Socioeconomic Disadvantage and Change in Blood Pressure Associated With Aging

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Background—Few studies have examined how the longitudinal change in blood pressure associated with aging differs across social groups within industrialized countries.

Methods and Results—Data from the Atherosclerosis Risk In Communities Study were used to investigate differences in the incidence of hypertension and in aging-related changes in blood pressure by neighborhood and individual socioeconomic factors over a 9-year follow-up. Disadvantage in multiple socioeconomic dimensions was associated with the greatest risk of developing hypertension (age- and sex-adjusted hazard ratio [HR] and 95% CI: HR 1.95, 95% CI 1.38 to 2.75 in whites and HR 1.43, 95% CI 0.96 to 2.13 in blacks). Aging-related increases in systolic blood pressure were inversely associated with socioeconomic position in whites (mean [SEM] 5-year increase in systolic blood pressure 7 [0.7] mm Hg in the most disadvantaged category and 5.4 [0.4] mm Hg in the most advantaged category). In whites, low socioeconomic position was also associated with more rapid declines in diastolic blood pressure after 50 years of age. Socioeconomic differences in hypertension incidence and changes in systolic blood pressure were reduced after adjustment for baseline blood pressure.

Conclusion—The change in blood pressure associated with aging varies by social groups within the United States. **(*Circulation*. 2002;106:703-710.)**

Key Words: blood pressure ■ hypertension ■ aging ■ risk factors

High blood pressure is an established risk factor for cardiovascular disease.[1] Although numerous risk factors for hypertension have been identified,[2] a complete understanding of the causes of hypertension and of the reasons for its high prevalence[3] remains elusive.

A key predictor of blood pressure in many populations is age.[2] The investigation of factors associated with age-related changes may yield insights into the causes of hypertension generally. Although several studies have compared age-related changes in urban and rural or isolated populations,[4–6] there has been little examination of whether aging-related changes in blood pressure vary across social groups within industrialized countries. In addition, most studies of age effects have been cross-sectional. Few studies have examined true longitudinal change in blood pressure over time associated with aging.

Using longitudinal data from the Atherosclerosis Risk In Communities (ARIC) study, we investigated how both the incidence of hypertension and aging-related changes in blood pressure varied by socioeconomic groups over a 9-year follow-up. In addition to traditional socioeconomic indicators such as income, education, and occupation, we also investigated the role of neighborhood socioeconomic characteristics and the effects of cumulative disadvantage in multiple socioeconomic dimensions. Associations were investigated before and after adjustment for baseline blood pressure, body mass index, physical activity, and alcohol intake.

Methods

The ARIC cohort comprised 15 792 persons aged 45 to 64 years at baseline, selected by probability sampling in Forsyth County, NC; Jackson, Miss; the northwestern suburbs of Minneapolis, Minn; and Washington County, Md. Two of the samples (Washington County and Minneapolis suburbs) are virtually all white. The Forsyth County sample is 85% white. The Jackson sample is entirely black. The baseline examination took place between 1987 and 1989. Follow-up examinations were performed approximately 3, 6, and 9 years later. Retention rates were 93%, 87%, and 81% at the first, second, and third follow-up examinations, respectively.

Seated blood pressure was measured at each visit after a 5-minute rest by a standardized Hawksley random-zero sphygmomanometer. The average of the last 2 of 3 seated readings was used in analyses. Hypertension was defined as systolic blood pressure ≥140 mm Hg

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TABLE 1. Characteristics of Study Participants by Race and Sex

	Whites		Blacks	
	Men (n=3137)	Women (n=3706)	Men (n=510)	Women (n=834)
Mean baseline age, y	54.2	53.3	52.6	52.0
Income (% distribution)				
<$12 000	3.2	6.4	23.9	32.1
$12 000–$24 999	13.7	19.0	27.3	25.7
$25 000–$34 999	19.1	18.6	12.2	14.9
$35 000–$49 999	23.9	22.0	13.7	10.1
≥$50 000	36.6	28.9	12.2	6.1
Unknown	3.5	5.2	10.8	11.2
Education (% distribution)				
Incomplete high school	15.7	12.3	36.3	30.2
Complete high school or GED	38.9	51.0	27.1	29.6
1–3 Years of college	15.7	19.3	12.2	9.7
4 Years of college	15.5	11.0	8.8	10.3
Graduate school	14.2	6.5	15.7	20.1
Occupation (% distribution)				
Executive/managers/professionals (I)	38.5	23.3	25.1	30.0
Technical/sales/administrative (II)	21.4	35.5	11.0	13.8
Service (III)	4.2	8.9	15.1	32.3
Precision production/craft/repair* (IV–V)	21.7	2.3	18.6	3.1
Operators/fabricators/laborers (VI)	14.2	7.4	29.2	10.2
Homemakers	0	22.6	1.0	10.7
Neighborhood score, median (25th, 75th percentile)	2.4 (−0.03, 5.0)	2.3 (0.03, 5.0)	−2.8 (−6.1, 0.8)	−3.5 (−6.4, −1.3)
Age-adjusted mean blood pressure at baseline,† mm Hg (SEM)				
Systolic	114.6 (0.2)	110.9 (0.2)	117.6 (0.5)	116.9 (0.4)
Diastolic	71.2 (0.1)	67.6 (0.1)	75.6 (0.3)	72.8 (0.3)
Age-adjusted incidence rates of HT per 1000 person-years (95% CI)	40 (37–44)	37 (34–40)	67 (56–81)	77 (67–89)
Age-adjusted 5-year change in blood pressure,†‡ mm Hg (SEM)				
Systolic	4.4 (0.1)	6.3 (0.1)	5.2 (0.4)	6.9 (0.4)
Diastolic				
Baseline age<50 y	0.5 (0.2)	1.2 (0.1)	0.1 (0.4)	1.2 (0.3)
Baseline age≥50 y	−0.6 (0.1)	−0.1 (0.1)	−1.0 (0.3)	−0.2 (0.3)

*Also includes small number of persons in farming, forestry, and fishing occupations.

†Estimates for continuous blood pressure measurements are based on slightly larger numbers because persons with missing information on skipped visits were included.

‡Adjusted for age at baseline and medication use at each visit.

or diastolic pressure ≥90 mm Hg or use of antihypertensive medication in the past 2 weeks.

Information on participants' income, education, and occupation was obtained from the baseline interview. Participants reported their annual family income and the highest year of school completed. Information on current or most recent occupation was coded into 6 US census defined categories (Table 1). Information on neighborhood socioeconomic characteristics was obtained from the 1990 US census. Participants were linked to their neighborhood of residence by their baseline home address. Census-defined block-groups (subdivisions of census tracts) were used as proxies for neighborhoods. A summary score was used to characterize the neighborhood socioeconomic environment.[7] Six census variables representing the dimensions of wealth/income (log median household income, log median value of housing units, and percent of households receiving interest, dividend, or net rental income), education (percentage of adults with complete high school education, percentage of adults with complete college education), and occupation (percentage of persons in executive, managerial, or professional specialty occupations) were combined into the neighborhood summary score. For each variable, a *z* score for each block-group was estimated by subtracting the overall mean and dividing by the standard deviation. The neighborhood summary score was constructed by summation of the *z* scores for each of the 6 variables. Neighborhood scores for block-groups in the sample ranged from −11.3 to 14.5, with increasing score signifying increasing neighborhood advantage.

Information on body mass index, physical activity, and alcohol intake was obtained at the baseline examination. Physical activity

TABLE 2. Adjusted Hazard Ratios (95% CIs) of Hypertension by Neighborhood- and Individual-Level Socioeconomic Indicators

	Whites		Blacks	
	Adjusted for Age, Sex, and Center	Adjusted for Age, Sex, Center, and Baseline Blood Pressure*	Adjusted for Age, Sex, and Center	Adjusted for Age, Sex, Center, and Baseline Blood Pressure*
Neighborhood score tertiles†				
Lowest	1.31 (1.15–1.49)	1.09 (0.96–1.24)	1.07 (0.86–1.32)	0.89 (0.72–1.11)
Middle	1.15 (1.03–1.30)	1.07 (0.95–1.21)	1.13 (0.92–1.38)	1.00 (0.82–1.23)
Highest	1.0	1.0	1.0	1.0
P trend	0.0001	0.2	0.6	0.3
Income†				
Lowest	1.35 (1.19–1.55)	1.10 (0.96–1.25)	1.46 (1.13–1.90)	1.39 (1.07–1.81)
Middle	1.21 (1.08–1.35)	1.10 (0.98–1.22)	1.44 (1.13–1.83)	1.25 (0.98–1.59)
Highest	1.0	1.0	1.0	1.0
P trend	0.0001	0.2	0.007	0.02
Education				
Incomplete high school	1.33 (1.14–1.56)	1.08 (0.92–1.26)	1.21 (0.98–1.51)	1.08 (0.87–1.35)
Complete high school	1.26 (1.12–1.42)	1.06 (0.95–1.20)	1.12 (0.91–1.38)	1.06 (0.86–1.30)
Complete college	1.0	1.0	1.0	1.0
P trend	0.0001	0.3	0.08	0.5
Occupation‡				
IV–VI	1.23 (1.08–1.40)	1.06 (0.94–1.21)	1.28 (1.00–1.62)	1.28 (1.01–1.63)
II–III	1.16 (1.03–1.30)	0.98 (0.87–1.10)	1.29 (1.05–1.58)	1.16 (0.94–1.43)
I	1.0	1.0	1.0	1.0
P trend	0.001	0.4	0.03	0.04

*Adjusted for baseline age, sex, center, and baseline systolic and diastolic blood pressure.

†Neighborhood score and income categories are race specific. Income categories are: <$25 000, $25 000–49 999, and $50 000 or more in whites; and <$12 000, $12 000–34 999, and $35 000 or more in blacks.

‡Categories I–VI as shown in Table 1.

was summarized in 3 indices that corresponded to leisure, sport, and work.[8] Usual ethanol intake in g/wk was estimated based on intake of wine, beer, and liquor. Information on body mass index and alcohol intake was updated at each follow-up visit. Physical activity measures were updated at the 6-year follow-up. Participants were asked to identify their race from a list of 4 groups: white, black, Asian/Pacific Islander, or American Indian/Native Alaskan.

Of the 15 792 participants at baseline, 90% (14 158) were linked to block-group data. Participants were excluded from the analyses if they were not black or white, if they were blacks living in the Minneapolis or Washington sites, or if they had no information on education and/or occupation (n=154). Participants with prevalent hypertension at baseline (n=4877) or missing information on hypertension prevalence (n=73) were also excluded. Of the remaining 9054 participants, 867 had no information on any of the follow-up visits or had skipped visits. Incidence analyses were based on 8187 participants with complete information on consecutive visits (8% with baseline and first follow-up only, 10% with baseline and first 2 follow-ups only, and 82% with information on all 4 visits). Analyses of trends in blood pressure included all 8555 participants with follow-up information regardless of whether they had skipped visits. Risk-factor–adjusted analyses were based on slightly smaller numbers because of missing information on some of the covariates.

There were large differences in personal and neighborhood socioeconomic characteristics between white and black participants. Black participants were also drawn predominantly (88%) from the Jackson field center. Analyses of socioeconomic differences were therefore stratified by race. Neighborhood score was categorized into race-specific tertiles. Individual-level income, education, and occupation were each categorized into 3 race-specific groups. To examine the cumulative effects of the 4 socioeconomic indicators, we constructed mutually exclusive groups based on the number of socioeconomic indicators for which the participant was in the lowest or highest category: all 4 indicators in the lowest category, 3 indicators in the lowest category, 2 indicators in the lowest category, 1 indicator in the lowest category, no indicators in the lowest category but not all 4 indicators in the highest category, and all 4 indicators in the highest category.

Incidence rates of hypertension were calculated by dividing the number of events by the person-years of follow-up. Follow-up time was estimated with individual examination dates. Hypertension onset was assumed to have occurred halfway between the visit at which the participant was first classified as hypertensive and the preceding visit. Nonhypertensive participants were censored at their last examination date. Relative hazards of hypertension incidence were estimated by Cox proportional hazards regression. Results were virtually identical to those obtained with discrete proportional hazards[9] and that accounted for potential within-neighborhood correlations. Models were run before and after adjustment for baseline blood pressure. To correct model estimates for the measurement error in baseline blood pressure, the regression calibration method was used.[10] Estimates of measurement-error variance as a proportion of total variance were obtained from an ARIC ancillary study (0.28 for systolic blood pressure, 0.22 for diastolic blood pressure, and 0.25 for their measurement-error covariance).

Time since baseline was the variable used to examine longitudinal aging-related changes. Adjusted mean changes in blood pressure over time were estimated by pooling blood pressure measurements across visits and using linear mixed models with the unstructured covariance specification to account for within-person correlations in repeat measures.[11] Models included age, center, sex, medication use, time since baseline, and socioeconomic indicators. Interactions

TABLE 3. Adjusted Hazard Ratios (95% CIs) of Hypertension by Number of Socioeconomic Indicators in the Lowest Category*

	Whites			Blacks		
	n	Adjusted for Age, Center, and Sex	Adjusted for Age, Center, Sex, Baseline Blood Pressure, and Risk Factors†	n	Adjusted for Age, Center, and Sex	Adjusted for Age, Center, Sex, Baseline Blood Pressure, and Risk Factors†
Four indicators in lowest category	153	1.95 (1.38–2.75)	1.27 (0.88–1.82)		‡	‡
Three indicators in lowest category	435	1.75 (1.33–2.31)	1.15 (0.86–1.53)	140	1.43 (0.96–2.13)	1.22 (0.80–1.85)
Two indicators in lowest category	876	1.54 (1.21–2.00)	1.10 (0.85–1.42)	244	1.38 (0.96–1.99)	1.21 (0.82–1.77)
One indicator in lowest category	1604	1.51 (1.20–1.91)	1.16 (0.91–1.48)	273	1.18 (0.82–1.69)	0.85 (0.59–1.25)
No indicators in lowest category and not all 4 indicators in highest category	2245	1.31 (1.04–1.65)	1.06 (0.84–1.34)	315	1.20 (0.84–1.71)	1.04 (0.72–1.50)
All 4 indicators in highest category	447	1.0	1.0	106	1.0	1.0
P trend		0.0001	0.2		0.05	0.1

*The 4 socioeconomic indicators used are neighborhood score, individual-level income, education, and occupation. Lowest and highest categories refer to those shown in Table 2. Persons with no information on income and homemakers are excluded.

†Adjusted for baseline systolic and diastolic blood pressure, as well as body mass index, physical activity, and alcohol intake as time-dependent covariates.

‡Not shown because of small number of individuals in this cell (n=40).

between time and sex and between time and baseline age were included to allow changes over time to vary by sex and baseline age. Interactions between time and socioeconomic indicators were included to test the hypotheses that changes over time differed by socioeconomic categories. Exploratory analyses showed that diastolic blood pressure increased over the follow-up period among persons <50 years old at baseline but decreased over time in persons 50 years or older at baseline. Diastolic blood pressure models were therefore stratified by baseline age. Models were rerun adjusted for baseline blood pressure (including a time-by-baseline blood pressure interaction) and with correction for measurement error in the baseline measurement. Estimates were also adjusted for body mass index, physical activity indices, and alcohol intake as time-dependent, continuous covariates. The Institutional Review Board at each site approved the study. All subjects gave informed consent.

Results

Table 1 shows characteristics of the study population. Blacks were more likely than whites to be of low socioeconomic position and to live in disadvantaged neighborhoods. Age-adjusted incidence rates of hypertension ranged from a high of 77 per 1000 person-years in black women to a low of 36 per 1000 person-years in white women. Differences in incidence rates across race groups were reduced when baseline blood pressure was controlled for (age and baseline blood pressure–adjusted incidence rates per thousand person-years [95% CI]: 28 [25 to 31] in white men, 34 [32 to 37] in white women, 42 [31 to 59] in black men, and 54 [45 to 63] in black women). Systolic blood pressure increased over time in all race/sex groups. Diastolic blood pressure generally increased over the follow-up period in persons <50 years old at baseline and decreased over follow-up in persons aged 50 and over.

Being in the lower socioeconomic categories was generally associated with increased risk of developing hypertension (Table 2). Whites in the lowest socioeconomic categories had a 23% to 35% higher risk of hypertension than those in the highest category. Among blacks, being in the lowest individual-level socioeconomic category was associated with a 21% to 46% increased risk. No differences in hypertension risk were observed for neighborhood characteristics in blacks. With the exception of income and occupation in blacks, socioeconomic differences were weak and statistically nonsignificant after adjustment for baseline blood pressure.

In whites, the risk of hypertension increased with the number of indicators in the lowest category (Table 3). Whites with all 4 indicators in the lowest category had nearly twice the risk of developing hypertension as whites with all 4 indicators in the highest category. A positive association between number of indicators in the lowest category and hazard rate ratio of hypertension was also observed in blacks. Adjustment for baseline blood pressure and risk factors reduced the magnitude of the associations, although patterns remained. Estimates from the fully adjusted model were virtually identical to those from the baseline blood pressure–adjusted model.

In whites, 5-year increases in systolic blood pressure were significantly greater in the lower than in the higher socioeconomic categories for 3 of the 4 indicators (Table 4), with trends approaching statistical significance. However, only income was inversely related to increase in systolic blood pressure in black participants. Differences between the top and bottom socioeconomic categories were reduced after adjustment for baseline blood pressure. Among white participants aged <50 years at baseline, increases over time in diastolic blood pressure were greater in the higher than in the lower socioeconomic categories (Table 5). In addition, among whites 50 years of age or older, diastolic blood pressure decreased more rapidly in the lower than in the higher socioeconomic categories (*P* for trend <0.05 for all indicators). These associations were virtually unchanged and remained statistically significant after adjustment for baseline blood pressure. No consistent patterns in changes over time in diastolic blood pressure by socioeconomic categories were observed in black participants (data not shown).

Among white participants, the number of socioeconomic indicators in the lowest category was generally positively associated with increases over time in systolic blood pressure (Table 6). In addition, having more indicators in the lowest category was associated with stronger decreases over time in diastolic blood pressure among persons 50 years or older at

TABLE 4. Adjusted Mean 5-Year Changes in Systolic Blood Pressure in mm Hg (SEM) by Neighborhood- and Individual-Level Socioeconomic Indicators

	Whites		Blacks	
	Adjusted for Age, Sex, Center, and Medication Use*	Adjusted for Age, Sex, Center, Medication Use, and Baseline Blood Pressure*	Adjusted for Age, Sex, and Medication Use*	Adjusted for Age, Sex, Center, Medication Use, and Baseline Blood Pressure*
Neighborhood score tertiles†				
Lowest	5.6 (0.2)	5.6 (0.2)	5.8 (0.4)	5.5 (0.5)
Middle	5.5 (0.2)	5.5 (0.2)	6.6 (0.4)	6.3 (0.5)
Highest	5.2 (0.2)	5.3 (0.2)	6.1 (0.4)	6.4 (0.5)
P trend	0.07	0.2	0.7	0.2
Income†				
Lowest	5.3 (0.2)	5.1 (0.1)	7.0 (0.5)	6.6 (0.5)
Middle	5.4 (0.2)	5.4 (0.2)	5.7 (0.4)	5.6 (0.4)
Highest	5.5 (0.2)	5.7 (0.2)	5.4 (0.6)	5.5 (0.6)
P trend	0.4	0.02	0.02	0.1
Education				
Incomplete high school	6.0 (0.3)	5.9 (0.3)	6.0 (0.4)	5.7 (0.5)
Complete high school	5.4 (0.1)	5.4 (0.1)	6.4 (0.4)	6.2 (0.5)
Complete college	5.3 (0.2)	5.5 (0.2)	6.1 (0.5)	6.4 (0.5)
P trend	0.05	0.3	0.9	0.4
Occupation‡				
IV–VI	5.9 (0.2)	5.8 (0.2)	5.7 (0.5)	5.8 (0.6)
II–III	5.3 (0.2)	5.3 (0.2)	6.6 (0.4)	6.4 (0.5)
I	5.4 (0.2)	5.6 (0.2)	5.7 (0.5)	5.8 (0.5)
P trend	0.1	0.4	0.9	0.9

*Mean yearly changes estimated from the model are extrapolated to a 5-year period. Estimates shown correspond to the mean age and sex distribution of the entire sample and the mean baseline blood pressure in each race.

†Neighborhood score and income categories are race specific. Neighborhood categories are based on race-specific tertiles. Income categories are: <$25 000, $25 000–49 999, and $50 000 or more in whites; and <$12 000, $12 000–34 999, and $35 000 or more in blacks.

‡Categories I–VI as shown in Table 1.

baseline (Table 6). These differences were also present after adjustment for baseline blood pressure and risk factors. Risk factor adjustment did not substantially alter estimates after controlling for baseline blood pressure.

Discussion

In this population-based sample, the risk of developing hypertension was inversely associated with socioeconomic indicators. In white participants, being in the lower socioeconomic categories was also associated with greater increases over time in systolic blood pressure and greater decreases over time in diastolic blood pressure after age 50 years.

Our findings regarding socioeconomic differences in the incidence of hypertension are consistent with previous work documenting inverse associations between socioeconomic characteristics and both prevalence[12–14] and incidence[15–17] of high blood pressure. Most studies of socioeconomic differences in hypertension are based on a single indicator (most commonly, education). We investigated exposure to a variety of adverse socioeconomic circumstances. Overall, findings were similar regardless of the indicator used. The effects of cumulative exposure to adverse socioeconomic conditions is demonstrated by the graded relation between the number of socioeconomic indicators in the lowest category and hypertension risk.

Socioeconomic differences in the longitudinal effects of aging on blood pressure have rarely been examined, and no clear patterns have been reported.[18,19] In the present analyses, increases in systolic blood pressure associated with aging were more pronounced in the lower than in the higher socioeconomic groups among white participants. Patterns observed in whites also suggested that the decline in diastolic blood pressure may begin earlier or may be more pronounced in persons of low socioeconomic position than in those of high position, possibly reflecting concomitant changes in large artery stiffness. If the importance of pulse pressure to cardiovascular risk is confirmed,[20] this socioeconomic patterning of systolic and diastolic blood pressure may have important implications for socioeconomic differences in disease risk.

There has been debate on the extent to which associations between potential risk factors and incidence of hypertension or changes in blood pressure over time should be estimated before or after controlling for baseline blood pressure, espe-

TABLE 5. Adjusted Mean 5-Year Changes in Diastolic Blood Pressure in mm Hg (SEM) by Neighborhood- and Individual-Level Socioeconomic Indicators in White Participants

	<50 Years of Age at Baseline		≥50 Years of Age at Baseline	
	Adjusted for Age, Sex, Center, and Medication Use*	Adjusted for Age, Sex, Center, Medication Use, and Baseline Blood Pressure*	Adjusted for Age, Sex, Center, and Medication Use*	Adjusted for Age, Sex, Center, Medication Use, and Baseline Blood Pressure*
Neighborhood score tertiles†				
Lowest	0.5 (0.2)	0.5 (0.2)	−0.8 (0.1)	−0.8 (0.1)
Middle	0.8 (0.2)	0.8 (0.2)	−0.4 (0.1)	−0.4 (0.1)
Highest	1.1 (0.2)	1.1 (0.2)	0.1 (0.1)	0.1 (0.1)
P trend	0.01	0.02	0.0001	0.0001
Income				
<$25 000	0.3 (0.4)	0.3 (0.3)	−0.5 (0.2)	−0.7 (0.2)
$25 000–49 999	0.7 (0.1)	0.5 (0.2)	−0.5 (0.1)	−0.5 (0.1)
≥$50 000	1.3 (0.2)	1.1 (0.2)	0.2 (0.2)	0.2 (0.1)
P trend	0.007	0.01	0.002	0.0001
Education				
Incomplete high school	0.3 (0.3)	0.3 (0.4)	−0.7 (0.2)	−0.6 (0.2)
Complete high school	0.5 (0.2)	0.6 (0.1)	−0.5 (0.1)	−0.5 (0.09)
Complete college	1.1 (0.2)	1.3 (0.2)	0.2 (0.1)	0.2 (0.2)
P trend	0.008	0.006	0.0001	0.001
Occupation†				
IV–VI	0.6 (0.3)	0.6 (0.3)	−0.5 (0.2)	−0.5 (0.2)
II–III	0.8 (0.2)	0.7 (0.2)	−0.3 (0.1)	−0.3 (0.1)
I	1.2 (0.2)	1.3 (0.2)	−0.0 (0.1)	0.0 (0.1)
P trend	0.04	0.02	0.01	0.009

*Mean yearly changes estimated from the model are extrapolated to a 5-year period. Estimates shown correspond to the mean age and sex distribution of the entire sample and the mean baseline blood pressure.

†Occupation categories as shown in Table 1.

cially if the factor of interest is itself associated with baseline levels. Baseline blood pressure has been found to be positively associated with hypertension incidence[18,21] and future increases in blood pressure over time.[22,23] Persons with higher blood pressures at baseline may be more likely to cross the threshold that places them in the hypertensive range. Higher baseline levels could also "cause" faster progression,[24] through the effects of blood pressure itself on peripheral resistance or large artery stiffness.[25] On the other hand, high baseline levels (for example, higher systolic blood pressure in the low socioeconomic groups) may be the consequence of more rapid increases before the study's baseline measurement.[26] In this case, adjustment for "baseline" measures could lead to underestimations of the true effects of the factor of interest on incidence or progression. We therefore report results before and after adjustment for baseline blood pressure. Socioeconomic differences in hypertension incidence and systolic blood pressure change were reduced after adjustment for baseline blood pressure. Baseline blood pressure adjustment had no effect on socioeconomic differences in diastolic blood pressure change. Additional adjustment for body mass index, physical activity, and alcohol intake as time-dependent covariates did not modify baseline-adjusted estimates.

Socioeconomic differences in incidence and progression were generally weaker and less consistent in blacks than in whites. Sample size was smaller in blacks than in whites, and a larger percentage of blacks than whites were excluded from the analyses because of hypertension at baseline. Thus, the present analyses are limited to a possibly selected group of black participants who remained free of hypertension until middle age. In addition, the socioeconomic range for each race differed markedly, which reflects in part the sampling procedure used and in part the reality of race differences in socioeconomic positions in the United States generally. Other factors (for example, related to active coping or discrimination) may also place blacks of relatively high socioeconomic position at higher risk of hypertension, thus reducing or eliminating the socioeconomic gradient. Persons excluded from the analyses because of unavailable follow-up information were more likely to be black and more likely to be of low socioeconomic position than those included. If those without follow-up information were also more likely to have rapidly increasing blood pressure with age, the present results may actually underestimate true socioeconomic differences.

A key advantage of this study is the availability of multiple standardized longitudinal measures in the context of a large, population-based sample. A disadvantage is the relatively late age window for the examination of aging-related blood

TABLE 6. Adjusted Mean 5-Year Changes in Blood Pressure in mm Hg (SEM) by Number of Socioeconomic Indicators in the Lowest Category* in White Participants

	Systolic Blood Pressure		Diastolic Blood Pressure			
			Baseline Age <50 Years		Baseline Age ≥50 Years	
	Adjusted for Age, Sex, Center, and Medication Use†	Additional Adjustment for Baseline Blood Pressure and Risk Factors‡	Adjusted for Age, Sex, Center, and Medication Use†	Additional Adjustment for Baseline Blood Pressure and Risk Factors‡	Adjusted for Age, Sex, Center, and Medication Use†	Additional Adjustment for Baseline Blood Pressure and Risk Factors‡
Four indicators in lowest category	7.0 (0.7)	6.2 (0.7)	§	§	−0.7 (0.5)	−1.1 (0.4)
Three indicators in lowest category	5.7 (0.4)	5.3 (0.4)	0.3 (0.6)	0.1 (0.6)	−0.6 (0.3)	−1.3 (0.3)
Two indicators in lowest category	5.3 (0.3)	4.7 (0.3)	0.4 (0.3)	−0.4 (0.3)	−0.7 (0.2)	−1.0 (0.2)
One indicator in lowest category	5.6 (0.2)	4.8 (0.2)	0.5 (0.2)	0.1 (0.2)	−0.3 (0.1)	−0.7 (0.1)
No indicators in lowest category, but not all 4 indicators in highest	5.2 (0.2)	4.3 (0.2)	1.0 (0.2)	0.5 (0.2)	0.0 (0.1)	−0.3 (0.1)
All 4 indicators in highest category	5.4 (0.4)	4.5 (0.4)	1.8 (0.4)	1.2 (0.3)	0.4 (0.3)	0.1 (0.3)
P trend	0.04	0.005	0.002	0.008	0.0002	0.0001

*The 4 socioeconomic indicators used are neighborhood score, individual-level income, education, and occupation. Lowest and highest categories refer to those shown in Table 2. Persons with no information on income and homemakers are excluded.

†Mean yearly changes estimated from the model are extrapolated to a 5-year period. Estimates shown correspond to the mean age and sex distribution of the entire sample.

‡Also adjusted for baseline blood pressure, as well as body mass index, physical activity, and alcohol intake as time-dependent covariates. Estimates correspond to the mean baseline blood pressure.

§Not shown because of small number of individuals in this cell (n=27).

pressure change. Aging-related changes are likely to begin early in life.[27] Consequently, socioeconomic differences in the effects of aging on blood pressure may be better reflected by differences in average blood pressures in middle age (resulting from differences in past increases over adolescence and young adulthood) than by differences in blood pressure change after age 45 to 64 years. The late-window problem may also have hampered our ability to detect socioeconomic gradients in blacks, especially if socioeconomic differences in progression occur early in life in this group.

Although the socioeconomic differences we observed were small, their cumulative effects may lead to substantial differences in cardiovascular risk. Our results add to the evidence that the change in blood pressure with age is not a universal, biologically determined phenomenon but is likely to reflect cumulative factors that operate over the course of one's life, the distribution of which is socially patterned. This highlights the need to address factors related to the social environment in research on the causes of hypertension and in prevention strategies.

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