the absolute disparity in uncontrolled hypertension (**Table 4**). Additionally, for a given reduction, the proportion of cardiovascular events prevented is higher among Blacks than whites, which would reduce relative and absolute disparities in the incidence of cardiovascular events in the population.

For example, a 20% relative reduction in uncontrolled SBP would reduce the prevalence of uncontrolled SBP from 30.4% to 24.3% (a 6.1% absolute decrease) among whites and from 42.5% to 34.0% (an 8.5% absolute decrease) among Blacks, still higher than the baseline prevalence of uncontrolled hypertension among whites. The absolute disparity in uncontrolled SBP would be reduced from 12.1% to 9.7%. A 20% relative reduction in uncontrolled SBP would be expected to prevent 5.8% (5.5%, 6.1%) of all cardiovascular events among Blacks and 4.2% (3.9%, 4.5%) among whites (**Figure 1**).

Exacerbation of disparities in cardiovascular events

We found that a 27.6% reduction in uncontrolled hypertension among whites would prevent the same proportion of cardiovascular events (5.8%) as a 20% reduction in uncontrolled hypertension among Blacks (**Figure 1**). Therefore, if the reduction in the prevalence of uncontrolled SBP is more than ~1.4 times higher (27.6% vs 20%) among whites than Blacks, there would be a greater reduction in the proportion of events prevented among whites than Blacks, thereby increasing relative and absolute disparities in cardiovascular event rates.

"Leveling up" the prevalence of uncontrolled systolic blood pressure

A 20% relative reduction in uncontrolled SBP among whites would reduce the prevalence of uncontrolled SBP to 24.3%. To achieve a comparable 24.3% prevalence of uncontrolled SBP among Blacks would require a 43% relative reduction in uncontrolled SBP (18.2% absolute reduction). Reducing the prevalence of uncontrolled SBP to 24.3% among Blacks would be expected to prevent 12.5% (11.7%, 13.2%) of cardiovascular events (**Figure 2**).

DISCUSSION

We found that nearly three-fourths of Black adults and nearly 60% of white adults aged 40 years and older had hypertension according to the definition used in the 2017 ACC/AHA guideline. Among those with hypertension, a greater proportion of Blacks than whites did not have their blood pressure controlled and were eligible for pharmacologic treatment. We found that with pharmacologic treatment among those eligible, 29% of cardiovascular events among Blacks and 21% of cardiovascular events among whites could be prevented. While this is the theoretical maximum, smaller reductions in uncontrolled hypertension could have population health benefits and reduce absolute and relative disparities in the incidence of cardiovascular events. However, if guideline-recommended treatment goals are achieved to a greater extent among whites than Blacks, it is possible there would be no reduction, or even an exacerbation, of existing disparities in cardiovascular events.

Health systems such as Kaiser Permanente Northern California (KPNC) have shown it is possible to substantially improve hypertension control.[24] The challenge is to do so in other settings and to do so equitably. A study in 12 safety-net clinics in San Francisco which adapted the KPNC hypertension program reduced uncontrolled hypertension (defined as <140/90 mmHg) among their overall patient population, and achieved 15% to 20% relative reductions in uncontrolled hypertension in all racial/ethnic groups, including white, Black, Latino, and Asian patients.[21] While there was a greater absolute improvement in hypertension control among Blacks, disparities were not eliminated; hypertension control was lower among Blacks (66%) than whites (75%), Latinos (72%), or Asians (78%) 2 years post-intervention.[21] The authors conclude targeted strategies are needed to eliminate disparities in hypertension control.

While we chose to discuss the impact of a 20% relative reduction in uncontrolled hypertension, it is unclear what a plausible reduction in uncontrolled hypertension would be using a lower blood pressure threshold for control. To achieve SBP <130 mmHg, the average SBP reduction needed among those eligible for pharmacotherapy is approximately 15 mmHg among whites and Black17 mmHg among Blacks. This means patients would likely require multiple drugs,[25] coupled with non-pharmacologic lifestyle modifications. Achieving this magnitude of SBP reduction in clinical care would likely require intensive follow up, and the uptake and efficacy of interventions is often socially patterned.[26] We showed that even a 1.4-fold difference in the reduction in uncontrolled hypertension among whites versus Blacks would not reduce or exacerbate disparities in cardiovascular events. Again, the challenge is to mitigate inconsistencies in guideline implementation and ensure targeted strategies complement broad efforts to improve hypertension control.[10]

Even if the guideline target of SBP <130 mmHg is not achieved in clinical care, a small shift in the distribution of blood pressure in the population can have large cardiovascular health benefits.[27] Our findings also highlight the importance of equity-promoting policy and environmental changes to reduce blood pressure in the population,[26,28] such as sodium reduction in the food supply, increasing access to supermarkets and healthy foods, and increasing access to safe spaces for physical activity, which decrease reliance on individual behavior change (by physicians, patients, caregivers/families) and may be necessary to achieve the desired magnitude of blood pressure reduction.[6,29] In addition to changing the context for health, achieving cardiovascular health equity will require us to directly address the root causes of racial inequalities in health. Specifically, it is necessary to address systemic racism in the U.S. as a fundamental cause of inequalities in socioeconomic resources and health outcomes.[30]

Our study has several limitations. First, we assume that the hazard ratios are the same among Blacks and whites. However, for the same SBP, the risk of stroke for example, is higher among Blacks than whites.[6] Second, we are unable to estimate the uncertainty for the relative and absolute differences in uncontrolled SBP under these scenarios. We algebraically estimated the proportion of individuals in each SBP category under the counterfactual and thus do not have confidence intervals for the prevalence. Additionally, we assumed reductions in uncontrolled SBP occurred uniformly across categories which may not occur. Third, due to limited sample sizes, we did not examine the PAF or PIF among population subgroups within racial groups or among other racial/ethnic subgroups. Fourth, we did not consider the risks of adverse events, though the benefits of lowering blood pressure to a more stringent target outweigh the risks at the population level.[8] Our study also has several strengths. We used a similar method as two previous studies of the potential impact of the 2017 ACC/AHA guideline to estimate the PAF.[8,19] Though we used a different method than Clark et al, who estimated hazard ratios for hypertension based on analyses of the Jackson Heart Study and the Reasons for Geographic and Racial Differences in Stroke

(REGARDS) studies, our estimates for the PAF among Blacks are similar.[14] Our work extends previous studies by considering the implications for racial disparities in uncontrolled hypertension and cardiovascular disease events. We also consider scenarios when less than complete implementation occurs.

Conclusion

Recently, the American Heart Association announced its 2030 High Impact Goal to equitably increase healthy life expectancy in the population.[31] Improving primordial prevention and treatment of hypertension can play a major role in achieving this goal. Reducing blood pressure to the ACC/AHA guideline-recommended target of <130/80 mmHg would disproportionately benefit populations with higher blood pressures who are at increased risk of cardiovascular disease events and deaths, including African Americans. Efforts are warranted to promote equitable improvements in hypertension control in practice.

TABLES

Table 1. Blood pressure thresholds used in 2017 ACC/AHA guideline to define hypertension, recommend pharmacologic treatment initiation, and pharmacologic treatment goals.

Criteria	Population	Blood pressure threshold
Hypertension definition		
Systolic blood pressure	All adults	≥130 mmHg
Diastolic blood pressure	All adults	≥80 mmHg
Pharmacologic treatment initiation		
Systolic blood pressure		
	General population	≥140 mmHg
	Diabetes or chronic kidney disease	≥130 mmHg
	History of cardiovascular disease or ASCVD risk ≥10%	≥130 mmHg
	Aged ≥65 years	≥130 mmHg
Diastolic blood pressure		
	General population	≥90 mmHg
	Diabetes or chronic kidney disease	≥80 mmHg
	History of cardiovascular disease or ASCVD risk ≥10%	≥80 mmHg
Pharmacologic treatment goal		
Systolic blood pressure		
	General population	<130 mmHg
	Diabetes or chronic kidney disease	<130 mmHg
	History of cardiovascular disease or ASCVD risk ≥10%	<130 mmHg
	Aged ≥65 years	<130 mmHg
Diastolic blood pressure		
	General population	<90 mmHg
	Diabetes or chronic kidney disease	<80 mmHg
	History of cardiovascular disease or ASCVD risk ≥10%	<80 mmHg

ASCVD = Atherosclerotic cardiovascular disease. 10-year ASCVD risk calculated using race-sex specific Pooled Cohort Equations.

Table 2. Characteristics of non-Hispanic white and black adults aged ≥40 years with hypertension and recommended pharmacologic treatment according to the 2017 ACC/AHA guideline – NHANES 2011-2016.

	Overall			Hypertension			Uncontrolled hypertension eligible for pharmacologic treatment		
	White % (SE)	Black % (SE)	*P*-value	White % (SE)	Black % (SE)	*P*-value	White % (SE)	Black % (SE)	*P*-value
Female	52.0 (0.8)	56.1 (0.8)	0.003	50.8 (1.0)	55.4 (1.1)	0.008	48.9 (1.3)	51.5 (1.5)	0.24
Aged ≥65 years	32.8 (1.0)	22.6 (1.0)	<0.001	41.1 (1.1)	27.2 (1.2)	<0.001	55.0 (1.4)	33.6 (1.4)	<0.001
Diagnosed diabetes	13.7 (0.6)	22.6 (0.9)	<0.001	18.5 (0.9)	26.8 (1.1)	<0.001	21.2 (1.3)	31.7 (1.7)	<0.001
Chronic kidney disease	19.6 (0.8)	22.4 (0.9)	0.01	26.0 (1.0)	27.3 (1.1)	0.51	34.0 (1.5)	35.3 (1.5)	0.58
History of cardiovascular disease	13.4 (0.5)	15.5 (0.8)	0.02	17.5 (0.7)	18.4 (1.0)	0.35	19.6 (1.2)	20.7 (1.4)	0.52
ASCVD risk ≥10%*	27.6 (1.0)	38.9 (1.4)	<0.001	39.6 (1.4)	50.8 (1.7)	0.47	64.5 (1.8)	73.2 (1.7)	<0.001
Hypertension	59.9 (1.0)	74.0 (1.1)	<0.001	100	100	–	100	100	–
Uncontrolled hypertension	43.0 (1.0)	56.3 (1.2)	<0.001	71.7 (1.5)	76.1 (1.3)	0.01	100	100	–
Uncontrolled hypertension eligible for pharmacologic treatment	31.9 (1.0)	44.4 (1.2)	<0.001	53.2 (1.5)	60.0 (1.3)	0.002	100	100	–
Mean systolic blood pressure (SE)	125.7 (0.4)	131.5 (0.6)	<0.001	133.5 (0.5)	137.3 (0.6)	<0.001	144.6 (0.6)	147.2 (0.6)	0.003
Mean diastolic blood pressure (SE)	71.3 (0.3)	73.1 (0.4)	<0.001	73.3 (0.4)	74.9 (0.5)	0.02	75.0 (0.6)	77.5 (0.7)	0.01

*Among those without cardiovascular disease aged 40-79 years

SE = Standard error

ASCVD = Atherosclerotic cardiovascular disease

Hypertension defined as systolic blood pressure ≥130 mmHg, diastolic blood pressure ≥80 mmHg, or currently taking antihypertensive medication.

Uncontrolled hypertension defined as systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥80 mmHg.

Uncontrolled hypertension eligible for pharmacologic treatment includes those with a) systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg, and b) systolic blood pressure 130-139 mmHg or diastolic blood pressure 80-89 mmHg who are currently taking antihypertensive medication or are aged ≥65 years, have diabetes, chronic kidney disease, or 10-year ASCVD risk ≥10%.

Chronic kidney disease defined as albumin-to-creatinine ratio ≥30 mg/g or estimated glomerular filtration rate (eGFR) <60 mL/min/1.73 m^2.

10-year ASCVD risk calculated using race-sex specific Pooled Cohort Equations.

Table 3. Systolic blood pressure category and eligibility for pharmacologic treatment overall and among those with hypertension, by race – NHANES 2011-2016.

Systolic blood pressure (mmHg)	Treatment eligibility	Overall		Hypertension	
		White % (SE)	Black % (SE)	White % (SE)	Black % (SE)
<130	Not eligible	64.7 (0.9)	51.2 (1.2)	34.3 (1.6)	30.1 (1.5)
130-139, not high risk	Not eligible	4.9 (0.5)	6.3 (0.6)	9.1 (0.9)	9.0 (0.9)
130-134, high risk or on treatment	Eligible	6.5 (0.4)	8.2 (0.5)	12.2 (0.9)	11.8 (0.8)
135-139, high risk or on treatment	Eligible	5.2 (0.4)	6.2 (0.5)	9.6 (0.8)	8.9 (0.7)
140-144	Eligible	5.8 (0.5)	6.9 (0.5)	10.9 (0.9)	9.9 (0.9)
145-149	Eligible	3.9 (0.3)	5.0 (0.5)	7.3 (6.3)	7.1 (0.7)
150-154	Eligible	3.0 (0.4)	4.6 (0.6)	5.5 (0.8)	6.5 (0.7)
155-159	Eligible	1.8 (0.2)	3.5 (0.5)	3.3 (0.4)	5.0 (0.7)
≥160	Eligible	4.2 (0.4)	8.1 (0.6)	7.9 (0.8)	11.6 (0.8)
Total SBP ≥130 eligible for pharmacologic treatment	Eligible	30.4 (0.9)	42.5 (1.2)	56.6 (1.6)	60.9 (1.5)

High risk includes those individuals who are aged ≥65 years, have diabetes, chronic kidney disease, or 10-year ASCVD risk ≥10%. Those with systolic blood pressure 130-139 mmHg who are already on treatment are also eligible for further systolic blood pressure lowering.

Table 4. Proportion of cardiovascular events prevented with reductions in uncontrolled systolic blood pressure and disparities in uncontrolled systolic blood pressure.

Relative reduction in uncontrolled SBP	% uncontrolled SBP		Absolute disparity in % uncontrolled SBP (ref white)	% CVD events prevented	
	White	Black		White	Black
0% reduction	30.4	42.5	12.1	–	–
5% reduction	28.9	40.4	11.5	1.1 (1.0, 1.1)	1.5 (1.4, 1.5)
10% reduction	27.4	38.3	10.9	2.1 (2.0, 2.2)	2.9 (2.7, 3.1)
15% reduction	25.8	36.1	10.3	3.2 (3.0, 3.3)	4.3 (4.1, 4.6)
20% reduction	24.3	34.0	9.7	4.2 (3.9, 4.5)	5.8 (5.5, 6.1)
25% reduction	22.8	31.9	9.1	5.2 (4.9, 5.6)	7.2 (6.8, 7.8)
50% reduction	15.2	21.2	6.1	10.5 (9.8, 11.2)	14.5 (13.6, 15.4)
75% reduction	7.6	10.6	3.0	15.7 (14.7, 16.7)	21.7 (20.5, 23.0)
100% reduction	–	–	–	21.0 (19.7, 22.3)	29.0 (27.3, 30.7)

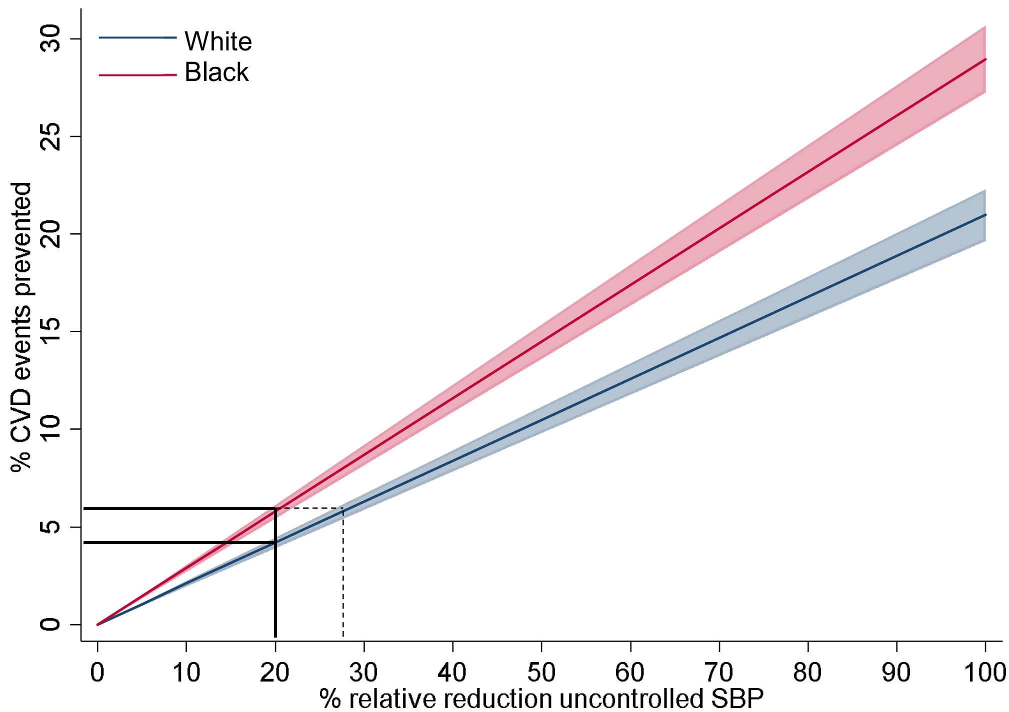
The reduction in uncontrolled systolic blood pressure (SBP) is applied to the categories of individuals with SBP ≥130 mmHg and eligible for pharmacologic treatment.

A 100% reduction in uncontrolled SBP corresponds to the population attributable fraction (PAF). We estimated 95% confidence intervals for the PAF using the centile method. The 95% confidence intervals for lesser implementation scenarios are scaled from those for the PAF.

In lesser implementation scenarios, we moved the relevant percentage of individuals from each SBP category to the reference group (<130 mmHg). For example, when there was a 20% reduction in uncontrolled SBP, we moved 20% of individuals in each SBP category eligible for treatment to the reference group. This was done algebraically and therefore, we do not present confidence intervals for the prevalence of uncontrolled SBP.

FIGURES

Figure 1. Relative reduction in prevalence of uncontrolled systolic blood pressure and proportion of cardiovascular events prevented.

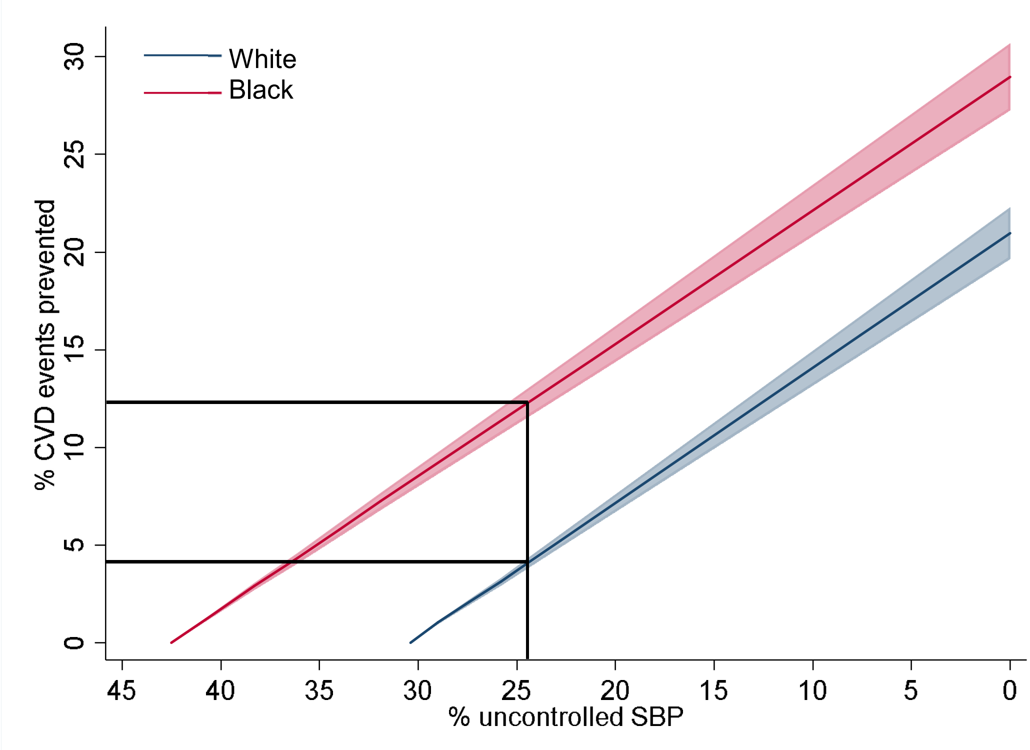


A 100% reduction in uncontrolled SBP corresponds to the population attributable fraction (PAF). A 100% reduction, or elimination, of uncontrolled SBP would prevent 29.0% (27.3%, 30.7%) of cardiovascular events among Blacks and 21.0% (19.7%, 22.3%) of cardiovascular events among whites.

The solid lines on the figure illustrate a 20% relative reduction in the prevalence of uncontrolled SBP among Blacks and whites. A 20% relative reduction in the prevalence of uncontrolled SBP is expected to prevent 5.8% (5.5%, 6.1%) and 4.2% (3.9%, 4.5%) of cardiovascular events among Blacks and whites, respectively.

The dashed lines on the figure show that to prevent 5.8% of cardiovascular events among whites would require a 27.6% relative reduction in the prevalence of uncontrolled SBP. If the percent reduction in uncontrolled SBP is >1.4 times higher among whites than Blacks (27.6% vs 20%), this would exacerbate existing disparities in the rate cardiovascular events.

Figure 2. Prevalence of uncontrolled systolic blood pressure and proportion of cardiovascular events prevented at baseline.



A 20% relative reduction in uncontrolled SBP among whites would reduce the prevalence of uncontrolled SBP to 24.3%, which would prevent 4.2% (3.9%, 4.5%) of cardiovascular events among whites. Reducing the prevalence of uncontrolled SBP to 24.3% among Blacks (i.e., "leveling up") would be expected to prevent 12.5% (11.7%, 13.2%) of cardiovascular events.

Conclusion

This dissertation examined key issues related to addressing disparities in hypertension management in the U.S. Hypertension is a leading modifiable risk factor for cardiovascular disease and contributes to cardiovascular health disparities in the population. Our work is timely given the focus on health equity in the American Heart Association's 2030 goals.[1] The results of our epidemiologic investigations can inform public health action and future research priorities.

Summary of Findings and Implications

In *Chapter 1,* we presented trends from 1999 to 2016 in hypertension prevalence, awareness, treatment, and control by age, sex, and race/ethnicity based on data from the National Health and Nutrition Examination Survey.[2] We observed increases in hypertension awareness, treatment, and control among all age groups. However, increases occurred primarily between 1999 and 2010, with few changes after. Hypertension control was lower for Blacks than whites of all ages, and awareness, treatment, and control were lower among younger Hispanics as compared to whites.

Given that the proportion of adults with hypertension who have their BP controlled has not increased since 2010, it was instructive to examine barriers to hypertension control by population subgroup. Our findings highlight that targeted efforts are needed to improve treatment to control among Blacks and address gaps at all stages among younger Hispanics.

In *Chapter 2*, we used data from a nationally representative audit of physician office visits to quantify the extent of terminal digit preference in office BP measurements among adults with treated hypertension. To our knowledge, this is the first study to examine terminal digit preference nationally in the U.S. and to report trends over time. We found that the proportion of BP measurements with a terminal digit zero was much greater (~40%) than expected by chance alone (~10-20%). Despite a modest decrease from 2014 to 2018 in the percent of visits with systolic (43.0% to 38.1%) or diastolic (44.3% to 39.4%) blood pressure recordings ending in zero, terminal digit preference remains a common source of BP measurement error.

Terminal digit preference was higher and there was less reduction among visits where treatment was first initiated (vs subsequent treatment visits) and at visits to cardiologists (vs primary care physicians). Terminal digit preference was reduced around thresholds for hypertension control, but it is unclear whether this reflects more accurate measurement when it may affect treatment decisions or a preference for BP values just below certain thresholds which may have adverse consequences for patients.[3] There was little change in the proportion of measurements ending in 1, 3, 7, or 9, which we would expect to increase with increasing use of automated BP devices. This may suggest continued use of manual devices even when automated devices are present or errors in recording, such as intentional rounding of measurements.

Blood pressure measurement error contributes to both under- and overtreatment of individuals with hypertension. It is feasible to reduce terminal digit preference through the use of automated devices, clinical training, and support.[4] Reducing terminal digit preference, which is pervasive in practice, is potentially low-hanging fruit for improving the accuracy of BP measurement and may drive other improvements in clinical management of hypertension.

Chapter 3 examined changes in hypertension control among Black and white older adults with treated hypertension in the Atherosclerosis Risk in Communities (ARIC) Study before and after the publication of a new hypertension guideline in 2014. The 2014 hypertension guideline raised BP treatment goals from <140/90 mmHg in the general population and <130/80 among those with diabetes or chronic kidney disease to <150/90 mmHg among adults aged ≥60 years without diabetes or chronic kidney disease, and to <140/90 mmHg for those with diabetes or chronic kidney disease; the 2014 guideline retained the target of <140/90 mmHg for adults <60 years of age without comorbidities.

We found that a greater proportion of white than Black adults had systolic blood pressure (SBP) <140 mmHg 2011-2013 (75.4% vs 66.0%), while a similar proportion of whites and

Blacks had SBP <140 mmHg in 2016-2017 (59.4% vs 56.5%). There were no differences in the prevalence of SBP <140 mmHg by diabetes status or chronic kidney disease among whites or Blacks at baseline. One-third of both whites and Blacks with SBP <140 at baseline had SBP ≥140 mmHg at follow up. Among those controlled at baseline, reduced kidney function was associated with uncontrolled SBP at follow up among whites [odds ratio (OR): 1.32; 95% confidence interval (CI): 1.00, 1.75] and among Blacks (OR: 1.47; 95% CI: 0.92, 2.35); though not statistically significant among Blacks, we focus on the magnitude of association. We also found that Blacks with diabetes who had controlled SBP at follow up were more likely than those without to have uncontrolled SBP at follow up (OR: 1.92; 95% CI: 1.27, 2.92), and that the association with diabetes among Blacks was significantly different than among whites (*P* for interaction = 0.009). Among those with uncontrolled SBP at baseline, ~40% of whites and Blacks were controlled at follow up. Blacks with reduced with reduced kidney function (OR: 0.44, 95% CI: 0.22, 0.87) had lower odds of control and there was a significant interaction by race (*P* for interaction = 0.004).

The 2014 hypertension guideline was controversial in its decision to raise hypertension treatment thresholds. Few studies have examined changes in hypertension control before and after this guideline was published.[5,6] Two previous studies showed no changes in control to BP <140/90 mmHg or mean BP from one year before to one year after the guideline, but are limited to single health care systems which may not capture variability in care practices, include mostly white patients, and one of the studies did not include patients with diabetes or chronic kidney disease.[5,6] Our work added to the literature by including Black and white adults from multiple geographic locations with well-characterized information on their health status, and examines hypertension control 2-3 years before and after the guideline publication which may allow us to capture changes in clinical practice in response to guideline changes. While we found that changes hypertension control overall were similar by race, we found that Blacks with diabetes or reduced kidney function were less likely to have hypertension control at follow up. Higher treatment goals recommended in 2014 for older adults and those with diabetes and chronic kidney disease may have contributed to these findings and unintended differences by race.

Finally, in *Chapter 4*, we examined the potential impact on cardiovascular disease events of treating individuals with hypertension to a lower BP goal of <130/80 recommended by the American College of Cardiology (ACC) and American Heart Association (AHA) in 2017. We calculated the proportion of all cardiovascular disease events which could be prevented among Black and white adults aged ≥40 if all those eligible for pharmacologic treatment were treated to the ACC/AHA guideline-recommended goal. We estimated that 29.0% (95% CI: 27.3%, 30.7%) of cardiovascular events among Blacks and 21.0% (95% CI: 19.7, 22.3%) of cardiovascular events among whites could be prevented, which would reduce relative and absolute racial disparities in cardiovascular events in the population. Even in if less than 100% of individuals eligible for pharmacologic therapy were treated to the goal, with the same relative reduction in uncontrolled hypertension, the proportion of cardiovascular events prevented is higher among Blacks than whites. However, if the relative reduction in uncontrolled hypertension is more than ~1.4 times higher among whites than Blacks, there would be a greater reduction in the proportion of events prevented among whites than Blacks, thereby exacerbating disparities.

Treating hypertension to the 2017 ACC/AHA goal could reduce absolute and relative racial disparities in cardiovascular events in the population, but there are challenges with respect to implementation and ensuring equitable improvements in hypertension control occur in practice. For example, the magnitude of BP reduction required to reach the goal of <130/80 mmHg among those eligible for new or additional antihypertensive treatment is large (~15 mmHg among whites and ~17 mmHg among Blacks), thus treatment to a lower goal will likely require intensive efforts to engage patients and address barriers to hypertension control which exist at multiple levels.[7,8] Additionally, though the benefits in terms of prevention of cardiovascular disease events would be greater among Blacks than whites for a comparable relative reduction in uncontrolled hypertension, our goal should be to eliminate absolute disparities in uncontrolled hypertension.

Some health systems have shown it is possible to achieve similar relative reductions in uncontrolled hypertension among racial/ethnic groups, but targeted approaches are likely needed to achieve the same absolute levels of hypertension control.[9]

Future directions

Blood pressure measurement

To identify and address the determinants of terminal digit preference, it would be useful to conduct research to understand the types of BP devices currently used in practice for screening and diagnosis of hypertension, and to monitor the response to hypertension treatment.[10] We believe the use of automated BP devices has increased in clinical practice, but our results suggest BP may still be measured with manual devices and/or that BP measurements from automated devices are rounded to zero; it is important to understand the source of error to design appropriate interventions.

The 2017 ACC/AHA guideline states that there is growing evidence to support the use of automated office BP measurements, but stops short of recommending the use of automated BP devices in office settings as Canadian hypertension guidelines explicitly recommend.[11,12] Future U.S. guidelines could more strongly recommend the use of automated BP devices in clinical care.

Regardless of the type of BP device used, accurate BP measurement is critical to patient care. Implementation research is needed to better incorporate recommended BP measurement procedures, which may not always be practical in the current clinical environment.

Guideline-recommended treatment

The results from chapters 3 and 4 of this dissertation highlight the potential positive impact on cardiovascular health in the population and disparities in cardiovascular health associated with implementing current recommended hypertension treatment goals, but also the potential to widen disparities if recommendations are applied inconsistently across population subgroups. Inconsistent application could occur as a result of controversy or confusion regarding available hypertension guidelines from leading professional societies in the U.S.

One area for future research is to understand at the health system and physician level what treatment targets are being used in clinical practice. However, it is also well-documented that physicians do not always adhere to guidelines.[13] Factors may include lack of agreement with guideline recommendations, inertia to treat based on previous higher BP targets, "lack of outcome expectancy," and others.[13,14] The Institute of Medicine has previously recommended research to understand why physicians do not adhere to hypertension guidelines.[15] Increasing understanding the factors which influence decision-making among physicians and patients about hypertension treatment would be a major contribution to the field, but to our knowledge, this research recommended in 2010 has not been funded and should be prioritized.

Another area of for future study is implementation research regarding the use of guideline-driven hypertension treatment protocols in clinical care. Protocols help standardize clinical care and may help to ensure patients from different racial/ethnic groups or by socioeconomic status are treated consistent with current guidelines. It is unknown how widely adopted protocols are in clinical care in the U.S. Further, given more intensive treatment will be needed to achieve the lower target recommended by the 2017 ACC/AHA guideline, protocols aimed at achieving this goal should be evaluated in diverse care settings and effective practices should be disseminated and scaled up.

Lastly, future guideline committees, which could include an explicit consideration for how clinical practice guidelines address issues of equity.[16,17] Guideline committees can consider equity when formulating research questions.[17] Additionally, guideline committees can address key questions about their recommendations such as the value of the interventions to different subgroups, the expected effects among population subgroups, how to minimize barriers to implementation among disadvantaged groups, and ensuring plans to evaluate the impact of the guideline recommendations include monitoring its effect by subgroup.[16,18] Guideline committees should also include diverse representation and seek feedback from members of disadvantaged groups during guideline development.[17]

Addressing the social determinants of health

Though this dissertation focuses on hypertension treatment, it will not be possible to treat our way to health equity in the U.S. First, addressing the social determinants of health to prevent hypertension is necessary to achieving equity. Second, health care occurs in the context of the social determinants of health.[8] Public health and health care interventions will not be optimally effective unless we address the fundamental causes of racial health disparities, which are inequalities in socioeconomic resources resulting from historical, social, and political injustices.[19–21] Factors such as institutional and interpersonal racism, access and affordability of care, neighborhood conditions and residential segregation, are associated with blood pressure levels and may also have independent effects on health outcomes. [21,22] Further, the place-based historical legacy of slavery is associated with smaller decreases in heart disease mortality among U.S. Blacks, even after controlling for potential mediators.[23]

When designing interventions in the health care setting, approaching clinical care in the framework of the socioecological model may help to develop targeted interventions which address barriers to hypertension control among population subgroups.[8] Multilevel interventions may be uniquely effective for addressing health disparities and the National Institutes of Health has invested in such approaches.[24–26] The Patient Centered Outcomes Research Institute (PCORI) has also specifically funded studies multilevel interventions to reduce disparities in hypertension control, which are ongoing.[27,28] However, there is much more work to be done to advance research methods and to grow the evidence base,[8,24,26,29] and additional investments are warranted.

Summary

This dissertation contributes to our knowledge of disparities in hypertension control in the U.S. and the implications of recent hypertension guidelines for patient outcomes, population health, and health disparities. Further research can help understand factors which influence BP measurement and treatment, and inform interventions to improve hypertension control and eliminate disparities. Eliminating disparities in hypertension control is a priority for cardiovascular health equity in the U.S.

Appendices

Appendix for Chapter 1

Table of Contents:

Web Table 1. Hypertension Prevalence, Awareness, Treatment, Control and Control Among Those Treated – US adults aged ≥25, National Health and Nutrition Examination Survey 1999–2016.

	1999–2004	2005–2010	2011–2016
Hypertension prevalence, % (SE)			
25–44	11.8 (0.7)	12.0 (0.6)	12.8 (0.7)
45–64	39.5 (1.3)	39.7 (1.1)	40.7 (0.9)
≥65	70.6 (1.0)	70.2 (1.1)	67.6 (1.3)
Hypertension awareness, % (SE)			
25–44	62.5 (3.1)	66.7 (2.6)	74.3 (2.0)*,†
45–64	74.1 (1.6)	81.8 (1.0)*	83.2 (1.1)*
≥65	74.0 (1.1)	83.7 (1.0)*	86.7 (0.9)*,†
Hypertension treatment, % (SE)			
25–44	46.1 (3.4)	51.2 (2.7)	56.6 (2.3)*
45–64	62.8 (1.7)	73.1 (1.2)*	74.6 (1.5)*
≥65	67.1 (1.6)	79.9 (0.9)*	82.1 (1.1)*
Hypertension control, % (SE)			
25–44	33.5 (3.0)	38.6 (2.6)	44.6 (2.3)*
45–64	39.3 (1.7)	51.7 (1.4)*	55.7 (1.9)*
≥65	31.7 (1.3)	49.3 (1.1)*	49.9 (1.6)*
Hypertension control among treated, % (SE)			
25–44	72.7 (3.2)	75.3 (2.4)	78.8 (2.2)
45–64	62.6 (1.5)	70.7 (1.4)*	74.6 (1.5)*
≥65	47.2 (1.5)	61.7 (1.1)*	60.8 (1.6)*

*Statistically significant difference (*P*<0.05) as compared to 1999–2004.
†Statistically significant difference (*P*<0.05) as compared to 2005–2010.

Web Table 2. Hypertension Prevalence, Awareness, Treatment, Control, and Control Among Those Treated by Age Group in 2-Year Survey Cycles – US Adults Aged ≥25, National Health and Nutrition Examination Survey 1999–2016.

	1999–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	Difference (SE) 2015–2016 minus 2013–2014	Difference (SE) 2015–2016 minus 1999–2000
Hypertension prevalence, % (SE)											
25–44	12.3 (1.8)	10.4 (0.8)	12.5 (0.9)	12.0 (1.4)	13.3 (0.9)	10.7 (0.7)	12.6 (1.4)	13.0 (1.0)	12.8 (1.4)	-0.2 (1.7)	0.4 (2.3)
45–64	37.9 (2.2)	37.7 (2.4)	42.8 (2.3)	39.8 (2.1)	39.8 (1.3)	39.5 (2.2)	40.5 (1.5)	41.2 (1.5)	40.5 (1.8)	-0.7 (2.3)	2.6 (2.9)
≥65	70.3 (2.0)	70.7 (1.4)	70.0 (2.1)	68.8 (1.1)	70.3 (2.4)	71.2 (1.8)	67.5 (1.9)	69.5 (1.5)	66.0 (2.6)	-3.5 (3.0)	-4.3 (3.3)
Hypertension awareness, % (SE)											
25–44	61.4 (7.0)	57.8 (4.1)	66.8 (4.6)	60.3 (3.9)	72.8 (4.9)	66.1 (4.3)	70.8 (4.5)	78.2 (2.0)	73.6 (3.3)	-4.6 (3.9)	12.2 (7.7)
45–64	75.0 (3.3)	72.2 (2.3)	75.1 (2.9)	81.0 (2.0)	80.4 (1.3)	84.0 (1.7)	82.9 (2.4)	84.3 (1.6)	82.2 (1.7)	-2.1 (2.3)	7.2 (3.7)
≥65	67.9 (1.8)	74.2 (1.5)	79.7 (1.9)	82.4 (1.7)	83.1 (1.2)	85.4 (2.0)	87.5 (1.6)	88.2 (1.6)	84.7 (1.7)	-3.4 (2.3)	16.8 (2.4)*
Hypertension treatment, % (SE)											
25–44	43.4 (6.5)	41.6 (3.7)	52.1 (6.4)	40.5 (3.6)	57.0 (4.5)	56.5 (4.5)	54.1 (4.4)	57.3 (3.7)	58.1 (4.0)	0.8 (5.5)	14.7 (7.7)
45–64	66.1 (3.1)	61.3 (2.1)	61.9 (3.5)	70.2 (2.0)	71.1 (1.9)	77.8 (2.3)	75.4 (3.0)	75.8 (2.4)	72.6 (2.2)	-3.2 (3.2)	6.2 (3.8)
≥65	60.1 (3.1)	67.0 (2.4)	74.3 (2.1)	77.7 (1.6)	79.7 (1.2)	82.1 (1.8)	84.1 (1.9)	82.6 (2.2)	80.0 (1.8)	-2.6 (2.8)	19.9 (3.5)*
Hypertension control, % (SE)											
25–44	28.7 (5.1)	28.2 (2.9)	42.4 (6.3)	30.9 (3.8)	47.4 (4.3)	36.2 (4.4)	45.8 (5.5)	46.7 (3.3)	41.3 (3.1)	-5.3 (4.5)	12.6 (6.0)*
45–64	39.9 (2.9)	38.9 (2.4)	39.4 (3.2)	48.2 (2.3)	49.7 (2.5)	57.1 (2.3)	56.3 (3.3)	57.0 (3.6)	53.8 (2.8)	-3.2 (4.6)	13.7 (4.1)*
≥65	24.3 (2.4)	32.2 (1.7)	38.8 (2.1)	44.0 (1.8)	48.1 (1.9)	55.1 (2.2)	50.1 (2.6)	54.1 (2.5)	45.9 (3.1)	-8.2 (4.0)*	21.6 (4.0)*
Hypertension control among treated, % (SE)											
25–44	66.2 (6.0)	67.7 (5.9)	81.3 (4.5)	76.4 (5.3)	83.1 (2.6)	65.0 (4.9)	84.7 (4.3)	81.4 (2.4)	71.1 (4.1)	-10.3 (4.8)*	5.0 (7.3)
45–64	60.3 (2.6)	63.4 (2.4)	63.6 (2.8)	68.9 (2.9)	69.8 (2.2)	73.4 (2.0)	74.6 (2.0)	75.2 (2.8)	74.1 (3.0)	-1.1 (4.1)	13.8 (4.0)*
≥65	40.4 (2.8)	48.0 (1.9)	52.2 (2.8)	56.6 (2.0)	60.3 (1.9)	67.2 (1.7)	59.6 (2.4)	65.5 (2.2)	57.3 (3.3)	-8.1 (4.0)*	17.0 (4.4)*

*Statistically significant difference (P<0.05) as compared to reference survey cycle.

Web Table 3. Hypertension Prevalence, Awareness, Treatment, Control and Control Among Those Treated by Age Group and Sex – US adults aged ≥25, National Health and Nutrition Examination Survey 1999–2016.

		Estimate, % (SE)			Difference (Women vs Men), % (SE)		
		1999–2004	2005–2010	2011–2016	1999–2004	2005–2010	2011–2016
Prevalence							
25–44	Men	14.3 (1.1)	14.9 (0.8)	14.1 (1.1)			
	Women	9.1 (0.7)	8.9 (0.6)	11.4 (0.8)*,†	-5.2 (1.3)‡	-6.1 (0.8)‡	-2.7 (1.2)‡,‖
45–64	Men	38.5 (1.8)	39.5 (1.3)	43.3 (1.4)*,†			
	Women	40.5 (1.5)	39.9 (1.5)	38.2 (1.2)	2.0 (1.9)	0.5 (1.8)	-5.1 (1.8)‡,§,‖
≥65	Men	62.7 (1.7)	65.6 (1.7)	63.7 (1.7)*			
	Women	76.5 (1.1)	73.7 (1.3)	70.6 (1.4)	13.8 (2.0)	8.1 (2.1)‡,§	7.0 (1.8)‡,§
Awareness							
25–44	Men	57.8 (3.3)	58.0 (3.2)	66.4 (2.9)			
	Women	70.8 (4.1)	81.9 (3.5)*	84.5 (2.0)*	13.0 (4.4)‡	23.9 (4.3)‡	18.1 (3.2)‡
45–64	Men	72.6 (2.1)	78.8 (1.4)*	81.0 (1.5)*			
	Women	75.4 (2.6)	84.7 (1.3)*	85.5 (1.7)*	2.8 (3.6)	5.8 (1.9)‡	4.5 (2.3)
≥65	Men	74.6 (1.5)	84.0 (1.3)*	85.8 (1.4)*			
	Women	73.6 (1.5)	83.5 (1.3)*	87.4 (1.1)*,†	-1.0 (2.2)	-0.6 (1.7)	1.5 (1.6)
Treatment							
25–44	Men	40.0 (3.9)	41.5 (3.3)	45.3 (3.3)			
	Women	57.0 (4.3)	68.3 (4.0)	71.2 (2.8)*	17.0 (5.3)‡	26.8 (4.9)‡	25.8 (4.0)‡
45–64	Men	61.0 (1.9)	69.1 (1.5)*	70.1 (1.9)*			
	Women	64.4 (2.6)	76.9 (1.6)*	79.4 (1.9)*	3.5 (2.9)	7.8 (1.9)‡	9.3 (2.5)‡
≥65	Men	68.3 (1.8)	80.0 (1.3)*	80.9 (1.3)*			
	Women	66.4 (2.1)	79.9 (1.2)*	83.0 (1.4)*	-1.9 (2.4)	-0.1 (1.8)	2.0 (1.7)
Control							
25–44	Men	27.7 (3.7)	29.4 (2.9)	32.0 (2.7)			
	Women	43.8 (4.4)	54.8 (4.5)	61.0 (2.9)*	16.2 (5.8)‡	25.4 (5.2)‡	29.0 (2.9)‡
45–64	Men	39.7 (2.4)	48.2 (2.0)*	50.2 (2.5)*			
	Women	39.0 (2.1)	55.1 (1.8)*	61.5 (2.1)*,†	-0.7 (3.0)	6.8 (2.5)‡	11.3 (2.7)‡,§
≥65	Men	38.7 (1.9)	53.4 (1.6)*	55.1 (2.0)*			
	Women	27.3 (1.5)	46.5 (1.2)*	46.2 (2.0)*	-11.3 (2.2)‡	-7.0 (1.7)‡	-8.9 (2.4)‡

Control among treated							
25–44	Men	69.2 (5.3)	70.8 (3.5)	70.5 (3.9)			
	Women	77.0 (4.1)	80.1 (3.4)	85.7 (2.3)	7.7 (7.3)	9.3 (5.1)	15.2 (4.5)
45–64	Men	65.1 (3.0)	69.8 (2.2)	71.7 (2.2)*			
	Women	60.5 (1.8)	71.6 (1.6)	77.5 (2.0)*,†	-4.6 (3.8)	1.8 (2.7)	5.8 (2.9)‡,§
≥65	Men	56.6 (2.1)	66.8 (1.5)*	68.1 (1.9)*			
	Women	41.2 (1.8)	58.1 (1.3)*	55.7 (2.0)*	-15.4 (2.7)‡	-8.7 (1.8)‡,§	-12.4 (2.4)‡

*Statistically significant difference ($P<0.05$) as compared to 1999–2004 within category of age and sex.

†Statistically significant difference ($P<0.05$) as compared to 2005–2010 within category of age and sex.

‡Statistically significant difference ($P<0.05$) within survey cycle for women versus men.

§Statistically significant change in difference ($P<0.05$) as compared to 1999–2004 (ie, interaction).

ǁStatistically significant change in difference ($P<0.05$) as compared to 2005–2010 (ie, interaction).

Web Table 4. Hypertension Prevalence, Awareness, Treatment, Control and Control Among Those Treated by Age Group and Race/Ethnicity – US Adults Aged ≥25, National Health and Nutrition Examination Survey 1999–2016.

		Estimate, % (SE)			Difference (Reference White), % (SE)		
		1999–2004	**2005–2010**	**2011–2016**	**1999–2004**	**2005–2010**	**2011–2016**
Prevalence							
25–44	White	10.7 (0.8)	11.8 (0.8)	12.2 (1.1)			
	Black	20.3 (1.5)	20.0 (1.3)	22.3 (1.3)	9.6 (1.7)‡	8.2 (1.7)‡	10.0 (1.4)‡
	Hispanic	9.4 (1.0)	7.9 (0.9)	12.0 (1.1)†	-1.3 (1.2)	-3.8 (1.2)‡	-0.2 (1.4)
45–64	White	37.6 (1.6)	37.5 (1.3)	38.7 (1.3)			
	Black	57.2 (1.9)	58.9 (2.1)	60.0 (1.6)	19.6 (2.5)‡	21.4 (2.4)‡	21.3 (2.1)‡
	Hispanic	35.2 (2.0)	35.3 (2.0)	35.0 (2.6)	-2.4 (2.7)	-2.2 (2.3)	-3.7 (2.8)
≥65	White	69.4 (1.2)	69.0 (1.3)	65.7 (1.5)			
	Black	81.9 (2.2)	83.5 (1.4)	80.7 (1.5)	12.5 (2.4)‡	14.5 (1.8)‡	15.0 (1.9)‡
	Hispanic	69.1 (2.1)	67.7 (2.5)	68.5 (2.8)	-0.3 (2.5)	-1.3 (2.7)	2.8 (2.8)
Awareness							
25–44	White	66.5 (4.1)	67.6 (3.4)	75.4 (3.6)			
	Black	62.4 (4.3)	71.2 (3.7)	79.2 (2.5)*	-4.1 (5.9)	3.6 (4.4)	3.8 (4.9)
	Hispanic	44.4 (5.9)	46.4 (6.0)	65.6 (4.4)*,†	-22.1 (7.6)‡	-21.2 (6.3)‡	-9.8 (6.3)
45–64	White	72.9 (2.0)	82.0 (1.3)*	83.6 (1.6)*			
	Black	81.4 (1.6)	84.9 (1.5)	85.5 (1.5)	8.5 (2.3)‡	2.9 (1.9)	1.9 (2.2)§
	Hispanic	70.7 (3.8)	75.6 (2.0)	78.6 (2.8)	-2.2 (4.3)	-6.4 (2.3)‡	-5.0 (3.3)
≥65	White	73.5 (1.2)	83.1 (1.1)*	87.2 (1.2)*,†			
	Black	80.6 (1.9)	90.4 (1.7)*	89.1 (1.0)*	7.2 (2.0)‡	7.4 (2.1)‡	1.9 (1.5)§,‖
	Hispanic	69.7 (2.2)	77.5 (4.2)	83.7 (2.4)*	-3.8 (2.5)	-5.5 (4.3)	-3.5 (2.6)
Treatment							
25–44	White	49.0 (4.2)	52.4 (3.4)	60.0 (3.5)*			
	Black	45.9 (4.2)	58.7 (4.1)*	57.9 (3.2)*	-3.1 (5.7)	6.3 (4.9)	-2.0 (4.6)
	Hispanic	24.0 (5.2)	29.0 (4.8)	45.0 (4.7)*,†	-25.0 (6.1)‡	-23.4 (6.2)‡	-15.0 (5.7)‡
45–64	White	62.3 (1.9)	73.9 (1.7)*	75.3 (2.2)*			
	Black	70.4 (2.1)	74.4 (1.9)	77.8 (1.9)*	8.0 (2.6)‡	0.5 (2.6)§	2.5 (3.0)
	Hispanic	56.6 (4.9)	67.4 (2.5)	70.9 (3.0)*	-5.7 (5.0)	-6.5 (2.7)‡	-4.4 (3.8)
≥65	White	66.5 (1.6)	79.5 (1.1)*	82.4 (1.4)*			
	Black	75.9 (2.0)	86.8 (2.0)*	85.3 (1.2)*	9.4 (2.2)‡	7.4 (2.4)‡	2.9 (1.7)§

	Hispanic	62.5 (1.7)	71.3 (4.5)	79.3 (2.4)*	-4.0 (2.1)	-8.1 (4.6)	-3.2 (2.9)
Control							
25–44	White	38.9 (4.0)	42.1 (3.5)	50.4 (3.5)*			
	Black	24.9 (2.8)	35.6 (3.6)*	38.1 (3.4)*	-14.0 (4.7)‡	-6.5 (4.6)	-12.3 (4.6)‡
	Hispanic	15.6 (3.7)	16.8 (3.9)	35.1 (4.3)*,†	-23.3 (5.1)‡	-25.3 (5.6)‡	-15.2 (4.9)‡
45–64	White	41.6 (2.0)	54.6 (1.8)*	58.4 (2.8)*			
	Black	38.0 (2.0)	45.8 (2.1)*	50.9 (2.2)*	-3.6 (2.7)‡	-8.8 (2.6)‡	-7.6 (3.7)‡
	Hispanic	30.8 (4.3)	46.1 (2.1)*	50.0 (3.9)*	-10.7 (4.3)‡	-8.5 (2.7)‡	-8.5 (5.0)
≥65	White	32.2 (1.4)	50.0 (1.3)*	51.3 (2.0)*			
	Black	31.9 (2.2)	49.9 (2.7)*	45.9 (1.9)*	-0.3 (2.7)	-0.1 (3.1)	-5.3 (2.4)‡
	Hispanic	25.5 (2.3)	34.8 (3.2)*	46.0 (3.6)*,†	-6.7 (2.6)‡	-15.2 (3.4)‡,§	-5.2 (4.2)
Control among treated							
25–44	White	79.3 (4.3)	80.3 (3.5)	84.0 (3.0)			
	Black	54.3 (4.9)	60.6 (5.5)	65.8 (4.2)	-25.0 (6.3)‡	-19.7 (7.0)‡	-18.2 (5.2)‡
	Hispanic	65.1 (7.9)	57.9 (10.0)	78.2 (5.9)	-14.2 (9.2) ‡	-22.4 (11.0)‡	-5.8 (6.5)
45–64	White	66.7 (2.0)	73.9 (1.4)*	77.7 (2.1)*			
	Black	54.0 (2.4)	61.5 (2.3)*	65.4 (1.8)*	-12.7 (3.1)‡	-12.4 (2.6)‡	-12.3 (2.7)‡
	Hispanic	54.4 (4.4)	68.4 (2.6)*	70.6 (3.5)*	-12.3 (4.5)‡	-5.5 (2.8)	-7.1 (4.1)
≥65	White	48.4 (1.7)	62.9 (1.2)*	62.2 (1.9)*			
	Black	42.0 (2.6)	57.4 (3.1)*	53.8 (2.2)*	-6.4 (3.1)‡	-5.4 (3.3)	-8.3 (2.5)‡
	Hispanic	40.8 (3.6)	48.7 (3.2)*	58.0 (3.6)*	-7.6 (4.1)	-14.2 (3.6)‡	-4.1 (4.1)

*Statistically significant difference (*P*<0.05) as compared to 1999–2004 within category of age and race/ethnicity.

†Statistically significant difference (*P*<0.05) as compared to 2005–2010 within category of age and race/ethnicity.

‡Statistically significant difference (*P*<0.05) within survey cycle for blacks or Hispanics as compared to whites.

§Statistically significant change in difference (*P*<0.05) as compared to 1999–2004 (ie, interaction).

ǁStatistically significant change in difference (*P*<0.05) as compared to 2005–2010 (ie, interaction).

Web Table 5. Trends in hypertension control by age group before and after adjustment for demographic and clinical characteristics – US adults aged ≥25, National Health and Nutrition Examination Survey 1999–2016.

	Unadjusted		Adjusted for sex, race/ethnicity, age		Additionally adjusted for BMI and diabetes		Additionally adjusted for insurance coverage and usual source of care		Additionally adjusted for hypertension awareness	
Age	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**
25–44										
1999–2004	33.5 (27.7-39.4)	Ref	33.7 (28.3-39.1)	Ref	34.0 (28.5-39.5)	Ref	33.9 (28.3-39.5)	Ref	52.8 (45.9-59.7)	Ref
2005-2010	38.6 (33.5-43.7)	1.15 (0.90-1.40)	38.8 (33.4-43.9)	1.15 (0.92-1.38)	38.5 (33.5-43.6)	1.13 (0.90-1.36)	38.3 (33.4-43.3)	1.13 (0.90-1.36)	56.1 (50.4-61.8)	1.06 (0.89-1.24)
2011-2016	44.6 (40.0-49.2)	1.33 (1.06-1.60)	44.1 (39.5-48.7)	1.31 (1.07-1.55)	43.2 (38.7-47.8)	1.27 (1.03-1.51)	43.8 (39.1-48.6)	1.29 (1.04-1.54)	60.8 (56.1-65.6)	1.15 (0.98-1.33)
2011–2016 vs 2005–2010		1.15 (0.96-1.35)		1.13 (0.95-1.32)		1.12 (0.94-1.31)		1.14 (0.95-1.33)		1.08 (0.95-1.22)
45–64										
1999–2004	39.3 (36.1-42.6)	Ref	39.2 (36.0-42.4)	Ref	40.3 (37.1-43.4)	Ref	40.1 (37.0-43.2)	Ref	53.2 (50.5-55.9)	Ref
2005-2010	51.7 (48.9-54.5)	1.32 (1.18-1.44)	51.7 (49.0-54.3)	1.32 (1.19-1.44)	51.7 (49.0-54.4)	1.28 (1.17-1.40)	52.1 (49.5-54.8)	1.30 (1.18-1.42)	63.3 (60.3-66.3)	1.19 (1.11-1.27)
2011-2016	55.7 (51.9-59.4)	1.42 (1.27-1.57)	55.9 (52.1-59.7)	1.43 (1.27-1.58)	55.2 (51.2-59.1)	1.37 (1.23-1.51)	55.1 (51.2-58.9)	1.37 (1.23-1.52)	67.1 (63.6-70.6)	1.26 (1.17-1.35)
2011–2016 vs 2005–2010		1.08 (0.98-1.17)		1.08 (0.99-1.17)		1.07 (0.97-1.16)		1.06 (0.97-1.15)		1.06 (0.99-1.13)
≥65										
1999–2004	31.7 (29.2-34.2)	Ref	32.2 (29.8-34.6)	Ref	32.4 (29.8-34.9)	Ref	32.6 (30.0-35.1)	Ref	43.3 (40.6-46.0)	Ref
2005-2010	49.3 (47.1-51.5)	1.56 (1.41-1.70)	49.3 (47.1-51.5)	1.53 (1.40-1.66)	49.2 (46.8-51.5)	1.52 (1.38-1.65)	49.1 (46.8-51.5)	1.51 (1.37-1.64)	59.0 (56.8-61.3)	1.37 (1.27-1.46)
2011-2016	49.9 (46.7-53.1)	1.57 (1.41-1.73)	49.5 (46.2-52.7)	1.54 (1.38-1.69)	49.1 (45.8-52.3)	1.52 (1.36-1.67)	49.2 (45.9-52.5)	1.51 (1.35-1.66)	57.2 (53.9-60.5)	1.32 (1.21-1.43)
2011–2016 vs 2005–2010		1.01 (0.93-1.09)				1.00 (0.92-1.08)		1.00 (0.92-1.08)		0.97 (0.90-1.04)

CI = Confidence Interval. BMI = Body mass index. Diabetes status based on self-report. Insurance coverage and usual source of care categorized as yes/no.

Web Table 6. Trends in hypertension control by age group before and after adjustment for demographic and clinical characteristics among those aware of their hypertension – US adults aged ≥25, National Health and Nutrition Examination Survey 2007–2016.

	Unadjusted		Adjusted for sex, race/ethnicity, age		Additionally adjusted for BMI and diabetes		Additionally adjusted for insurance coverage and usual source of care		Additionally adjusted for hypertension duration	
Age	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**	**Prevalence (95% CI)**	**Prevalence ratio (95% CI)**
25–44										
2007–2010	42.3 (36.0-48.6)	Ref	60.7 (54.9-66.3)	Ref	60.3 (54.9-65.7)	Ref	60.1 (54.7-65.5)	Ref	59.0 (53.7-64.2)	Ref
2011–2016	44.6 (40.0-49.2)	1.05 (0.86-1.24)	60.0 (55.4-64.6)	0.99 (0.87-1.11)	60.3 (55.6-65.0)	1.00 (0.89-1.12)	60.0 (55.2-64.8)	1.00 (0.88-1.11)	61.0 (56.2-65.9)	1.04 (0.92-1.15)
45–64										
2007–2010	65.0 (61.2-68.7)	Ref	64.7 (61.0-68.4)	Ref	64.7 (60.8-68.6)	Ref	64.8 (60.9-68.7)	Ref	65.0 (61.0-68.9)	Ref
2011–2016	66.9 (63.5-70.4)	1.02 (0.95-1.11)	67.2 (63.7-70.6)	1.04 (0.96-1.11)	67.3 (63.7-70.8)	1.04 (0.96-1.12)	67.2 (63.6-70.7)	1.04 (0.96-1.12)	67.1 (63.6-70.6)	1.03 (0.95-1.11)
≥65										
2007–2010	61.4 (58.7-64.1)	Ref	61.7 (59.0-64.3)	Ref	61.9 (58.9-64.8)	Ref	61.9 (59.0-64.7)	Ref	62.1 (59.0-65.2)	Ref
2011–2016	57.8 (54.4-60.8)	0.94 (0.87-1.00)	57.4 (54.1-60.6)	0.93 (0.87-0.99)	57.3 (54.0-60.6)	0.93 (0.86-0.99)	57.4 (54.1-60.7)	0.93 (0.86-1.00)	57.7 (54.3-61.0)	0.93 (0.86-1.00)

CI = Confidence interval. BMI = Body mass index. Diabetes status based on self-report. Insurance coverage and usual source of care categorized as yes/no. Duration of hypertension calculated as age at exam minus age at which participant was told they had hypertension.

Web Table 7. Hypertension Treatment Goals from Major National Guidelines During 1999–2016.

Dates	Guideline	Blood Pressure Goals
1999–2003	JNC6*	<140/90 mmHg for all patients – lower if tolerated
2003–2014	JNC7	<130/80 mmHg for those with diabetes or chronic kidney disease <140/90 for all other patients
2014–2016	JNC8 Panel Member Report	<150/90 mmHg for adults aged ≥60 years without diabetes or chronic kidney disease <140/90 for all other patients

JNC = Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure.
*Issued in 1997.

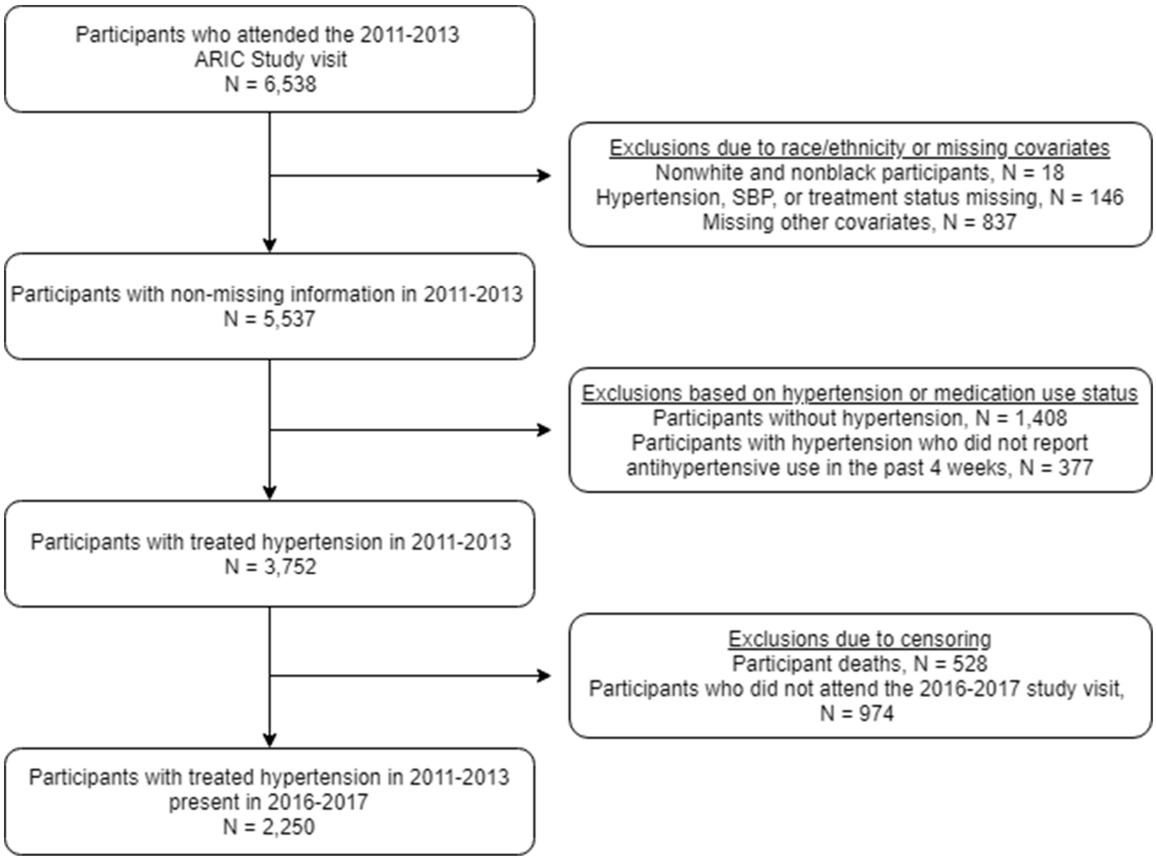
Appendix for Chapter 2

Supplemental Table. Proportion of systolic and diastolic blood pressure measurements above and below guideline-recommended treatment goals – Hypertension treatment visits, 2014–2018.

	2014	2015	2016	2017	2018
Systolic blood pressure (mmHg)					
128-129	4.1	4.8	4.3	3.9	4.1
131-132	3.9	4.3	4.2	4.1	4.5
138-139	4.3	4.3	4.4	4.8	4.8
141-142	2.8	2.9	2.7	3.1	3.0
148-149	2.2	2.0	2.4	1.8	2.1
151-152	1.1	1.3	1.0	1.2	1.4
Diastolic blood pressure (mmHg)					
78-79	5.6	6.0	6.1	7.0	6.4
81-82	6.0	5.8	6.1	5.5	6.1
88-89	3.9	4.4	4.5	5.2	5.7
91-92	2.1	2.3	2.3	2.2	2.7

Appendix for Chapter 3

Supplemental Figure 1. Study inclusion criteria.



Supplemental Table 1. Characteristics of older adults with treated hypertension in 2011–2013 present and absent at 2016–2017 study visit.

	Present at 2016-2017 Exam	Missing at 2016-2017 Exam	p-value
N (%)	2250 (60%)	1502 (40%)	
Age, mean years (SD)	74.8 (4.7)	76.9 (5.4)	<0.001
Female sex	59.3%	57.7%	0.32
Black race	28.9%	25.6%	0.029
Education			
Less than high school	13.3%	18.4%	<0.001
High school or vocational school	41.7%	44.0%	
College or higher	44.9%	37.5%	
Poor physical function	88.3%	76.6%	<0.001
Pre-frail or frail	51.3%	65.6%	<0.001
Mild cognitive impairment or dementia	18.7%	32.6%	<0.001
Depressive symptoms	6.4%	6.9%	0.54
Medication adherence			
High	59.7%	59.9%	0.92
Intermediate	38.0%	38.1%	
Low	2.3%	2.1%	
Hypertension duration, mean years (SD)	17.2 (7.2)	18.6 (6.7)	<0.001
BMI category, kg/m^2			
<25	17.7%	23.8%	<0.001
25-<30	40.0%	39.1%	
≥30	42.3%	37.1%	
Diabetes	32.1%	40.1%	<0.001
eGFR <60 mL/min/1.73 m^2	28.6%	39.7%	<0.001
Prevalent coronary heart disease	16.1%	20.7%	<0.001
Prevalent stroke	3.7%	4.9%	0.091
Prevalent heart failure	13.5%	21.0%	<0.001

SD = Standard Deviation. eGFR = Estimated Glomerular Filtration Rate. BMI = Body Mass Index.

Supplemental Table 2. Characteristics of older adults with systolic blood pressure <u>≤140 mmHg in 2011-2013</u>, by systolic blood pressure in 2016–2017 and race.

	White			Black		
SBP in 2016-2017	**<140**	**≥140**	**p-value**	**<140**	**≥140**	**p-value**
N (%)	808 (66.9%)	399 (33.1%)		281 (65.5%)	148 (34.5%)	
Age, mean years (SD)	74.4 (4.6)	75.7 (4.9)	<0.001	73.5 (4.6)	74.3 (4.7)	0.10
Female sex	48.1%	59.9%	<0.001	66.5%	70.9%	0.35
Education						
Less than high school	9.3%	9.8%	0.001	21.4%	23.6%	0.71
High school or vocational school	41.8%	52.1%		32.7%	29.1%	
College or higher	48.9%	38.1%		45.9%	47.3%	
Poor physical function	5.9%	8.8%	0.07	22.8%	21.6%	0.79
Pre-frail or frail	47.3%	55.1%	0.01	51.6%	58.8%	0.16
Mild cognitive impairment or dementia	17.6%	19.5%	0.40	14.2%	22.3%	0.04
Depressive symptoms	5.1%	5.3%	0.89	6.8%	10.1%	0.22
Medication adherence						
High	60.4%	61.7%	0.20	59.8%	53.4%	0.34
Intermediate	38.7%	36.3%		36.3%	40.5%	
Low	0.9%	2.0%		3.9%	6.1%	
Hypertension duration, mean years (SD)	15.8 (7.5)	16.2 (7.4)	0.46	18.0 (7.5)	19.8 (6.0)	0.01
BMI category, kg/m^2						
<25	17.8%	22.1%	0.08	8.9%	12.2%	0.05
25-<30	40.5%	42.1%		34.2%	43.2%	
≥30	41.7%	35.8%		56.9%	44.6%	
Diabetes	28.6%	27.3%	0.64	38.8%	52.7%	0.006
eGFR <60 mL/min/1.73 m^2	26.6%	33.1%	0.02	22.8%	28.4%	0.20
Prevalent coronary heart disease	18.7%	21.1%	0.33	8.9%	8.1%	0.78
Prevalent stroke	2.6%	4.0%	0.18	3.9%	7.4%	0.12
Prevalent heart failure	11.6%	10.5%	0.57	17.8%	17.6%	0.95

SBP = Systolic Blood Pressure. eGFR = Estimated Glomerular Filtration Rate. BMI = Body Mass Index.

Supplemental Table 3. Characteristics of older adults with systolic blood pressure ≥140 mmHg in 2011-2013, by systolic blood pressure in 2016–2017 and race.

	White			Black		
SBP in 2016-2017	**<140**	**≥140**	**p-value**	**<140**	**≥140**	**p-value**
N (%)	142 (36.1%)	251 (63.9%)		86 (38.9%	135 (61.1%)	
Age, mean years (SD)	76.0 (4.5)	75.6 (4.6)	0.47	74.8 (4.8)	74.3 (4.8)	0.46
Female sex	48.6%	68.9%	<0.001	75.6%	79.3%	0.52
Education						
Less than high school	9.2%	10.0%	0.67	25.6%	23.0%	0.13
High school or vocational school	44.4%	48.2%		25.6%	38.5%	
College or higher	46.5%	41.8%		48.8%	38.5%	
Poor physical function	11.3%	7.6%	0.22	26.7%	19.3%	0.19
Pre-frail or frail	50.7%	51.8%	0.84	51.2%	54.8%	0.60
Mild cognitive impairment or dementia	23.9%	20.3%	0.40	14.0%	22.2%	0.13
Depressive symptoms	4.2%	5.6%	0.56	8.1%	14.8%	0.14
Medication adherence						
High	63.4%	61.4%	0.59	55.8%	51.9%	0.57
Intermediate	35.9%	36.7%		38.4%	44.4%	
Low	0.7%	2.0%		5.8%	3.7%	
Hypertension duration, mean years (SD)	18.0 (6.8)	17.3 (6.7)	0.36	19.9 (6.0)	20.7 (4.8)	0.32
BMI category, kg/m^2						
<25	18.3%	25.5%	0.26	15.1%	14.8%	0.99
25-<30	44.4%	40.2%		36.0%	37.0%	
≥30	37.3%	34.3%		48.8%	48.1%	
Diabetes	28.2%	25.5%	0.56	38.4%	43.7%	0.43
eGFR <60 mL/min/1.73 m^2	38.7%	31.9%	0.17	17.4%	30.4%	0.03
Prevalent coronary heart disease	19.7%	15.9%	0.34	14.0%	8.1%	0.17
Prevalent stroke	2.1%	4.0%	0.32	4.7%	5.9%	0.68
Prevalent heart failure	14.8%	11.6%	0.36	17.4%	20.0%	0.64

SBP = Systolic Blood Pressure. eGFR = Estimated Glomerular Filtration Rate. BMI = Body Mass Index.

Appendix for Chapter 4

Supplemental Table 1. Systolic blood pressure distribution and proportion of cardiovascular events prevented by reducing systolic blood pressure to <130 mmHg, by race.

Systolic blood pressure (mmHg)	White % (SE)	Black % (SE)
<130	64.7 (0.9)	51.2 (1.2)
130-134	9.7 (0.6)	11.9 (0.7)
135-139	6.9 (0.4)	8.8 (0.6)
140-144	5.8 (0.5)	6.9 (0.5)
145-149	3.9 (0.3)	5.0 (0.5)
150-154	3.0 (0.4)	4.6 (0.6)
155-159	1.8 (0.2)	3.5 (0.5)
≥160	4.2 (0.4)	8.1 (0.6)
Total SBP ≥130	35.3 (0.9)	48.8 (1.2)
Population attributable fraction (2.5, 97.5)	22.3 (20.9, 23.6)	30.3 (28.5, 32.1)

In this analysis, we assume individuals with systolic blood pressure ≥130 have their systolic blood pressure reduced regardless of whether they are eligible for pharmacotherapy or lifestyle change intervention only.

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Curriculum Vitae

Kathryn Foti

Personal Data

Place of Birth
Mt. Kisco, NY

Home Address
111 S. Castle St.
Baltimore, MD 21231
(914) 393-4919

Work Address
Welch Center for Prevention, Epidemiology, and Clinical Research
2024 E. Monument St.
Suite 2-600
Baltimore, MD 21287
kfoti1@jhu.edu

Education

2016-Present **Doctor of Philosophy, Johns Hopkins Bloomberg School of Public Health**
Department of Epidemiology
NIH/NHLBI Pre-Doctoral Training Grant in Cardiovascular Disease Epidemiology (HL007024)
Dissertation: "Racial disparities in blood pressure control and implications of hypertension guidelines"
Advisers: Elizabeth Selvin, PhD and Lawrence J. Appel, MD, MPH
Current GPA: 4.0/4.0

2006-2008 **Master of Public Health, Yale School of Public Health**
Chronic Disease Epidemiology
Thesis: "Serious Mental Illness in New Orleans One Year after Hurricane Katrina"

2002-2006 **Bachelor of Science**
Major: Chemistry
Minor: French
University Honors Scholar, Thesis: "Photogeneration and Degradation of Colloidal Silver Particles"
Summa cum laude

Experience

2018-Present **Research Assistant**

Addressing Hypertension Control in Africa (ADHINCRA) Study
Co-Principal Investigators: Dr. Yvonne Commodore-Mensah, Johns Hopkins University School of Nursing and Dr. Fred Stephen Sarfo, Kwame Nkrumah University of Science and Technology

2018-Present **Research Assistant**
Dr. Wendy Bennett, Johns Hopkins University School of Medicine

2018-Present **Research Assistant**
Dr. Caleb Alexander, Johns Hopkins Bloomberg School of Public Health, Department of Epidemiology

2011-2016 **Special Assistant to the CDC Director**
Centers for Disease Control and Prevention

2010-2011 **Health Scientist**
Centers for Disease Control and Prevention
Division of Adolescent and School Health
Surveillance Research Team

2008-2010 **Association of Schools of Public Health (ASPH)/CDC Fellow**
Centers for Disease Control and Prevention
Division of Adolescent and School Health
Surveillance Research Team

2007-2008 **Research Assistant**
Yale Center for Public Health Preparedness
Yale School of Public Health

2007-2007 **Intern**
New Orleans Health Department

2007-2007 **Intern**
Matrix Public Health Consultants, Inc.

2006-2007 Research Assistant
Dr. Xiaomei Ma, Yale School of Public Health, Chronic Disease Epidemiology

Publications

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Foti KE, Eaton DK, Lowry R, McKnight-Eily LR. Sufficient sleep, physical activity, and sedentary behaviors. *Am J Prev Med*. 2011;41(6):596-602.

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Foti K, Lowry R. Trends in perceived overweight status among overweight and nonoverweight adolescents. *Arch Pediatr Adolesc Med*. 2010;164:636-642.

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Brener ND, McManus T, **Foti K**, Shanklin SL, Hawkins J, Kann L, Speicher N. School Health Profiles 2008: Characteristics of health programs among secondary schools. Atlanta: Centers for Disease Control and Prevention; 2009.

Ma X, Selvin S, Raza A, **Foti K**, Mayne ST. Clustering in the incidence of myelodysplastic syndromes. *Leuk Res*. 2007;31(12):1683-6.

Conference Presentations

International conferences

Foti K, Appel LJ, Matsushita K, Coresh J, Alexander GC, Selvin, ES. National Trends in the Quality Of Office Blood Pressure Measurements, 2014-2018. Joint Meeting of the European Society of Hypertension and the International Society of Hypertension. Glasgow, UK. May 30, 2020. (Oral presentation) *(Accepted; postponed due to COVID-19)*

National conferences

Foti K, Appel LJ, Matsushita K, Coresh J, Alexander GC, Selvin, ES. National Trends in the Quality Of Office Blood Pressure Measurements, 2014-2019. American Heart Association Epi|Lifestyle Scientific Sessions 2020. Phoenix, AZ. March 4, 2020 (accepted). (Poster presentation)

Foti K, Appel LJ, Matsushita K, Koton S, Walker K, Coresh J, Selvin E. Blood Pressure Control Among Older Adults - Results from the Atherosclerosis Risk in Communities Study. American Heart Association Epi|Lifestyle Scientific Sessions 2019. Houston, TX. March 6, 2019. (Poster presentation)

Foti K, Wang D, Selvin E. Trends in Hypertension Prevalence, Awareness, Treatment, and Control: The National Health and Nutrition Examination Survey, 1999-2014. American Heart Association Epi|Lifestyle Scientific Sessions 2018. New Orleans, LA. March 21 and 22, 2018. (Moderated Poster and Poster presentations)

Foti K, Kann L. Global School-based Student Health Survey, 2003-2008. American Public Health Association Annual Meeting 2011. Washington, DC. October 31, 2011. (Oral presentation)

Brener N, Foti K, Eaton D, Kann L. Behaviors and Behavioral Determinants Related to Physical Activity and Nutrition—National Youth Physical Activity and Nutrition Study, United States, 2010. American Public Health Association Annual Meeting 2011. Washington, DC. October 31, 2011. (Oral presentation)

Fisher C, Brener N, Foti K, Rasberry C. What's New! Health and Academic Achievement. American School Health Association Annual School Health Conference. Kansas City, MO. October 15, 2010. (Oral presentation)

Foti K. Uses of Youth Risk Behavior Survey and School Health Profiles Data: Applications for Improving Adolescent and School Health. American School Health Association Annual School Health Conference. Kansas City, MO. October 16, 2010. (Roundtable presentation)

Fisher C, Brener N, Foti K, Rasberry C. What's New! Health and Academic Achievement. DASH Funded Partners' Meeting. Kansas City, MO. October 16, 2010. (Oral presentation)

Anderson C, Bashal C, Boelsterl M, Chaturvedi S, Foti K, Frye L, and Karsif B. Analysis of Greater New Haven Perinatal Outcomes: Prematurity, Sudden Unexplained Infant Deaths and Fetal & Infant Mortality. American Public Health Association Annual Meeting 2008. San Diego, CA. October 26, 2008. (Poster presentation)

Local conferences

Foti K, Selvin E, Shah S, Appel LJ, Alexander GC. Ambulatory treatment of hypertension in the United States, 2014-2018. Johns Hopkins Cardiovascular Research Retreat. Baltimore, MD. May 21, 2019. (Poster presentation)

Foti K, Wang D, Selvin E. Trends in Hypertension Prevalence, Awareness, Treatment, and Control: The National Health and Nutrition Examination Survey, 1999-2014. Johns Hopkins Cardiovascular Research Retreat. Baltimore, MD. April 20, 2018. (Poster presentation)

Honors and Awards

Abraham Lilienfeld Scholarship Fund, Johns Hopkins Bloomberg School of Public Health Department of Epidemiology, 2020

W.H. Linda Kao Collaboration Award, Johns Hopkins Bloomberg School of Public Health Department of Epidemiology, 2020

Johns Hopkins University Diversity Recognition Award, Group Category, Epidemiology Inclusion, Diversity, Equity, and Science Workgroup, 2019

American Heart Association Council on Epidemiology and Prevention Early Career Travel Grant, American Heart Association Epi|Lifestyle Scientific Sessions, 2019

Johns Hopkins Bloomberg School of Public Health Student Assembly Student Recognition Award, 2017-2018

Dorothy and Arthur Samet Student Support Fund in Epidemiology, Johns Hopkins Bloomberg School of Public Health Department of Epidemiology, 2018

Stanley L. Blumenthal, MD Cardiology Award Recipient 2018**,** 2nd place Clinical/Translational/Population Science Poster at the Johns Hopkins Cardiovascular Research Retreat, "Trends in Hypertension Prevalence, Awareness, Treatment, and Control: National Health and Nutrition Examination Survey, 1999-2014"

Charlotte Silverman Fund award, Johns Hopkins Bloomberg School of Public Health Department of Epidemiology, 2017

CDC Honor Award Winner – Excellence in Policy, Making Public Housing Smoke-Free Team, 2016

CDC Honor Award Nominee – Innovation in Science/Program, Million Hearts Hypertension Control Challenge Team, 2014

CDC Chief of Staff Champion Award, Fall 2013

CDC National Center for Emerging and Zoonotic Infectious Diseases Honor Award for Partnership (For forging a novel partnership aimed at eliminating infections in healthcare settings and protecting patients), 2013

Professional Activities

- Society for Epidemiologic Research, Member, 2017 – present
- American Heart Association (Epidemiology Council), Member, 2017 – present
- Member, American Heart Association Working Group on Evidence for Prevention Policy, 2017 – present
- Reviewer: Atherosclerosis Risk in Communities Study (Internal Manuscript Review), 2019 – present
- Epidemiology Section Editor, *Current Diabetes Reports*, 2017-2019

School and Community Service

- Johns Hopkins Center for Health Equity Training Core**,** 2019 – present
- Epidemiology Inclusion, Diversity, Equity & Science (Epi-IDEAS) Workgroup Member, 2017 – present
- Epidemiology Student Organization Co-President**,** Academic Year (AY) 2017-2018
- Back on My Feet Volunteer, 2017 – present (Co-Team Leader 2017-2019)
- Hopkins Marathon Team Co-Captain, 2017-2019
- Abbott Memorial Presbyterian Church Tutoring Center, 2017 – present
- Commodore John Rogers School, Walking School Bus Volunteer, 2018-2019
- Baltimore Point-in-Time Count Team Leader, 2017

Teaching Assistant Experience

- Global Tobacco Control, 2nd Term AY 2019-2020 (online)
- Tobacco Prevention and Control, 1st Term AY 2019-2020 (online)
- Epidemiologic Practice Methods for Population Health Research, 4th Term AY 2017-2018* & 2018-2019; Guest Lecturer AY 2018-2019 & 2019-2020
- Applications of Innovative Methods in Health Equity Research, 3rd Term AY 2017-2018 (online)* & 2018-2019 (online), Summer Institute 2017* & 2018
- Economics of Tobacco Control, 2nd Term AY 2017-2018 (online)
- Epidemiologic Methods 1 and 2, 1st and 2nd Terms AY 2017-2018
- Welch Center Journal Club, 1st – 4th Terms AY 2017-2018

* *Indicates new course offering*