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## Trends and Cardiovascular Mortality Effects of State-Level Blood Pressure and Uncontrolled Hypertension in the United States

Majid Ezzati, PhD; Shefali Oza, SB; Goodarz Danaei, MD; Christopher J.L. Murray, MD, DPhil

**Background**—Blood pressure is an important risk factor for cardiovascular disease and mortality and has lifestyle and healthcare determinants that vary across states. Only self-reported hypertension status is measured at the state level in the United States. Our aim was to estimate levels and trends in state-level mean systolic blood pressure (SBP), the prevalence of uncontrolled systolic hypertension, and cardiovascular mortality attributable to all levels of higher-than-optimal SBP.

**Methods and Results**—We estimated the relationship between actual SBP/uncontrolled hypertension and self-reported hypertension, use of blood pressure medication, and a set of health system and sociodemographic variables in the nationally representative National Health and Nutrition Examination Survey. We applied this relationship to identical variables from the Behavioral Risk Factor Surveillance System to estimate state-specific mean SBP and uncontrolled hypertension. We used the comparative risk assessment methods to estimate cardiovascular mortality attributable to higher-than-optimal SBP. In 2001–2003, age-standardized uncontrolled hypertension prevalence was highest in the District of Columbia, Mississippi, Louisiana, Alabama, Texas, Georgia, and South Carolina (18% to 21% for men and 24% to 26% for women) and lowest in Vermont, Minnesota, Connecticut, New Hampshire, Iowa, and Colorado (15% to 16% for men and  $\approx$ 21% for women). Women had a higher prevalence of uncontrolled hypertension than men in every state by 4 (Arizona) to 7 (Kansas) percentage points. In the 1990s, uncontrolled hypertension in women increased the most in Idaho and Oregon (by 6 percentage points) and the least in the District of Columbia and Mississippi (by 3 percentage points). For men, the worst-performing states were New Mexico and Louisiana (decrease of 0.6 and 1.3 percentage points), and the best-performing states were Vermont and Indiana (decrease of 4 and 3 percentage points). Age-standardized cardiovascular mortality attributable to higher-than-optimal SBP ranged from 200 to 220 per 100 000 (Minnesota and Massachusetts) to 360 to 370 per 100 000 (District of Columbia and Mississippi) for women and from 210 per 100 000 (Colorado and Utah) to 370 per 100 000 (Mississippi) and 410 per 100 000 (District of Columbia) for men.

**Conclusions**—Lifestyle and pharmacological interventions for lowering blood pressure are particularly needed in the South and Appalachia, and with emphasis on control among women. Self-reported data on hypertension diagnosis from the Behavioral Risk Factor Surveillance System can be used to obtain unbiased state-level estimates of blood pressure and uncontrolled hypertension as benchmarks for priority setting and for designing and evaluating intervention programs. (*Circulation*. 2008;117:905-914.)

**Key Words:** blood pressure ■ cardiovascular diseases ■ hypertension ■ models, statistical ■ mortality ■ risk factors ■ United States

High blood pressure is an important risk factor for cardiovascular disease and mortality, accounting for an estimated 14% of cardiovascular deaths worldwide and 18% in high-income countries.<sup>1</sup> Although in some clinical applications specific thresholds are used to define hypertension (eg, 140 mm Hg

for systolic blood pressure [SBP]),<sup>2</sup> epidemiological studies have established that cardiovascular disease and mortality risks increase continuously with blood pressure from levels well below the conventional thresholds used in the definition of hypertension.<sup>3,4</sup> Therefore, in addition to hypertension diagnosis

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and control, shifting the whole distribution of blood pressure is important for reducing cardiovascular disease mortality. In the United States, age-standardized mean blood pressure declined for both men and women between the 1970s and early 1990s as measured in the first 3 rounds of the National Health and Nutrition Examination Survey (NHANES), possibly as a result of a combination of lifestyle and pharmacological interventions.<sup>5,6</sup> Since the early 1990s, however, these declines appear to have stagnated or reversed, possibly because of the rise in risk factors associated with blood pressure (eg, overweight and obesity) and the fact that hypertension remains underdiagnosed and only partially controlled.<sup>7-9</sup>

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State-specific data on levels and trends of blood pressure and hypertension are essential inputs for priority setting; for the design, delivery, and evaluation of interventions; and for understanding disparities in hypertension levels, diagnosis, and treatment.<sup>10-13</sup> In the United States, NHANES III provided information on blood pressure in broad regions of the country,<sup>14-16</sup> but estimates in NHANES III were based on data from only 81 of the 3141 US counties in 26 states. At the state level, only self-reported hypertension status is measured in the Behavioral Risk Factor Surveillance System (BRFSS).<sup>17-20</sup> BRFSS estimates cannot be directly used to assess cardiovascular risk and to evaluate interventions for a number of reasons (see also earlier assessments of BRFSS).<sup>21-23</sup> First, some people may be unaware of their hypertension status because they have not had contact with a health professional or have not been diagnosed during such a contact. Second, some people who were diagnosed with hypertension may have effectively controlled and lowered their actual blood pressure through lifestyle and/or pharmacological interventions. Because the risk of cardiovascular diseases is determined by actual blood pressure and not by whether this level is maintained through interventions,<sup>24</sup> such people are no longer a part of the “high-cardiovascular-risk” group. Finally, self-reported questions allow analysis of only the high-risk (hypertension) status, not the underlying continuous exposure.

We used 2 national health and health examination surveys, NHANES and BRFSS, to characterize the relationship between actual SBP and self-reported hypertension status, use of blood pressure medication, and a set of health system and sociodemographic variables. We then used this relationship to estimate for the first time mean SBP and uncontrolled hypertension prevalence at the state level by sex and age group for 2 time periods, 1988–1992 and 2001–2003. We then calculated cardiovascular mortality attributable to all levels of higher-than-optimal SBP at the state level.

## Methods

### Data Sources

NHANES, conducted by the Centers for Disease Control and Prevention, is part of a cross-sectional survey series conducted in the United States since 1959. This nationally representative survey uses a complex, multistage, stratified, clustered probability sample design to determine health and nutrition characteristics of the civilian, noninstitutionalized population  $\geq 2$  months of age. NHANES includes an in-person interview and a subsequent physical examination

and measurement component in a mobile examination clinic (MEC); those unable to visit the MEC are offered a limited examination at home. NHANES III was conducted from 1988 to 1994. Beginning in 1999, NHANES became a continuous survey with data released in 2-year increments. We used NHANES 1999–2002 because complete data files for 2003–2004 were not yet released at the time of analysis. The response rate for the household interview was 86%, 82%, and 84% for NHANES III, NHANES 1999–2000, and NHANES 2001–2002, respectively. The corresponding response rates for the medical examination after completing the household interview were 92%, 93%, and 95% (The overall response rate for medical examination is therefore the product of the 2 separate response rates). Additional information on survey design and methods, including blood pressure measurement, is available elsewhere<sup>25,26</sup> and online (<http://www.cdc.gov/nchs/nhanes.htm>).

BRFSS, overseen by the Centers for Disease Control and Prevention, is an annual cross-sectional telephone survey that started in 1984. Currently, the survey is conducted by health departments in all 50 states and the District of Columbia using a random-digit dialing method to obtain a state-representative sample of the civilian, noninstitutionalized population  $\geq 18$  years of age. The state samples can be combined to form a nationally representative sample. In 2002, the response rate among calls that were answered ranged from 62% to  $>99\%$  by state, with a median rate of 77%. Additional information on the full survey design is available elsewhere<sup>20,27</sup> and online (<http://www.cdc.gov/brfss>).

We included adults  $\geq 30$  years of age in NHANES and BRFSS who answered this self-reported hypertension question: Have you ever been told by a health professional that you have high blood pressure?

### Statistical Analysis

We used measured and self-reported data from NHANES, which are representative at the national but not state level, to characterize the relationship between measured SBP and self-reported hypertension status, blood pressure medication, and a set of health system and sociodemographic variables listed in Table 1. This relationship was estimated in a series of linear regressions in which the dependent variable was the individual's SBP measurements and the independent variables were the health system and sociodemographic covariates (Figure 1). We conducted the analysis based on SBP because it has been found to be a better predictor of cardiovascular risk than diastolic blood pressure.<sup>2-4</sup>

We estimated the regression model separately for 6 subgroups of the NHANES data. Men and women were divided into 3 groups each. Group A comprised those who answered no to the question, “Have you ever been told by a health professional that you have high blood pressure?” Group B included those who answered yes to that question and no to “Are you currently taking medicine for your high blood pressure?” Group C included those who answered yes to both questions. We used these divisions because the effects of health system and sociodemographic factors (eg, age or insurance status) on blood pressure may vary across these groups, as confirmed by our regression coefficients.

We used a random-effects linear regression model to estimate SBP.<sup>28</sup> When  $>1$  measurement of the dependent variable (ie, SBP) is available for each subject, the random-effects model can be used to separate the regression error term (ie, unexplained variation) into stochastic (within-person) and systematic (between-person) components. The second term can be used to obtain unbiased estimates of the SD of the blood pressure distribution in the population. In this regression, the dependent variable was each subject's SBP measurements, excluding the first measurement. We also used a standard logistic regression to estimate the proportion of the population with uncontrolled hypertension, defined as the average of MEC-based SBP measurements, excluding the first measurement,  $\geq 140$  mm Hg (Table 1).<sup>2</sup>

We applied the regression coefficients to identical questions in BRFSS, which is state representative, to estimate SBP for each BRFSS observation in the years corresponding to each NHANES round (Table 1 and Figure 1). The BRFSS sample was stratified into the same 6 groups as those used for the above regressions. The

**Table 1. Description of the Outcome and Explanatory Variables From NHANES and BRFSS Used in the Regression Analysis**

Variable	Possible Values	Reason for Inclusion in Analysis
Outcome (dependent) variables for the 2 sets of regressions		
Measured SBP (available in NHANES; predicted in BRFSS)*	SBP in mm Hg	Outcome variable to estimate complete SBP distribution (random-effects linear regression)
Measured hypertension status (available in NHANES only; predicted in BRFSS)†	0 (SBP <140 mm Hg), 1 (SBP ≥140 mm Hg)	Outcome variable to obtain prevalence of uncontrolled hypertension (logistic regression)
Explanatory (independent) variables		
Sex	Male, female	Predictor of blood pressure through lifestyle and healthcare determinants
Age	30–39, 40–49, 50–59, 60–69, ≥70 y	Predictor of blood pressure
Race‡	Non-Hispanic white, non-Hispanic black, Hispanic, other	Predictor of blood pressure, healthcare access, and/or other sociocultural determinants
Doctor visit (Have you seen a doctor in the past year?)§	Yes, no, missing	Indicator for hypertension knowledge and control of hypertension
Insurance status (Do you currently have health insurance?)	Yes, no, missing	Indicator for hypertension knowledge and control of hypertension
Body mass index¶	<25, 25–29, ≥30 kg/m <sup>2</sup>	Determinant of blood pressure and indicator for selected lifestyle factors such as diet and physical activity
Smoking (Do you currently smoke?)	Yes, no, missing	Indicator for lifestyle factors
Self-reported hypertension diagnosis (Have you ever been told by a health professional that you have hypertension?)#	Yes, no, missing	Indicator for hypertension status, knowledge, and control
Self-reported antihypertensive use (Are you currently taking medicine to lower your blood pressure?)#	Yes, no, missing	Indicator for hypertension control

\*For each observation, NHANES 1988–1994 contains up to 3 MEC-based SBP measurements and NHANES 1999–2002 contains up to 4 measurements. We excluded the first measurement, as is also recommended by NHANES documentation, because it was significantly higher than subsequent ones. We dropped observations that did not have at least 1 MEC-based blood pressure measurement.

†Average MEC-based SBP for each individual was calculated, excluding the first measurement.

‡For consistency, race in BRFSS and NHANES 1999–2002 was analyzed in the same categories as NHANES III, which had fewer race categories.

§This variable was defined as a composite of multiple questions about physician contact for specific conditions in BRFSS.

||Insurance status was not included in the 1988–1992 period (NHANES III) because the insurance question is asked only from 1991 in BRFSS. Regression results for 1999–2002 including and excluding insurance status were similar. The difference in regression coefficients for 1999–2002 including and excluding insurance status was not statistically significant; therefore, insurance was retained in the analysis for this period.

¶Body mass index was corrected for bias in self-reported height and weight in telephone interviews using methods reported elsewhere.<sup>31</sup>

#The years 1994, 2000, and 2002 were not included in the analysis because BRFSS in most states did not ask about self-reported hypertension. The years 1993, 1994, and 1999 were not included in the analysis because the blood pressure medication question was not asked in BRFSS. In 1991 and 1992, BRFSS asked only if medication has been prescribed. A comparison of this question with the medication use question during 1988–1990 showed that almost all individuals (97.5%) who reported being prescribed medication also reported using medication. Therefore, we used these variables as equivalent. To have a sufficient number of years for NHANES 1999–2002 period, we included the 2003 BRFSS, assuming that 2003 data are not systematically different from those between 1999 and 2002. Wyoming was excluded from the 1988–1992 analysis because self-reported hypertension status was not asked in BRFSS in this state.

individual BRFSS observations were then pooled using appropriate sample weights to obtain estimates of mean SBP and prevalence of uncontrolled hypertension by age, sex, and state. We present the results in 2 broad age groups (30 to 59 years of age and ≥60 years of age), age standardized to the 2000 US population to account for differences in age distributions across states and/or over time.

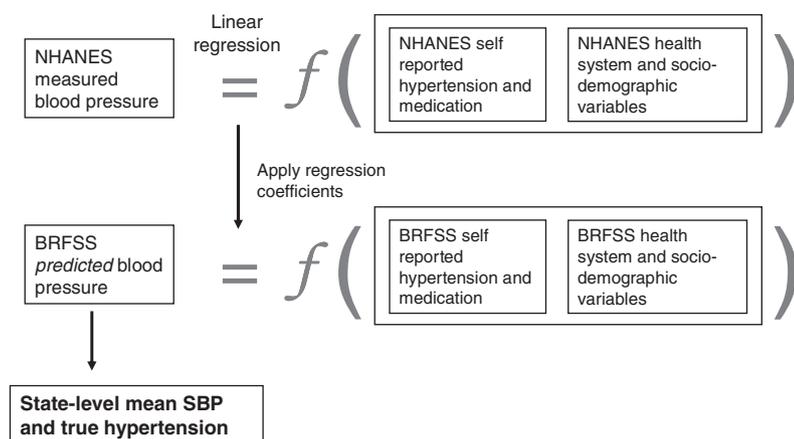
We estimated cardiovascular mortality attributable to higher-than-optimal SBP using the methods of the comparative risk assessment project, which is described in detail elsewhere.<sup>29,30</sup> On the basis of the evidence from observational and intervention studies, attributable mortality was estimated by calculating proportional reduction in cause-specific cardiovascular mortality if the current SBP distribution was reduced to the optimal level of 115 mm Hg (SD,

6 mm Hg).<sup>3</sup> Relative risks for cause-specific mortality for each 10-mm Hg SBP increment were from the meta-analyses of the Prospective Studies Collaboration.<sup>4</sup>

The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

## Results

**National SBP and Hypertension Levels and Trends** Between the early 1990s and early 2000s, the (age-standardized) proportion of American women with SBP



**Figure 1.** Flowchart of statistical analyses used to estimate state-level mean blood pressure and uncontrolled hypertension.

$\geq 140$  mm Hg increased by 4.3 percentage points; for American men, it declined by  $\approx 2$  percentage points (Table 2). Both men and women had minor increases in self-reported hypertension over this period (0.5 and 2.2 percentage points, respectively). Measured prevalence of uncontrolled hypertensive status (including both those who are aware of their hypertension and those who are not) is  $\approx 10$  percentage points lower than self-reported hypertension in NHANES for both time periods, indicating that many of those diagnosed with hypertension have controlled their blood pressure. Between

**Table 2. National Age-Standardized Mean SBP and Measured Uncontrolled Hypertension From NHANES by Sex, Age, and Time Period**

	NHANES 1988–1994	NHANES 1999–2002
All ages		
Mean SBP, mm Hg		
Male	125.4 (124.6–126.2)	125.3 (124.3–126.3)
Female	121.4 (120.7–122.1)*	124.9 (123.9–125.9)*
Hypertension, %		
Male	18.8 (17.4–20.2)	17.0 (15.3–18.6)
Female	17.4 (16.3–18.5)*	21.7 (20.4–23.1)*
Ages 30–59 y		
Mean SBP, mm Hg		
Male	121.6 (120.7–122.5)	121.6 (120.6–122.7)
Female	115.0 (114.2–115.8)*	118.1 (117.1–119.1)*
Hypertension, %		
Male	11.3 (9.8–12.9)	9.6 (8.1–11.1)
Female	7.6 (6.6–8.6)*	10.1 (8.6–11.6)*
Ages $\geq 60$ y		
Mean SBP, mm Hg		
Male	135.2 (133.8–136.5)	134.8 (133.2–136.3)
Female	137.7 (136.6–138.8)*	142.3 (140.3–144.3)*
Hypertension, %		
Male	37.9 (34.8–41.0)	35.7 (32.6–38.9)
Female	42.4 (39.6–45.2)*	51.4 (48.0–54.8)*

Values in parentheses are 95% confidence intervals, which accounted for the complex survey design (calculated with the `svy:mean` command in Stata).

\*Difference between 1988–1994 and 1999–2002 is statistically significant with  $P < 0.05$ .

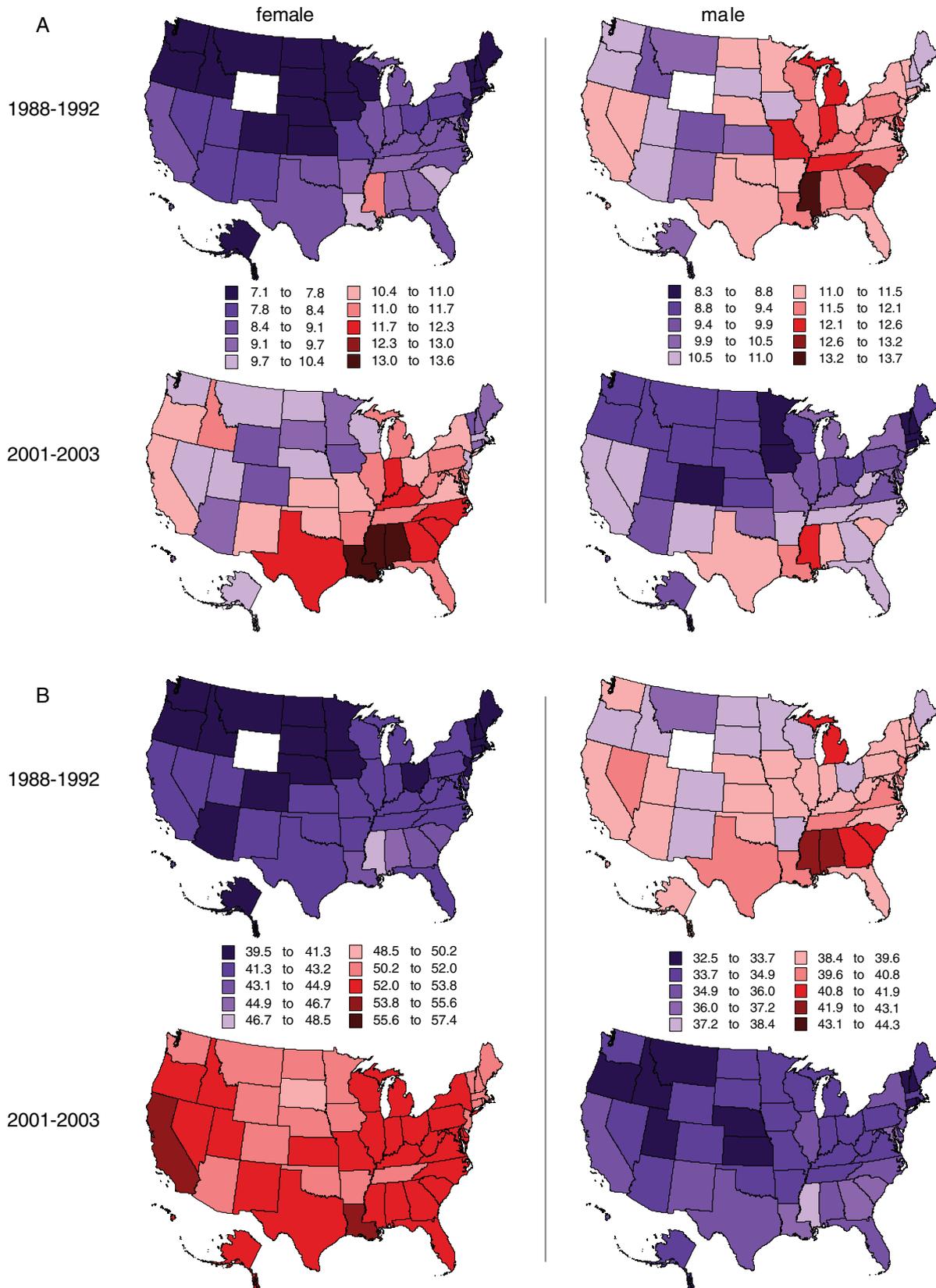
the early 1990s and early 2000s, the largest change in SBP occurred in women  $\geq 60$  years of age, whose mean SBP increased by  $> 4.5$  mm Hg and uncontrolled hypertension prevalence increased by 9 percentage points, compared with a decrease of 0.4 mm Hg and 2.2 percentage points in older men (Table 2). Below 60 years of age, men had higher mean SBP than women in both 1988–1994 and 1999–2002, although the sex difference declined over time, reflecting the unfavorable differential trends among women. Proportionally, fewer individuals who knew their hypertension status remained unmedicated in 1999–2002 compared with 1988–1992 (Table I of the online-only Data Supplement). Of those using medication, a larger proportion achieved SBP below the 140-mm Hg threshold in 2001–2003 than 1988–1992 (see also Hajjar and Kotchen<sup>8</sup>).

Previous analyses have shown that self-reported weight and height differ between in-person interviews with subsequent measurement (NHANES) and telephone surveys (BRFSS).<sup>31</sup> Testing whether self-reported hypertension is affected by the same phenomenon shows that although age- and sex-specific self-reported hypertension prevalence differed slightly between NHANES and BRFSS, particularly in those  $\geq 50$  years of age, no consistent pattern is apparent to indicate systematic bias as a result of telephone survey versus in-person interview (Figure I of the online-only Data Supplement).

### Regression Results

Regression coefficients are provided in the online-only Data Supplement. A common result in all 24 regressions (6 regressions for each time period for both the random-effects linear and logistic models) was that SBP and uncontrolled hypertension status increased with age, consistent with the vast available evidence on age association of blood pressure.<sup>3,9</sup> However, the age gradient was attenuated for those using medication (ie, group C), especially in 1999–2002, and strongest in those diagnosed with hypertension but not using medication (group B). This result possibly indicates the effectiveness of blood pressure control, which also may have improved over time.

Overweight and obesity were associated with significantly higher SBP in those not diagnosed with hypertension (group A). A generally positive relationship between SBP and body



**Figure 2.** Estimated uncontrolled hypertension prevalence by state, sex, and time period. Within each age group, figures are age standardized to the 2000 US population: 30 to 59 years (A) and  $\geq 60$  years (B). No estimates are shown for Wyoming for 1988–1992 because BRFSS did not include questions about hypertension diagnosis. See Table X in the online-only Data Supplement for numerical state estimates.

mass index was present in group B, but the coefficients were nonsignificant; an almost universally nonsignificant negative relationship was present in group C. These findings may illustrate stricter blood pressure control among those who are overweight or obese once they are diagnosed (see also Gregg et al<sup>6</sup>). Not having seen a doctor in the past year had a significant and positive effect on SBP, except for those currently managing their hypertension, for whom the coefficient for physician visit was no longer significant. After controlling for all other factors, including stratification by awareness and medication status, blacks had consistently higher SBP than whites.

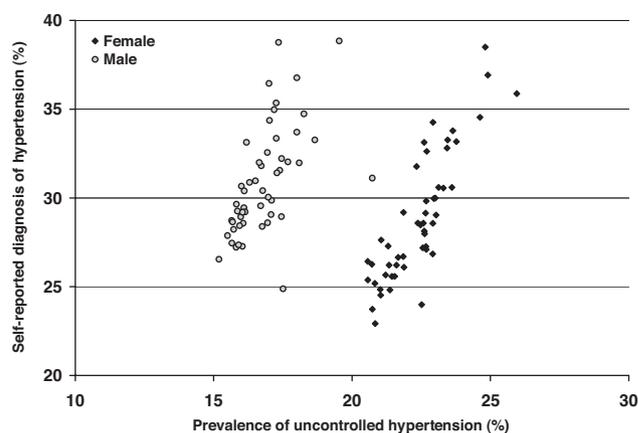
To validate that levels of variables included in the model were similar between the 2 surveys, we applied the estimated regression coefficients to data from both NHANES itself and BRFSS to compare estimated national mean SBP and uncontrolled hypertension. The largest differences in age- and sex-specific national estimates were 1.1 mm Hg and 2 percentage points, respectively. Similar validation checks by race and region gave results within 0.6 mm Hg and 1.4 percentage points, respectively.

### State-Level Uncontrolled Hypertension Status and Self-Reported Hypertension

In 2001–2003, age-standardized uncontrolled hypertension prevalence was highest in the District of Columbia and primarily southern states, including Mississippi, Louisiana, Alabama, Texas, Georgia, and South Carolina (18% to 21% for men and 24% to 26% for women); it was lowest in the Midwest and the Northeast, including Vermont, Minnesota, Connecticut, New Hampshire, Iowa, and Colorado (15% to 16% for men and ≈21% for women) (Figure 2).

Prevalence of uncontrolled hypertension increased among women and decreased among men in every state, but significant variations were present in state-level trends. For men, the smallest decrease was predominantly in the South, whereas female trends had no clear geographical pattern. For women, age-standardized uncontrolled hypertension prevalence increased the most in Idaho and Oregon (6 percentage points) and the least in the District of Columbia and Mississippi (3 percentage points); for men, the largest decreases were in Vermont and Indiana (3 to 4 percentage points), and the smallest were in New Mexico and Louisiana (0.6 to 1.3 percentage points). Correlation coefficients between prevalence in 1988–1994 and change in prevalence during the 1990s were  $-0.12$  for men and  $-0.43$  for women.

In 2001–2003, women had higher uncontrolled hypertension than men in every state by 4 (Arizona) to 7 (Kansas) percentage points. The female-male difference in 1988–1992 was on average 1.4 percentage points across states and as low as 0.2 in Arkansas and Louisiana. No relationship existed between change in female and male hypertension prevalence between the early 1990s and early 2000s (correlation coefficient for sex-specific hypertension change, 0.07). For example, the largest and smallest declines in male prevalence were in Vermont ( $-3.8$  percentage points) and New Mexico ( $-0.6$  percentage points), but both states had about an average increase in female prevalence (4.2 and 5.0 percentage points, respectively). Similarly, the smallest increase in female prev-



**Figure 3.** State-level prevalence of uncontrolled hypertension vs self-reported hypertension diagnosis.

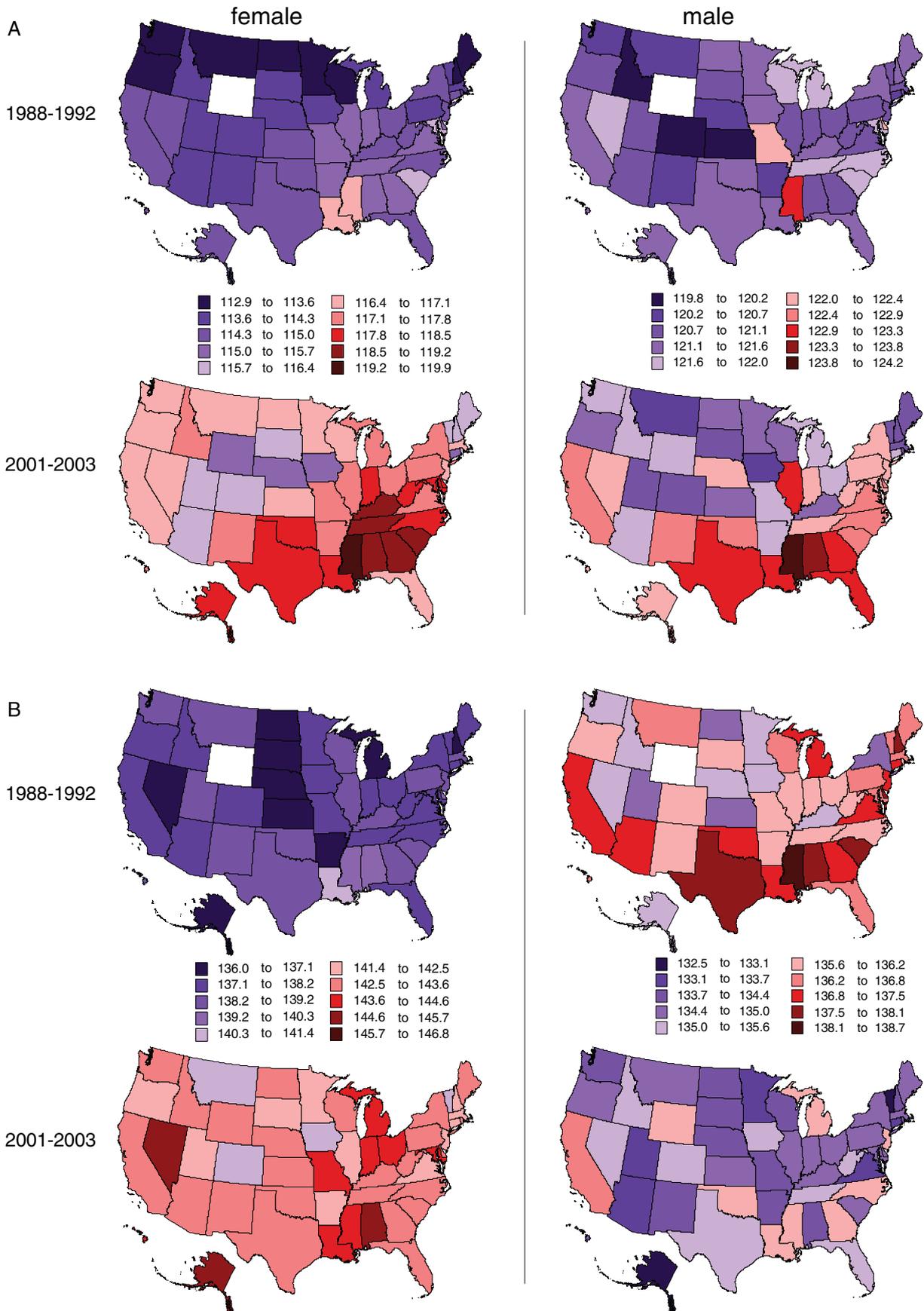
alence was in the District of Columbia (2.8 percentage points), and the largest increases were in Idaho and Oregon (6.1 and 5.9 percentage points); these states had relatively similar decreases in male prevalence ( $-1.6$ ,  $-1.5$ , and  $-2.5$  percentage points in the District of Columbia, Idaho, and Oregon, respectively).

In 2001–2003, self-reported hypertension was higher than measured high-risk status for both men and women in every state, but the difference was larger for men (Figure 3 and Figure II and Table XI of the online-only Data Supplement). Although women had higher measured hypertension prevalence than men in all states, they had lower self-reported prevalence in all but 6 states (Alabama, Alaska, District of Columbia, Georgia, Louisiana, and North Carolina). Furthermore, self-reported hypertension and measured uncontrolled hypertension had lower correlation across states for men than for women (Figure 3). For example, men in Washington and the District of Columbia had self-reported hypertension prevalence of ≈30% to 31%, but actual prevalence of those with blood pressure  $\geq 140$  mm Hg was 16% in the former and 21% in the latter. Similarly, West Virginia and New Mexico had actual prevalence of uncontrolled hypertension of ≈17%, but self-reported hypertension prevalence was 39% in the former and 25% in the latter.

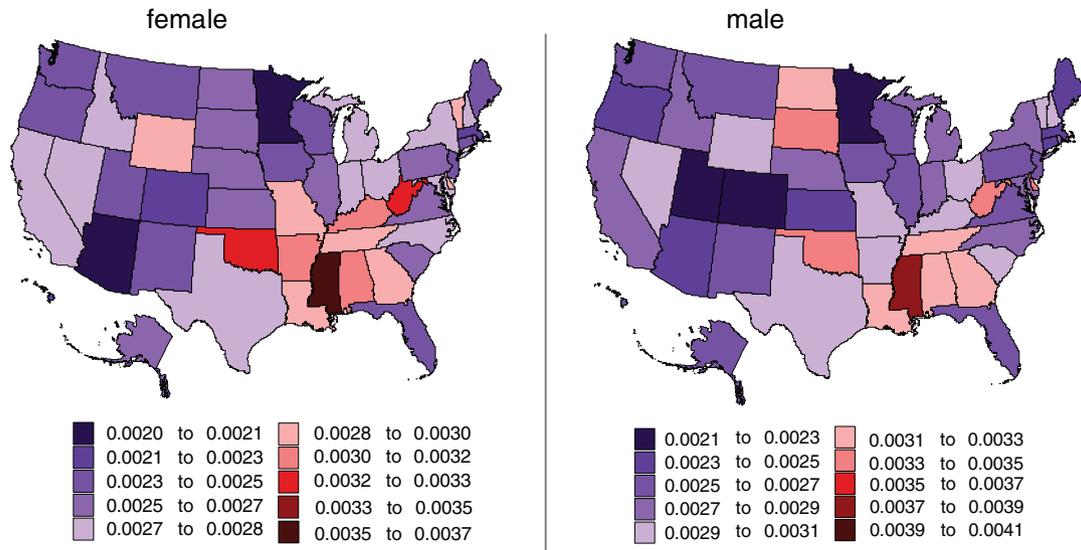
### State-Level Mean Blood Pressure and Hypertension by Age and Sex

When considered by age (Figure 4), older women ( $\geq 60$  years of age) had higher mean SBP (by 5.8 to 12.6 mm Hg) and uncontrolled hypertension (by 14 to 20 percentage points) than men in every state in 2001–2003. Iowa, New Jersey, Wyoming, and South Dakota had the smallest male-female disparities; Nevada, Alaska, and Colorado had the largest. Younger and middle-aged (30 to 59 years of age) women had lower SBP and uncontrolled hypertension than men of the same ages in all states except in Arizona, Hawaii, Nevada, Rhode Island, and Wyoming, where women had slightly higher prevalence.

Among women, mean SBP and uncontrolled hypertension increased in both age groups and every state in the 1990s. The state trends for males were less homogeneous. For older men, uncontrolled hypertension declined by 1 to 7 percentage



**Figure 4.** Estimated mean blood pressure by state, sex, and time period. Within each age group, figures are age standardized to the 2000 US population: 30 to 59 years (A) and  $\geq 60$  years (B). No estimates are shown for Wyoming for 1988–1992 because BRFSS did not include questions about hypertension diagnosis. See Table X in the online-only Data Supplement for numerical state estimates.



**Figure 5.** Cardiovascular mortality rate attributable to higher-than-optimal blood pressure by state and sex in 2001. Mortality rates are age standardized to the 2000 US population.

points in every state, and mean blood pressure declined in most states except for a few that had a negligible (<0.5 mm Hg) increase. Mean SBP and uncontrolled hypertension of younger and middle-aged men had a mixed performance, including decline (eg, Iowa), stagnation, or slight increase (eg, Alabama, Illinois, and New Mexico).

**Cardiovascular Mortality Attributable to Higher-Than-Optimal SBP by State**

Age-standardized cardiovascular mortality attributable to higher-than-optimal SBP ranged from 200 to 220 per 100 000 (Minnesota and Massachusetts) to 360 to 370 per 100 000 (District of Columbia and Mississippi) for women and from 210 (Colorado and Utah) to 370 (Mississippi) and 410 per 100 000 (District of Columbia) for men; the national averages were 260 and 290 per 100 000 for women and men, respectively (Figure 5). Of the states with the highest SBP-attributable cardiovascular mortality rate, all but Arkansas and Wyoming for women and South Dakota and North Dakota for men were also those with the highest mean SBP. In this latter group of states, even moderate SBP levels led to relatively high attributable mortality because background cardiovascular mortality risk is high. The cross-state correlation between age-standardized mean SBP and age-standardized cardiovascular mortality rate attributable to SBP was 0.59 for men and 0.64 for women.

**Discussion**

Our results illustrate important geographic patterns and trends in sex- and age-specific SBP and its cardiovascular mortality impacts that were masked by the shortcomings of self-reported data. The state-level estimates show that the District of Columbia, the South, and the Appalachia had the highest SBP and uncontrolled hypertension, consistent with regional results from NHANES III<sup>14-16</sup> and from the Coronary Artery Risk Development in Young Adults (CARDIA) study,<sup>11</sup> with Mississippi and the District of Columbia faring the worst. The Northern Plains, the Northeast, and the Midwest

had the lowest levels of SBP and uncontrolled hypertension. In the District of Columbia, Alabama, and Mississippi, the effects of high SBP were further magnified by high background cardiovascular mortality risk, leading to a very large absolute cardiovascular mortality rate attributable to this risk factor.

SBP and uncontrolled hypertension increased among women in the 1990s, particularly in older ages, in all US states, but considerable cross-state variation was present in levels and trends. Using the relative risks from the Prospective Studies Collaboration,<sup>4</sup> we can attribute 2% of coronary heart disease deaths and 2% of stroke deaths (≈400 annual deaths) to the average 3.1-mm Hg rise in mean SBP in young and middle-aged (30 to 59 years of age) women between the 2 NHANES rounds; the proportion of deaths attributable to the 4.6-mm Hg rise in blood pressure in women ≥60 years of age was 3% for coronary heart disease and 4% for stroke (≈12 000 deaths annually). Male SBP declined in older ages in all states, with more heterogeneous trends in the young and middle-aged. As a result of differential trends by sex, the male-female disparities in SBP and uncontrolled hypertension in older ages have increased in every state since 1988-1992; the female advantage in younger and middle-aged adults has shrunk or reversed.

An important finding of our analysis was that little correlation existed between changes in SBP of men and women across states. This indicates that state-level programs may not have systematically and uniformly benefited all demographic groups. Self-reported hypertension was higher than measured high-risk status in every state and for both sexes, broadly indicating benefits from hypertension diagnosis and management, especially among men. Definitive conclusions about diagnosis coverage and subsequent management among those diagnosed with hypertension and how they may vary by sex require further investigation, especially in longitudinal studies such as the CARDIA study.<sup>11</sup>

This analysis has a number of limitations. First, although our regression models included important sociodemographic,

lifestyle, and health system determinants of blood pressure and hypertension diagnosis, other factors affect these such as diet and quality of care.<sup>14,32</sup> For instance, we were unable to include salt intake, an important dietary determinant of blood pressure, in the model because this question is not asked in BRFSS. The effects of some of these factors may be captured by the variables in our model (eg, self-reported hypertension, body mass index, insurance status, and visit to a doctor). If the unexplained effects vary systematically across states, the model might underestimate cross-state variation in blood pressure. To consider the role of regional variation in blood pressure above and beyond the variables in our model, we repeated the analysis for 1988–1994 (NHANES III) and included region as a variable in the model. (Region is not included in the 1999–2002 data.) The resulting estimates of uncontrolled hypertension ranged between 16.2% and 23.7% for men and between 16.0% and 22.6% for women compared with the current range of 17.6% to 22.3% for men and 16.4% to 23.1% for women. The correlation of estimated uncontrolled hypertension across states with and without inclusion of region was 0.74 for men and 0.85 for women. Second, although BRFSS provides state-level data for the variables included in the model, some instruments have changed over time or have been implemented in some years only (Table 1). As a result, the analysis could use BRFSS data for some years only. Third, we conducted our analysis using SBP because of its stronger relationship with cardiovascular disease outcomes. Some of the people self-reporting hypertension may have been diagnosed on the basis of their diastolic blood pressure, which may cause error in our estimates (see Table 1 in the online-only Data Supplement for details). The single best way to reduce uncertainty in our analysis would be to add a validation component to BRFSS that includes measured blood pressure for a random subset of interviewees.

Despite the uncertainties, these first estimates of SBP and uncontrolled hypertension and their effects on cardiovascular mortality provide important guides and benchmarks for priority setting and for designing and evaluating cardiovascular prevention programs at the state level. Increasing the effective coverage of lifestyle (eg, reduced salt intake) and pharmacological interventions should be a policy priority in states with high levels of uncontrolled hypertension, with specific emphasis on improving diagnosis and control among women. Furthermore, in states where the absolute cardiovascular risk associated with higher-than-optimal blood pressure is high because SBP level is high and/or background cardiovascular risk is high, blood pressure control should be accompanied by management of other cardiovascular risks on the basis of similar analysis of other risk factors such as body mass index,<sup>31</sup> blood glucose, and cholesterol. Regular reporting of risk factor levels and trends also can help us evaluate the performance of programs in individual states and learn from states with successful programs.

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### Disclosures

None.

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### CLINICAL PERSPECTIVE

High blood pressure is one the most important risk factors for cardiovascular disease. Information on blood pressure and uncontrolled hypertension is needed for priority setting and for interventions. In the United States, national data on blood pressure are obtained by measurement, but at the state level, the data are limited to self-reported hypertension diagnosis. Such self-reported data may be biased for several reasons, including undiagnosed hypertension among people who may not have had health system contact and reduced risk among those with diagnosis who have effectively controlled their hypertension status. This analysis uses self-reported hypertension diagnosis and a number of other indicators such as insurance status, history of contact with a doctor, body mass index, age, and other sociodemographic factors to estimate true blood pressure and hypertension status. The results show that uncontrolled hypertension was highest in the District of Columbia, Mississippi, Louisiana, Alabama, Texas, Georgia, and South Carolina (18% to 21% of men and 24% to 26% of women in these states had uncontrolled hypertension after accounting for differences in age in these states). Uncontrolled hypertension was lowest in Vermont, Minnesota, Connecticut, New Hampshire, Iowa, and Colorado, ranging from 15% to 16% for men and  $\approx$ 21% for women. In the 1990s, uncontrolled hypertension increased among women, especially those  $\geq$ 60 years of age, in every state. As a result, early in the 2000s, women had a higher prevalence of uncontrolled hypertension than men in every state by 4 to 7 percentage points. Lifestyle and pharmacological interventions for lowering blood pressure are particularly needed in the South and Appalachia, with emphasis on control among women.