

Reducing the Blood Pressure–Related Burden of Cardiovascular Disease: Impact of Achievable Improvements in Blood Pressure Prevention and Control

Shakia T. Hardy, MPH; Laura R. Loehr, MD, PhD; Kenneth R. Butler, PhD; Sujatro Chakladar, MS; Patricia P. Chang, MD, MHS; Aaron R. Folsom, MD, MPH; Gerardo Heiss, MD, PhD; Richard F. MacLehose, PhD; Kunihiro Matsushita, MD, PhD; Christy L. Avery, PhD

Background—US blood pressure reduction policies are largely restricted to hypertensive populations and associated benefits are often estimated based on unrealistic interventions.

Methods and Results—We used multivariable linear regression to estimate incidence rate differences contrasting the impact of 2 pragmatic hypothetical interventions to reduce coronary heart disease, stroke, and heart failure (HF) incidence: (1) a population-wide intervention that reduced systolic blood pressure by 1 mm Hg and (2) targeted interventions that reduced the prevalence of unaware, untreated, or uncontrolled blood pressure above goal (per Eighth Joint National Committee treatment thresholds) by 10%. In the Atherosclerosis Risk in Communities Study (n=15 744; 45 to 64 years at baseline, 1987–1989), incident coronary heart disease and stroke were adjudicated by physician panels. Incident HF was defined as the first hospitalization with discharge diagnosis code of “428.” A 10% proportional reduction in unaware, untreated, or uncontrolled blood pressure above goal resulted in \approx 4.61, 3.55, and 11.01 fewer HF events per 100 000 person-years in African Americans, and 3.77, 1.63, and 4.44 fewer HF events per 100 000 person-years, respectively, in whites. In contrast, a 1 mm Hg population-wide systolic blood pressure reduction was associated with 20.3 and 13.3 fewer HF events per 100 000 person-years in African Americans and whites, respectively. Estimated event reductions for coronary heart disease and stroke were smaller than for HF, but followed a similar pattern for both population-wide and targeted interventions.

Conclusions—Modest population-wide shifts in systolic blood pressure could have a substantial impact on cardiovascular disease incidence and should be developed in parallel with interventions targeting populations with blood pressure above goal. (*J Am Heart Assoc.* 2015;4:e002276 doi: 10.1161/JAHA.115.002276)

Key Words: blood pressure • coronary heart disease • epidemiology • heart failure • stroke

Decades of research have characterized the associations between elevated blood pressure and a spectrum of cardiovascular diseases (CVD) including cerebral vascular disease, heart failure (HF), and coronary heart disease (CHD).^{1–5} Among blood pressure–related deaths, published

estimates suggest that approximately one third of excess CHD and all-cause mortality can be attributed to elevated systolic blood pressure (SBP) at levels designated as nonhypertensive,^{6,7} indicating that benefits achieved from decreases in blood pressure are not limited to populations with hypertension.^{8–12} Experimental and observational studies have also demonstrated the efficacy of lifestyle-based blood pressure interventions, such as increased physical activity and the Dietary Approaches to Stop Hypertension (DASH) diet, for CVD prevention.^{13–17} This body of evidence supports the development of population-wide interventions to reduce blood pressure alongside interventions targeted to populations with blood pressure above goal for CVD reduction.¹⁸

Several authors have estimated the theoretical effects of shifting the distribution of blood pressure, either by lowering the mean population blood pressure or by decreasing the proportion of the population classified as hypertensive.^{8,11,19–23} Framingham Heart Study investigators reported that a 2-mm Hg population-wide diastolic blood pressure (DBP)

From the Departments of Epidemiology (S.T.H., L.R.L., P.P.C., G.H., C.L.A.), Biostatistics (S.C.), and Medicine (P.P.C.), University of North Carolina, Chapel Hill, NC; Department of Medicine, University of Mississippi Medical Center, Jackson, MS (K.R.B.); Division of Epidemiology and Community Health, School of Public Health, University of Minnesota, MN (A.R.F., R.F.M.); Department of Epidemiology, Johns Hopkins University, Baltimore, MD (K.M.).

Correspondence to: Shakia T. Hardy, MPH, Cardiovascular Disease Program, Department of Epidemiology, University of North Carolina at Chapel Hill, 137 East Franklin Street, Suite 306-D, Chapel Hill, NC 27514. E-mail: sthardy@live.unc.edu
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reduction was associated with an estimated 17% decrease in the prevalence of hypertension, and a 6% reduction in the risk of CHD.¹⁹ Other published studies examined CHD and stroke events, but were conducted in predominantly white or European populations and considered blood pressure treatment guidelines no longer in use.^{8,19,20,23} The degree to which modest population-wide blood pressure shifts may affect the incidence of HF also remains unknown, as do the effects of blood pressure shifts in African American populations,¹⁹ who shoulder higher burdens of elevated blood pressure as well as CVD than do white populations.¹ Further, the majority of published studies estimated cardiovascular benefits from interventions that completely eliminated hypertension or uncontrolled hypertension from the population, despite the implausibility of such goals.^{24–26} Therefore, in a biracial, population-based setting, we assessed the impact of 2 types of pragmatic, hypothetical interventions on reducing the incidence of CHD, stroke, and HF after full implementation: a population-wide intervention that reduced SBP by 1 or 2 mm Hg and targeted interventions that achieved a 10% reduction in the proportion of the population with unaware, untreated, or uncontrolled blood pressure above goal.

Methods

Study Population

The Atherosclerosis Risk in Communities (ARIC) study is a prospective, population-based investigation of the etiology and natural history of CVD and its risk factors.²⁷ From 1987 to 1989, ARIC investigators sampled 15 792 predominately white and African American participants between the ages of 45 and 64 from 4 geographic regions in the United States: Washington County, Maryland; suburban Minneapolis, Minnesota; Forsyth County, North Carolina; and Jackson, Mississippi. The latter 2 communities contributed the majority of African Americans to the cohort. Physical examinations and standardized questionnaires were administered by trained study personnel at baseline and during 4 follow-up examinations. Cohort follow-up for identification and classification of health outcomes is ongoing. The ARIC study obtained institutional review board approval from all participating institutions, and informed consent was obtained at each study visit.

The following sequential exclusions were applied: participants who reported races other than African American or white (n=48); participants missing information to classify prevalent CHD, stroke, or HF or with prevalent CHD, stroke, or HF from each respective analysis (CHD [n=1106], stroke [n=315], or HF [n=1035]). Prevalent CHD was defined at baseline by self-reported history of a physician-diagnosed myocardial infarction, myocardial infarction identified by

electrocardiography, or prior coronary revascularization. Prevalent stroke was defined as a self-reported history of physician-diagnosed stroke.²⁸ Prevalent HF was defined by current use of medication prescribed for HF or manifest HF defined by the Gothenburg criteria stage 3.²⁹ After these exclusions, a total of 14 638, 15 429, and 14 709 participants were available for the evaluation of incident CHD, stroke, and HF, respectively. Follow-up time was calculated from study enrollment to the first CHD, stroke, or HF event, loss to follow-up, death, or December 31, 2011.

Exposure and Covariate Assessment

Seated blood pressure measurements were taken after a 5-minute rest using a random-zero sphygmomanometer; the mean of the second and third readings from the baseline examination was used for analysis. We used the 2014 Guidelines for the Management of High Blood Pressure from the Eighth Joint National Committee (JNC 8) to identify participants with blood pressure above goal: for participants aged ≥ 60 years, SBP ≥ 150 mm Hg or a DBP ≥ 90 mm Hg; for participants aged < 60 , SBP ≥ 140 mm Hg or a DBP ≥ 90 mm Hg.¹⁸ All study participants with blood pressure levels below goal were classified as unexposed, irrespective of medication use or history of hypertension, as they were ineligible for interventions targeted to populations with blood pressure above goal (Figure 1). Antihypertensive medication use, race, age, and gender were assessed at study baseline.

Contemporary race-specific weighted proportions of unaware, untreated, and uncontrolled blood pressure above goal in whites (n=1494, 11.9% blood pressure above goal: 40% unaware; 14% untreated; 46% uncontrolled) and African Americans (n=1004, 26.4% blood pressure above goal: 20% unaware; 22% untreated; 58% uncontrolled) 45 to 64 years of age were estimated from the National Health and Nutrition Examination Survey (NHANES, 2009–12). Individuals with hypertension who were aware and treated to JNC 8 treatment goals were not included in the intervention group (Figure 1).

Outcome Ascertainment and Definitions

ARIC Study participants were interviewed annually by phone and all hospitalizations and deaths during the preceding year were identified, abstracted, and adjudicated according to study criteria. Local hospital discharge records and vital records were also surveyed to detect hospitalizations and deaths of cohort participants. An incident CHD event was defined as a validated definite or probable hospitalized myocardial infarction, a definite CHD death, an unrecognized myocardial infarction defined by electrocardiographic assessment at study visits, or coronary revascularization.³⁰ An incident stroke event was defined as a first definite or

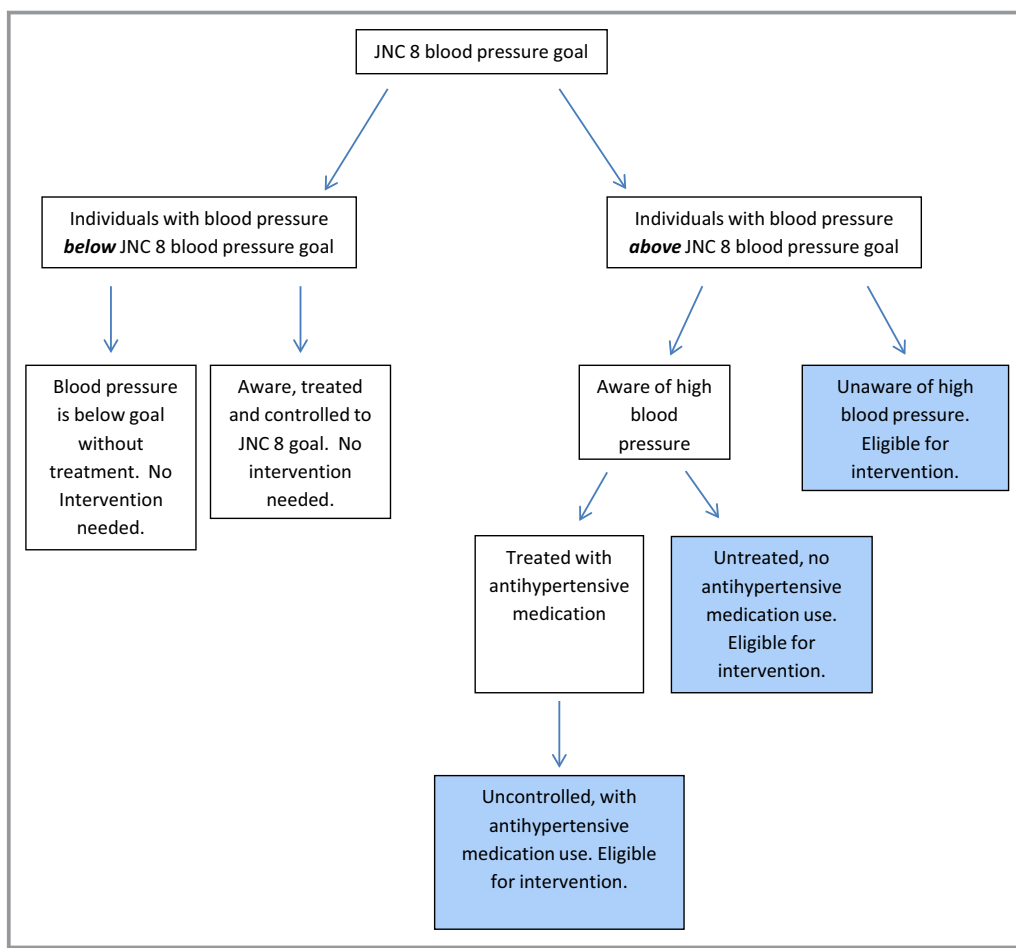


Figure 1. Diagram defining categories of blood pressure above and below the Eighth Joint National Committee (JNC 8) treatment goal. Groups targeted by hypothetical interventions achieving 10% proportional reductions in unaware, untreated, and uncontrolled blood pressure above the JNC 8 treatment goal are shaded blue. JNC 8 indicates, 2014 Evidence-based Guidelines for the Management of High Blood Pressure in Adults report from the Panel Appointed to the Eighth JNC.

probable hospitalized stroke occurring in a participant free of a baseline history of physician-diagnosed stroke.²⁸ Incident HF was identified as the first occurrence of either a hospitalization with discharge diagnosis code of 428.X in any position or an I50 or 428 listed on a death certificate.³¹

Statistical Analysis

To estimate the number of incident CHD, stroke, and HF events per 100 000 person-years (PY) potentially prevented after a population-wide 1- or 2-mm Hg SBP reduction, we used a least-squares linear regression approach³² to estimate race-specific incidence rate differences (IRD) adjusted for age, gender, and antihypertensive medication use. These models provided estimates of the IRDs for CHD, stroke, or HF associated with a 1 mm Hg decrement in SBP at study baseline potentially achievable after lifestyle interventions were fully implemented^{16,17,33–35}; estimates for a 2-mm Hg

reduction were obtained by multiplying the SBP regression coefficient by 2.

To evaluate interventions targeted to populations with blood pressure above goal (Figure 1) after full implementation, we first estimated race-, gender-, and age- (in 5-year increments) specific IRDs using the least-squares regression approach³² for the association between blood pressure above goal and incident CHD, stroke, or HF. Reduction on the incidence rate after a 10% reduction in unaware, untreated, or uncontrolled blood pressure above goal at study baseline was then estimated in the ARIC study using the following equation: $IRD_{ijk} \times (\text{proportion}_i - \text{proportion}_m)$ where i, j, and k index race, gender, and 5-year age categories, and proportion is the race-specific proportion of blood pressure above goal estimated in NHANES³⁶ pre- (l subscript) and post- (m subscript)- intervention that shifted 10% of the proportion of the population with unaware, untreated, or uncontrolled blood pressure above goal to unexposed (ie, below goal blood pressure). Results

were presented per 100 000 PY and represented a special case of the population attributable risk that considers partial, rather than complete, elimination of the risk factor. Here, we considered partial elimination of blood pressure above goal, achieved after fully implementing interventions that decreased the proportion of the population with unaware, untreated, or uncontrolled blood pressure by 10%.¹⁹ Age- and gender-specific results were then collapsed by race using a case-load-weighted summation method,^{37,38} and 95% confidence intervals (CIs) were obtained using bootstrapping.³⁹

As a sensitivity analysis, we also estimated the impact of a 10% reduction in the total population with blood pressure above goal. Hypothetical interventions that achieved a 5% and 20% reduction in the proportion of individuals with blood pressure above goal as well as the proportions of individuals with unaware, untreated, and uncontrolled blood pressure above goal were also examined. Contemporary race-specific population projections for the number of events prevented by the population-wide and the targeted interventions were calculated by multiplying the race-specific IRD estimates by the race-specific total population aged 45 to 64 years without a history of CHD, stroke, or HF, calculated by applying weighted prevalence proportions estimated in NHANES (2009–2012) (African Americans: CHD [n=40, weighted prevalence proportion 4.0%], stroke [n=62, weighted prevalence proportion 6.1%], HF [n=38, weighted prevalence proportion 3.8%]; whites: CHD [n=70, weighted prevalence proportion 3.3%], stroke [n=55, weighted prevalence proportion 2.2%], HF [n=42, weighted prevalence proportion 3.8%]) to the 2010 US census population. All statistical analyses were performed with SAS 9.3 software (SAS Institute, Cary, NC) and Stata12 (StataCorp, College Station, TX).

Results

At study baseline, a maximum of 15 744 (27% African American) ARIC cohort members were available for analysis (Table 1). African Americans were more likely to be female and on average to have higher estimated SBP and diastolic blood pressure than white participants. African American individuals were over twice as likely to have blood pressure above goal and to report the use of antihypertensive medications. Although African Americans were slightly younger at baseline, they contributed on average 1.2 years less person time through 2011 than did whites.

Over a mean 20 years of follow-up, 1803 incident CHD events, 1147 incident stroke events, and 2537 incident HF events were identified (Tables 1 and 2). Age-adjusted incidence rates for CHD, stroke, and HF were higher among African Americans than whites. The discrepancy by race was especially apparent for HF, where estimated incidence rates

Table 1. Baseline Characteristics of the ARIC Study Cohort (N=15 744) by Race, 1987–1989

Baseline Characteristics	African Americans (n=4266)	Whites (n=11 478)
Prevalent CHD, N (%)	171 (4.1)	594 (5.3)
Prevalent stroke, N (%)	53 (1.3)	52 (0.5)
Prevalent HF, N (%)	296 (7.1)	455 (4.0)
Mean follow-up in y, (SD)	19.1 (6.5)	20.3 (5.6)
Mean age in y, (SD)	53.6 (5.8)	54.4 (5.7)
Female, N (%)	2635 (61.8)	6050 (52.7)
Reported antihypertensive use, N (%)	1728 (51.5)	2271 (22.7)
Mean systolic blood pressure, mm Hg (SD)	128.9 (21.6)	118.5 (17.0)
Mean diastolic blood pressure, mm Hg (SD)	79.7 (12.3)	71.5 (10.1)
Blood pressure categories*		
Blood pressure below JNC 8 goal, N (%)	3031 (71.2)	10 285 (89.7)
Blood pressure above JNC 8 goal, N (%)	1229 (28.8)	1186 (10.3)
Above JNC 8 goal and unaware	332 (27.0)	419 (35.3)
Above JNC 8 goal, aware but untreated	272 (22.1)	258 (21.8)
Above JNC 8 goal, treated, but uncontrolled	608 (49.5)	487 (41.1)

ARIC indicates Atherosclerosis Risk in Communities Study; CHD, coronary heart disease; HF, heart failure; JNC, Joint National Committee.

*Blood pressure above goal, blood pressure values that exceed thresholds for management of blood pressure defined by JNC 8; blood pressure below goal, blood pressure values below thresholds for management of blood pressure defined by JNC 8.

were 1193/100 000 PY among African Americans but 786/100 000 PY among whites.

A population-wide hypothetical intervention that achieved an overall 1 mm Hg decrement in SBP at study baseline after

Table 2. Incident CHD, Stroke, and HF Events and Incidence Rates in the Cohort (N=15 744), by Race, 1987–2011 (ARIC Study)

Incident Characteristics	African Americans (n=4266)		Whites (n=11 478)	
	No. Events	IR*	No. Events	IR*
Incident CHD	554	711	1249	563
Incident Stroke	458	585	689	301
Incident HF	857	1193	1680	786

ARIC indicates Atherosclerosis Risk in Communities Study; CHD, coronary heart disease; HF, heart failure; IR, incidence rate; N, events, number of events; n, maximum number of individuals before exclusions.

*IR per 100 000 person-years.

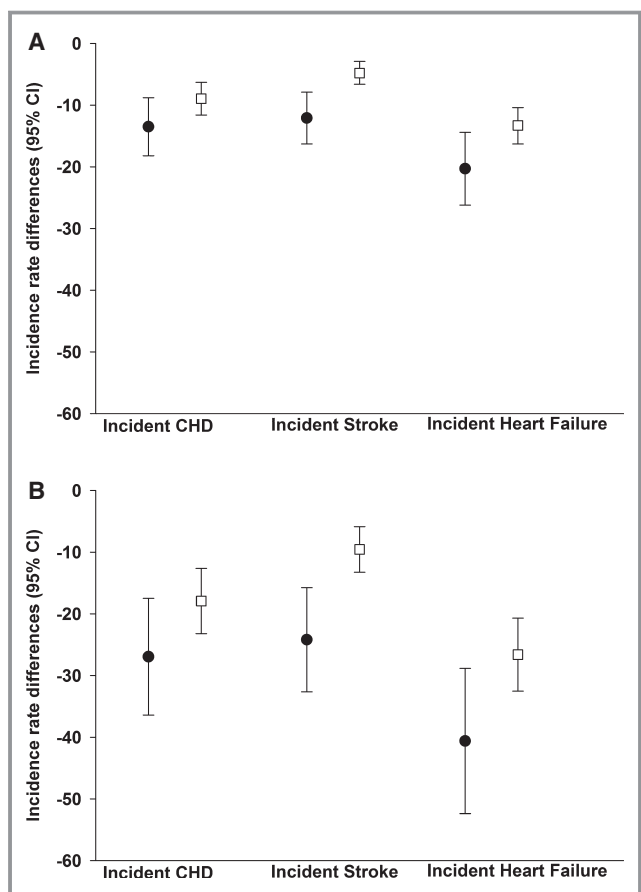


Figure 2. Incidence rate differences in CHD, stroke, and HF per 100 000 person-years associated with a 1 mm Hg (A) and a 2 mm Hg (B) reduction in SBP in African Americans (black circles) and whites (white squares), the ARIC cohort study, 1987–2011. A, Population-wide 1 mm Hg reduction in systolic blood pressure. B, Population-wide 2 mm Hg reduction in systolic blood pressure. ARIC indicates Atherosclerosis Risk in Communities; CHD, coronary heart disease; HF, heart failure; SBP, systolic blood pressure.

full implementation yielded a greater estimated number of preventable events per 100 000 PY for HF (Figure 2A, Table 3), than for CHD and stroke. Notably, the estimated benefits from modest population-wide decrements in SBP were

consistently greater for African Americans than for whites; the greatest difference by race was observed for incident HF, for which a 1 mm Hg population-wide decrement in SBP prevented 7.0 additional events per 100 000 PY in African Americans when compared to whites. If applied nationwide, a hypothetical 1 mm Hg shift in SBP among African American and white US populations aged 45 to 64 years was estimated to prevent ≈9338 incident HF events, 6210 incident CHD events, and 3761 incident stroke events annually (Table 4). As expected, the hypothetical intervention achieving the larger SBP reduction of 2 mm Hg was associated with larger reductions in the incidence of CHD, stroke, and HF for both racial groups (Figure 2B, Tables 3 and 4).

We then contrasted the hypothetical population-wide SBP reduction with interventions targeted to populations with blood pressure above goal that achieved a 10% proportional reduction in unaware, untreated, or uncontrolled blood pressure. For example, before intervention, 26.4% of African Americans and 11.9% of whites 45 to 64 years of age were classified as having blood pressure above goal (NHANES 2009–2012; Table 5); we therefore evaluated a targeted intervention that achieved a 10% proportional decrease in unaware blood pressure above goal (ie, 20% to 18% among African Americans and 40% to 36% among whites, respectively) resulting in post-intervention proportions of blood pressure above goal of 25.84% for African Americans and 11.41% for whites (Table 5). Similar to results from the population-wide SBP interventions, 10% proportional reductions in unaware, untreated, or uncontrolled blood pressure above goal produced the largest reduction in events for HF, the magnitude of which varied by race (Table 6, Figure 3). Specifically, a 10% proportional reduction in unaware, untreated, or uncontrolled blood pressure above goal at study baseline resulted in ≈4.61 (95% CI: 2.50–7.36), 3.55 (95% CI: 1.79–5.73), and 11.01 (95% CI: 6.17–17.52) fewer HF events per 100 000 PY, respectively, in African Americans and 3.77 (95% CI: 1.88–6.51), 1.63 (95% CI: 0.65–3.04), and 4.44 (95% CI: 2.49–6.81) fewer HF events per 100 000 PY, respectively,

Table 3. Estimated Events Reduced for CHD, Stroke, and HF From 2 Population-Wide Hypothetical Blood Pressure Reduction Interventions, by Race (N=15 744), 1987–1989, the ARIC Study

Outcome	African Americans			Whites		
	No. Events	Events Reduced by Population-Wide Intervention (95% CI)		No. Events	Events Reduced by Population-Wide Intervention (95% CI)	
		1-mm Hg Decrease*	2-mm Hg Decrease*		1-mm Hg Decrease*	2-mm Hg Decrease*
CHD	554	13.5 (8.8–18.2)	27.0 (17.5–36.4)	1249	9.0 (6.3–11.6)	17.9 (12.6–23.2)
Stroke	458	12.1 (7.9–16.3)	24.2 (15.8–32.6)	689	4.8 (2.9–6.6)	9.6 (5.9–13.3)
HF	857	20.3 (14.4–26.2)	40.6 (28.8–52.4)	1680	13.3 (10.4–16.3)	26.6 (20.7–32.5)

ARIC indicates Atherosclerosis Risk in Communities Study; CHD, coronary heart disease; HF, heart failure.
*Per 100 000 person-years.

Table 4. Estimated Events Reduced Annually for CHD, Stroke, and HF From 2 Population-Wide Hypothetical Blood Pressure Reduction Interventions, by Race, 2010 US Census Population Aged 45 to 64

Outcome	African Americans			Whites		
	Population (N)*	Population-Wide Intervention		Population (N)*	Population-Wide Intervention	
		1-mm Hg Decrease	2-mm Hg Decrease		1-mm Hg Decrease	2-mm Hg Decrease
CHD	8 701 219	1175	2349	55 946 031	5035	10 070
Stroke	8 501 707	1029	2057	56 575 526	2733	5465
HF	8 700 428	1766	3532	56 930 452	7572	15 144

CHD indicates coronary heart disease; HF, heart failure.

*Total 2010 US census race specific populations aged 45 to 64 (African Americans n=9 042 518, whites n=57 864 260) were used to calculate the population with prevalent CHD, stroke or HF excluded, respectively, using weighted prevalence proportions for history of CHD, stroke, and HF by above-goal blood pressure.

in whites (Table 6, Figure 3). If 10% proportional reductions in unaware, untreated, or uncontrolled blood pressure above goal were achieved nationwide in African Americans and white populations aged 45 to 64, \approx 2200, 1017, and 3164 fewer incident HF events, respectively, could be prevented annually; \approx 1390, 650, and 2016 incident CHD and 962, 497, and 1505 stroke events would be prevented annually given 10% proportional reductions in unaware, untreated, or uncontrolled blood pressure above goal, respectively (Table 7).

Sensitivity analyses examining 5% to 20% proportional reductions in the total population with blood pressure above goal target a larger segment of the population with blood pressure above goal and demonstrated considerably larger reductions in CHD, stroke, and HF events than interventions targeting unaware, untreated, or uncontrolled blood pressure above JNC 8 goals (Tables 7 and 8). Heterogeneity by race for interventions achieving reductions in the total population with blood pressure above goal was also observed, with event reductions for African Americans approximately twice as large as event reductions for whites.

Discussion

Predicted benefits from blood pressure reductions estimated in a biracial, population-based cohort showed that a modest population-wide 1 mm Hg decrement in SBP could prevent substantial numbers of cardiovascular events. Interventions targeted to the population with blood pressure above goal

that achieved a 10% proportional reduction in unaware, untreated, or uncontrolled blood pressure also achieved meaningful cardiovascular event reductions, but were of smaller magnitude. Of the 3 CVD outcomes investigated, hypothetical interventions that decreased SBP or blood pressure above goal had the greatest estimated impact on reducing HF incidence. With both intervention types, the estimated benefits of lowering blood pressure on CVD events were greater for African Americans compared to whites.

Decades of research have demonstrated that the medical management of blood pressure among hypertensive populations is effective in reducing the risk of CVD and addresses the medical responsibility to lower the risk of clinical events among those at highest risk.^{7,40–42} Accordingly, clinical and public health efforts to improve hypertension awareness, treatment, and control have translated into cardioprotective benefits, as shown between 1998 and 2008 when the mean SBP for US adults with hypertension declined by \approx 10 mm Hg.⁴⁰ However, declines in SBP were largely limited to hypertensive populations, as the average SBP for the entire US population changed little over the same time span.⁴⁰

The large cardioprotective benefits associated with the medical management of blood pressure led earlier studies to evaluate the hypothetical impact of 100% elimination of hypertension on the incidence of CVD through metrics like the population-attributable fraction.^{24,26} For reference, our results suggested that if 100% of aware and treated blood pressure above goal was controlled among African American and

Table 5. Proportion of African American and White NHANES Participants Aged 45 to 64 Years With Blood Pressure Above JNC 8 Goal Before and After Targeted Interventions Improving Unaware, Untreated, and Uncontrolled Blood Pressure by 10%, 2009–2012

Race	Proportion of Participants With Blood Pressure Above Goal			
	Before Intervention	After 10% Reduction in Proportion of Unaware Blood Pressure Above Goal	After 10% Reduction in Proportion of Untreated Blood Pressure Above Goal	After 10% Reduction in Proportion of Uncontrolled Blood Pressure Above Goal
African Americans	26.36	25.84	25.78	24.82
Whites	11.88	11.41	11.71	11.33

JNC indicates Joint National Committee; NHANES, National Health and Nutrition Examination Survey.

Table 6. Estimated Events Reduced for CHD, Stroke, and HF From a Hypothetical Intervention That Achieves a 5%, 10%, or 20% Reduction of Unaware, Untreated, or Uncontrolled BP Above JNC 8 Goals, by Race (N=15 744), 1987–2011, ARIC Study

Event Type	BP Category	Events Reduced* Per 100 000 PYs (95% CI) by Interventions Achieving Reductions in BP Above Goal					
		5% Proportional Reduction		10% Proportional Reduction		20% Proportional Reduction	
		African American	White	African American	White	African American	White
Hypothetical intervention—reduce unaware BP (above JNC 8 treatment threshold)							
CHD	BP above JNC 8 goal	1.55 (0.66–2.58)	1.05 (0.40–1.78)	3.10 (1.31–5.15)	2.09 (0.81–3.57)	6.21 (2.63–10.31)	4.19 (1.62–7.13)
Stroke	BP above JNC 8 goal	1.48 (0.73–2.37)	0.73 (0.32–1.27)	2.95 (1.46–4.75)	1.47 (0.64–2.55)	5.95 (2.92–9.50)	2.93 (1.27–5.09)
HF	BP above JNC 8 goal	2.30 (1.25–3.68)	1.89 (0.94–3.25)	4.61 (2.50–7.36)	3.77 (1.88–6.51)	9.21 (5.00–14.72)	7.54 (3.76–13.01)
Hypothetical intervention—reduce untreated BP (above JNC 8 treatment threshold)							
CHD	BP above JNC 8 goal	1.26 (0.55–2.13)	0.41 (0.13–0.74)	2.52 (1.10–4.25)	0.81 (0.27–1.48)	5.04 (2.19–8.51)	1.63 (0.53–2.97)
Stroke	BP above JNC 8 goal	1.27 (0.49–2.26)	0.29 (0.10–0.56)	2.53 (0.98–4.53)	0.57 (0.20–1.12)	5.07 (1.95–9.06)	1.14 (0.40–2.24)
HF	BP above JNC 8 goal	1.78 (0.89–2.87)	0.81 (0.32–1.52)	3.55 (1.79–5.73)	1.63 (0.65–3.04)	7.10 (3.57–11.47)	3.26 (1.29–6.08)
Hypothetical intervention—reduce uncontrolled BP (above JNC 8 treatment threshold)							
CHD	BP above JNC 8 goal	3.61 (1.54–5.79)	1.44 (0.55–2.57)	7.22 (3.08–11.57)	2.87 (1.11–5.15)	14.44 (6.17–23.14)	5.75 (2.22–10.30)
Stroke	BP above JNC 8 goal	3.52 (1.72–5.65)	0.98 (0.33–2.02)	7.04 (3.44–11.31)	1.95 (0.65–4.05)	14.08 (6.87–22.62)	3.90 (1.30–8.10)
HF	BP above JNC 8 goal	5.51 (3.09–8.76)	2.22 (1.25–3.40)	11.01 (6.17–17.52)	4.44 (2.49–6.81)	22.02 (12.34–35.04)	8.87 (4.99–13.62)

ARIC indicates Atherosclerosis Risk in Communities Study; BP, blood pressure; CHD, coronary heart disease; HF, heart failure; IRD, incidence rate differences; JNC 8, the 2014 Guidelines for the Management of High Blood Pressure from the Eighth Joint National Committee.

*Events reduced calculated as $IRD_{ijk} \times (\text{proportion}_i - \text{proportion}_m)$ where i, j, and k index race, gender, and 5-year age categories, proportion is the race-specific proportion of BP above goal³⁶ pre- (l subscript)-intervention, per 100 000 person years.

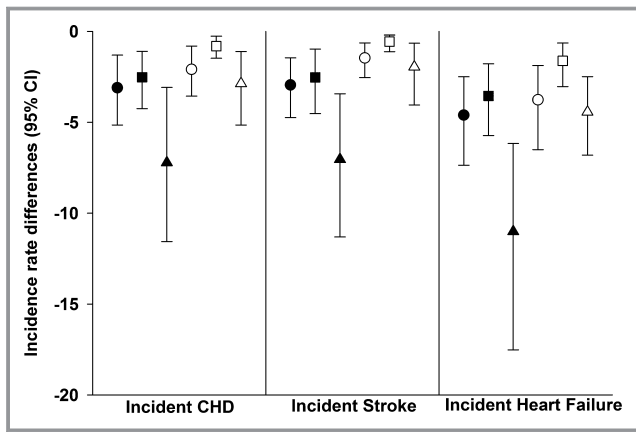


Figure 3. IRDs for CHD, stroke and HF per 100 000 person-years associated with 10% proportional reductions in unaware (circle), untreated (squares), or uncontrolled (triangles) blood pressure above JNC 8 treatment goal in African American (black symbols) and white (white symbols) ARIC participants, 1987–2011. ARIC indicates Atherosclerosis Risk in Communities; CHD, coronary heart disease; HF, heart failure; IRDs, incidence rate differences; JNC, Joint National Committee.

whites aged 45 to 64 years of age, $\approx 20\,154$ CHD events could be prevented annually in the United States, consistent with recently published estimates using the JNC 8 guide-

lines.²⁴ Despite considerable clinical and public health efforts to improve hypertension management, no historical precedent is available for achieving 100% control; instead, nationally representative estimates suggested that $\approx 43.5\%$ of adults with treatment-eligible hypertension are not treated to goal.⁴³ As an alternative, we estimated event reductions achieved by modest, but plausible decreases in the proportion of the population classified as having unaware, untreated, and uncontrolled blood pressure above goal. As expected, full implementation of interventions that achieved 10% changes in unaware, untreated, and uncontrolled blood pressure above goal were estimated to prevent considerably fewer CVD events than fully implemented interventions assuming 100% elimination of blood pressure above goal. This discrepancy reflects the proportion of the population for whom we assume a successful intervention. For example, in a population of 100 000 (prevalence of blood pressure above goal 20%; composed of 40% unaware, 14% aware but untreated, and 46% aware treated but uncontrolled), a successful intervention that reduced uncontrolled blood pressure above goal by 10% would target ≈ 920 people compared to the substantially larger population of 20 000 people targeted by an intervention assuming 100% elimination of blood pressure above goal.

Table 7. Estimated Events Reduced for CHD, Stroke, and HF From Hypothetical Targeted BP Reduction Interventions, by Race, 2010 US Census Population Aged 45 to 64

Event Type	BP Category	Events Reduced Annually by Interventions Achieving Reductions in BP Above Goal			
		Population (N)		10% Proportional Reduction	
		African American*	White*	African American	White
Hypothetical intervention to reduce unaware BP above goal					
CHD	BP above JNC 8 goal	8 701 219	55 946 031	211	1169
Stroke	BP above JNC 8 goal	8 501 707	56 575 526	213	749
HF	BP above JNC 8 goal	8 700 428	56 930 452	335	1865
Hypothetical intervention to reduce untreated BP above goal					
CHD	BP above JNC 8 goal	8 701 219	55 946 031	246	404
Stroke	BP above JNC 8 goal	8 501 707	56 575 526	238	259
HF	BP above JNC 8 goal	8 700 428	56 930 452	373	644
Hypothetical intervention to reduce uncontrolled BP above goal					
CHD	BP above JNC 8 goal	8 701 219	55 946 031	654	1362
Stroke	BP above JNC 8 goal	8 501 707	56 575 526	632	873
HF	BP above JNC 8 goal	8 700 428	56 930 452	991	2173
Hypothetical intervention to reduce total population with BP above goal					
CHD	BP above JNC 8 goal	8 701 219	55 946 031	1121	2934
Stroke	BP above JNC 8 goal	8 501 707	56 575 526	1083	1880
HF	BP above JNC 8 goal	8 700 428	56 930 452	1699	4682

BP indicates blood pressure; CHD, coronary heart disease; HF, heart failure; JNC, Joint National Committee.

*Total 2010 US census race-specific populations aged 45 to 64 (African Americans $n=9\,042\,518$, whites $n=57\,864\,260$) were used to calculate the population with prevalent CHD, stroke, or HF excluded, respectively, using weighted prevalence proportions for history of CHD, stroke, and HF by above-goal BP.

Table 8. Estimated Events Reduced for CHD, Stroke, and HF From a Hypothetical Intervention That Achieves a 5%, 10%, or 20% Reduction in BP Above JNC 8 Goals, by Race (N=15 744), 1987–2011, ARIC Study

Event Type	BP Category	Events Reduced* Per 100 000 PYs (95% CI) by Interventions Achieving Reductions in BP Above Goal					
		5% Proportional Reduction		10% Proportional Reduction		20% Proportional Reduction	
		African American	White	African American	White	African American	White
CHD	BP above JNC 8 goal	6.42 (2.77–9.83)	2.89 (1.13–4.93)	12.84 (5.53–19.67)	5.78 (2.26–9.86)	25.68 (11.06–39.33)	11.56 (4.52–19.73)
Stroke	BP above JNC 8 goal	6.26 (3.09–9.75)	1.99 (0.80–3.77)	12.53 (6.19–19.49)	3.99 (1.60–7.55)	25.05 (12.37–38.98)	7.98 (3.19–15.09)
HF	BP above JNC 8 goal	9.58 (5.64–14.36)	4.92 (2.63–7.77)	19.17 (11.29–28.72)	9.84 (5.27–15.55)	38.33 (22.58–57.44)	19.67 (10.54–31.09)

ARIC indicates Atherosclerosis Risk in Communities Study; BP, blood pressure; CHD, coronary heart disease; HF, heart failure; IRD, incidence rate differences; JNC 8, the 2014 Guidelines for the Management of High Blood Pressure from the Eighth Joint National Committee; PY, Person years.

*Events reduced calculated Person years as $IRD_{ijk} \times (\text{proportion}_{i,j} - \text{proportion}_{i,k})$ where i, j, and k index race, gender, and 5-year age categories, proportion is the race-specific proportion of BP above goal³⁶ pre- (l subscript) and post (m subscript)- intervention, per 100 000.

Targeted interventions and population-wide interventions are complementary, and it is admittedly difficult to compare the 2 since the clinical and public health prevention and control strategies, their associated costs, and target populations differ considerably. Targeted efforts to improve the management of hypertension have resulted in relatively low levels of unaware, untreated, and uncontrolled hypertension, particularly after the realignment introduced by the 2014 JNC 8 guideline for the management of high blood pressure.^{40,43} Interventions targeted to populations with blood pressure above goal will therefore become less effective in lowering CVD incidence as blood pressure awareness, treatment, and control continue to improve, limiting the target population.⁴⁰ Conversely, population-wide lifestyle approaches to blood pressure reduction, as encouraged by the 2013 AHA/ACC Guideline on Lifestyle Management to Reduce Cardiovascular Risk, have been successful in reducing CVD across a wide range of blood pressures.^{15,16,44} For example, prior population-wide intervention studies of salt reduction demonstrated decreases in morbidity, mortality, and healthcare costs with as little as 1 g less of salt per day (equivalent to 1/6 of a teaspoon)¹⁵ and are feasible, as evidenced by recent dietary salt reduction programs in the United Kingdom focused on manufactured food that decreased mean sodium content in the food supply by 7%.¹³ Other potential lifestyle interventions to reduce blood pressure include increasing physical activity,^{45,46} reducing weight,⁴⁷ and improving overall diet quality.⁴⁶ Further studies are needed to inform safety^{48,49} and selection of the most cost-effective population-wide interventions in the United States to decrease SBP.

Our results highlight the potential of population-wide SBP reduction approaches to complement interventions targeted to clinically defined populations with blood pressure above goal. Interventions targeting the US white populations with uncontrolled blood pressure would need to achieve approximately a 30% proportional reduction in uncontrolled blood pressure in order to achieve event reduction comparable to those estimated for population-wide interventions that achieve a 1-mm Hg shift in SBP. African American populations, among whom blood pressure elevation occurs at earlier ages and show elevated rates of CVD in the United States,^{1,40} likely would reap the greatest benefits of population-wide and targeted above goal blood pressure interventions, particularly for uncontrolled blood pressure, suggesting that both types of interventions have potential for reducing these persistent health disparities.

The strengths of this study include the use of a large, biracial cohort with high retention and quality assurance protocols over an average of 20 years of follow-up. There also are several limitations that deserve consideration. First, the ARIC cohort may not be fully generalizable to the US population, particularly for African Americans participants, who were primarily recruited from Jackson, Mississippi and

Forsyth County, North Carolina; other US minority groups were not represented in this study. The ARIC study was also restricted to participants aged 45 to 64 years at study baseline. Additionally, several studies suggest that the national incidence of CVD events has changed since the 1980s, with the incidence of CHD and stroke declining and the incidence of HF increasing,^{1,50,51} which may over- or underestimate the number of events reduced by population-wide and targeted blood pressure interventions. Secondly, we assumed the same incidence rate reduction when calculating the number of events that could be prevented from interventions that targeted unaware, untreated, and uncontrolled blood pressure above goal. We also estimated separate intervention effects, for unaware, untreated, and uncontrolled blood pressure above goal, although in practice, these interventions would likely be promoted in combination and associated with target-specific IRDs. Third, if future guidelines, following the results of the Systolic Blood Pressure Intervention Trial (SPRINT), reduce the thresholds for treatment or goal for blood pressure control, interventions that reduce untreated or uncontrolled blood pressure could result in substantially larger reductions in events.⁵² Despite these limitations, few studies have evaluated pragmatic blood pressure interventions and even fewer have included African Americans, who shoulder historic blood pressure and CVD disparities, positioning this study to contribute increased understanding of the population management of elevated blood pressure.

In conclusion, population-wide reductions in SBP of modest magnitude are predicted to have a substantial impact on CVD prevention and should be developed in parallel with interventions targeted to populations with blood pressure above goal. As advocated by many primary prevention statements,^{33,53,54} the management of blood pressure in adults should not be limited to those classified as hypertensive, but rather extend to the majority of the populations below hypertension treatment thresholds. Omitting such individuals leaves a large segment of the population at increased risk of cardiovascular events and constrains the ability of clinicians and public health practitioners to reduce the societal burden of blood pressure-related CHD, stroke, and HF.

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Disclosures

None.

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