Socioeconomic Disadvantage and Periodontal Disease: The Dental Atherosclerosis Risk in Communities Study

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Objectives. We used data from the Dental Atherosclerosis Risk in Communities study to examine whether individual- and neighborhood-level socioeconomic characteristics were associated with periodontal disease.

Methods. We assessed severe periodontitis with a combination of clinical attachment loss and pocket depth measures. Marginal logistic regression modeling was used to estimate the association between individual and neighborhood socioeconomic indicators and prevalence of severe periodontitis before and after control for selected covariates. Residual intraneighborhood correlations in outcomes were taken into account in the analyses.

Results. Individual-level income and education were associated with severe periodontitis among Whites and African Americans, and these associations remained significant after adjustment for age, gender, recruitment center, and neighborhood socioeconomic score. Low-income Whites residing in disadvantaged neighborhoods had 1.8-fold (95% confidence interval = 1.2, 2.7) higher odds of having severe periodontitis than high-income Whites residing in advantaged neighborhoods.

Conclusions. Individual income and education were associated with severe periodontitis independently of neighborhood socioeconomic circumstances. Although the association between neighborhood socioeconomic status and severe periodontitis was not statistically significant, poverty and residence in a disadvantaged neighborhood were associated with higher odds of severe periodontitis among Whites. (*Am J Public Health.* 2006;96:332–339. doi:10.2105/AJPH.2004.055277)

It has long been reported that periodontal diseases are more frequent and more severe among individuals of low socioeconomic status (SES) than among their peers of higher SES.[1–12] However, the nature of the association between periodontal disease and the socioeconomic indicators assessed (i.e., income, education) has rarely been the focus of investigations. In fact, socioeconomic indicators are usually included as covariates in analyses of factors associated with periodontal disease.

Although an association between area-based socioeconomic indicators and health outcomes has been documented,[13–15] the mechanisms by which area-based SES affects health are not well understood. Research has suggested that neighborhood-specific socioeconomic conditions can influence patterns of health behaviors and health-related beliefs independent of individual levels of SES.[14,16] In the case of periodontal diseases, higher neighborhood SES might be associated with healthy behaviors among community members (e.g., reductions in smoking prevalence) and dissemination of health-related information to these individuals, which in turn could prevent periodontal diseases independent of individual SES. Also, the SES of a geographic area can influence the available supply of health professionals.[17] However, studies have shown that manpower and access to dental services do not correlate well with improved health status.[18]

The dental ancillary component of the Atherosclerosis Risk in Communities (ARIC) cohort study ("Dental ARIC") afforded us the opportunity to investigate whether individual- and neighborhood-level socioeconomic characteristics are independently associated with periodontal disease before and after control for selected individual characteristics. We hypothesized that (1) individual and neighborhood SES characteristics would be independently associated with a higher probability of periodontal disease and (2) neighborhood socioeconomic characteristics would have different effects on residents according to their individual SES (e.g., poor individuals living in poor neighborhoods would have worse outcomes than their high-income peers living in more affluent neighborhoods).

METHODS

In the ARIC study, a prospective investigation of the etiology of atherosclerosis, 15 792 individuals aged 45 to 64 years were selected, via probability sampling, from 4 US communities: Forsyth County, North Carolina; Jackson, Miss; the northwestern suburbs of Minneapolis, Minn; and Washington County, Maryland.[19] Three of the samples reflected the demographic composition of their communities (99% White in Washington County and Minneapolis and 85% White in Forsyth County), whereas only African Americans were sampled in Jackson. A total of 26 427 individuals were invited to participate in the study. Baseline assessments took place during 1987 to 1989; approximately 60% (n = 15 792) of the participants completed both the home interview and the clinical examination at baseline.[20]

In this study, we used data from the Dental ARIC, a cross-sectional investigation conducted during the third reexamination of the ARIC cohort between 1996 and 1998 ("visit 4"). The response rate at this reexamination was 74% (representing 11 656 members of the initial sample). The main exclusion criteria for the Dental ARIC were contraindications for measuring pocket depth (per the guidelines of the American Heart Association; n = 1621) and cases in which participants were missing all of their teeth (1651 participants were edentulous). Of the 8284 individuals eligible to participate in the study, 6967 (84%) underwent a dental examination. Eighty-two percent of those undergoing an examination (n = 5729) were linked to block

group data via the home address reported at visit 4. Individuals of ethnic backgrounds other than African American or White, African Americans from the Minneapolis and Washington County sites (n=49), and individuals who were missing information on education level (n=9) were excluded. The final sample available for the analyses was composed of 5677 individuals in 759 block groups (median per block group: 4 participants; range: 1 to 67).

Study Variables

As described elsewhere, the Dental ARIC consisted of an oral examination and an interview conducted according to a protocol standardized across the 4 study sites.[21–23] Briefly, dental hygienists trained in a modification of the protocol from the third National Health and Nutrition Examination Survey[24] obtained clinical data, including measurements of pocket depth (distance between the free marginal gingival and the bottom of the sulcus between the gingival and the tooth) and cementoenamel junctions for 6 sites per tooth (range: 6 to 186 sites per participant).[25] Clinical attachment level (distance between the cementoenamel junction and the bottom of the sulcus between the gingival and the tooth) was derived through subtracting the cementoenamel junction measure from the pocket depth measure.

Periodontal examiners at the ARIC centers were calibrated to a standard examiner, and clinical attachment level agreement percentages within 1 mm between these examiners and the standard examiner ranged from 83.2% to 90.2%. Weighted kappa statistics ranged from 0.76 to 0.86, indicating excellent agreement, and intraclass correlation coefficients ranged from 0.76 to 0.90, indicating excellent to outstanding agreement. There is very little consensus on case definitions of periodontal disease. However, previous researchers have used combinations of pocket depth and clinical attachment level,[26,27] with the rationale being that this combination represents cumulative tissue destruction (clinical attachment level) and active disease (pocket depth).[17,28] We examined distributions of pocket depth and clinical attachment level both in the total study population and in each racial/ethnic group.

Before engaging in any hypothesis testing, we considered several clinical definitions until we arrived at the one used in the analyses described here. We defined severe periodontitis as a combination of at least 2 interproximal sites with clinical attachment levels of 6 mm or above and at least 1 interproximal site with pocket depths of 5 mm or above. However, these conditions did not need to be present in the same site or tooth. We choose a dichotomous definition rather than a continuous definition because the former would be more relevant to clinicians and public health professionals.

Census block groups—subdivisions of census tracts with an average of 1000 residents—were used as proxies for neighborhoods because they resembled the confines of what individuals thought of as their neighborhoods. A neighborhood SES score was developed on the basis of factor analyses of multiple 1990 US census variables (as reported elsewhere[14,29]). Briefly, 6 variables representing wealth/income (log of median household income, log of median value of owner-occupied housing units, and percentage of households receiving interest, dividends, or net rental income), education (percentage of adults 25 years or older who had completed high school and percentage who had completed college), and occupation (percentage of employed individuals 16 years or older in executive, managerial, or professional specialty occupations) were combined in calculating this score.

Subsequently, we transformed each covariate to a *z* score by subtracting its value from the grand mean for that covariate and dividing the result by the standard deviation of the grand mean. Other studies have shown that neighborhood disadvantage, as assessed via this score, is associated with a higher incidence of adverse outcomes.[14,30,31] In this sample, neighborhood SES scores ranged from −11.3 to 14.4, higher values reflecting increased SES.

Individual-level socioeconomic data were obtained from interviewer-administered questionnaires conducted during visit 4. Each participant selected his or her combined family annual income during the past 12 months from 10 categories (less than $5000, $5000–$7999, $8000–$11 999, $12 000–$15 999, $16 000–$24 999, $25 000–$34 999, $35 000–$49 999, $50 000–$74 999, $75 000–$99 999, $100 000 or above). Information on income was missing for 4% of the sample, and we included missing income as a separate category in our analyses. We used 3 income categories in this study: less than $25 000, $25 000 to $49 999, and $50 000 or more. Also, because of the different African American and White income distributions, we constructed race-specific income categories: less than $35 000 (36% of the sample), $35 000 to $74 999 (42%), and $75,000 or above (18%) for Whites and less than $16 000 (34%), $16 000 to $49 999 (41%), and $50 000 or above (17%) for African Americans.

Participants indicated their educational attainment by selecting from one of the following categories: (1) 8th grade or below, (2) 9th to 11th grade, (3) high school (or general equivalency diploma), (4) vocational school, (5) 4 years of college, or (6) graduate or professional school. In our analyses, we classified education levels as less than high school, high school/general equivalency diploma or vocational school, and some college, college, or professional school.

The covariates we included in our analyses were age, gender, and recruitment center. Because our main objective was to investigate the independent effects of individual-level and neighborhood-level SES indicators on periodontal disease, we did not examine additional covariates—marital status, presence of diabetes, smoking status, frequency of dental visits, and number of teeth—that might have wholly or partly mediated any of the differences observed.

Statistical Analyses

Because of the race distribution differences, neighborhood SES scores were divided into race-specific tertiles, and analyses were stratified in terms of race. We used linear and logistic regression analyses to estimate adjusted means and proportions for individual and neighborhood SES indicators according to presence of severe periodontitis. Also, we used logistic regression analyses to estimate associations between individual and neighborhood SES indicators and prevalence of severe periodontitis before and after adjustment for age, gender, and recruitment center.

TABLE 1—Neighborhood Characteristics and Individual Measures of Socioeconomic Status (SES), by Race and Neighborhood SES Score Tertiles: Dental ARIC Study, 1996–1998

	Whites (n = 4506)			African Americans (n = 1171)		
	Lowest Tertile (*z* = −7.26 to 1.24)	Middle Tertile (*z* = 1.25 to 3.91)	Highest Tertile (*z* = 3.92 to 14.4)	Lowest Tertile (*z* = −11.3 to −5.5)	Middle Tertile (*z* = −5.6 to −1.81)	Highest Tertile (*z* = −1.82 to 11.2)
Neighborhood level						
No. of participants	1495	1480	1531	405	365	401
No. of neighborhoods	207	185	199	49	50	67
Neighborhood score mean	−0.83	2.57	6.76	−7.22	−3.4	1.90
Median household income, $	29 529	37 443	49 588	12 076	19 304	34 651
Median housing unit value, $	73 572	89 052	117 087	33 277	44 026	64 418
Households with interest, dividends, or rental income, %	39	51	63	6	14	26
Adult residents with high-school diploma, %	71	83	93	46	66	82
Adult residents with college degree, %	10	21	41	8	17	37
Employed residents in executive, managerial, or professional occupation, %	17	29	43	12	20	34
Individual level, %						
Education						
Less than high school	19.6	8.4	3.6	41.2	30.4	16.2
High school/vocational school	55.0	51.9	32.7	33.1	32.1	22.7
College or higher	25.4	39.7	63.7	25.7	37.5	61.1
Income category[a]						
Low	50.9	30.4	22.3	52.6	41.2	19.2
Medium	41.9	44.0	45.1	41.2	46.8	45.6
High	7.2	16.6	32.6	6.1	12.0	35.2

[a]Income categories were race specific: < $35 000, $35 000–$74 999, and ≥ $75 000 for Whites and < $16 000, $16 000–$49 999, and ≥ $50 000 for African Americans.

We included interaction terms between neighborhood characteristics and individual incomes in our models and assessed these interaction terms with likelihood ratio tests. In addition, we tested interactions between gender and individual and neighborhood SES indicators. We conducted trend tests in which we included neighborhood score tertile and individual education and income categories as ordinal variables. Although income distributions are different for Whites and African Americans, poverty/wealth level is officially defined in the same way for both groups. Therefore, we fit models for income categories on the basis of the entire sample (less than $25,000; $25,000 to 49,999; and $50,000 or more) as well as race-specific categories.

In addition to the interaction terms between individual and neighborhood SES indicators, we created 9 cross-classified categories of neighborhood SES scores and individual incomes (e.g., lowest income category and lowest neighborhood SES score tertile). Specifically, we were interested in comparing prevalence of severe periodontitis among those with low individual incomes and neighborhood SES scores and those with high incomes and scores.

We used marginal models to account for possible residual intraneighborhood correlations in outcomes.[32,33] These models accounted for correlations between the outcomes of individuals selected from the same neighborhoods by modeling the correlations or covariances themselves rather than allowing for random effects or random coefficients, as in the case of multilevel models. Thus, we took such correlations into account in estimating regression coefficients and their standard errors. As a result, the odds ratios (ORs) reported here are population averages rather than unit-specific estimates. Statistical significance was set at the .05 level (2-sided). SAS PROC GENMOD was used in conducting all analyses.[34]

RESULTS

Overall, 17% of the participants had severe periodontitis, with African Americans exhibiting a higher prevalence (19.8%) than Whites (16.2%; P=.004; data not shown). On average, neighborhoods from which African Americans were recruited were more socioeconomically disadvantaged than those from which Whites were recruited (Table 1). Highly educated and affluent Whites and African Americans were more likely to reside in neighborhoods in the highest SES score tertile; however, in both groups, variations were evident in SES indicators across neighborhood tertiles. Whites and African Americans with severe periodontitis were more likely to be male and less educated than their counterparts without severe disease (P<.0001; Table 2). In addition, Whites with

TABLE 2—Characteristics of Dental ARIC Study Participants, 1996–1998

Characteristic	Whites		African Americans	
	No. (%)	Severe Periodontitis, %	No. (%)	Severe Periodontitis, %
Age, y				
52–59	1482 (32.9)	12.9	551 (47.0)	18.1
60–69	2289 (50.8)	17.3	494 (42.2)	20.6
≥70	735 (16.3)	19.7*	126 (10.8)	23.8
Gender				
Male	2105 (46.7)	21.1	448 (38.3)	33.0
Female	2401 (53.3)	11.9*	723 (61.7)	11.6*
Recruitment site				
Forsyth, NC	1299 (28.8)	9.2	97 (8.3)	37.1
Jackson, Miss	. . .	. . .	1074 (91.7)	18.2
Minneapolis, Minn	1679 (37.3)	13.7	. . .	. . .
Washington, Md	1528 (33.9)	24.7	. . .	. . .
Education				
Less than high school	473 (10.5)	21.8	343 (29.3)	25.7
High school/vocational school	2091 (46.4)	16.5	342 (29.2)	21.6
College or higher	1942 (43.1)	14.6*	482 (41.5)	14.4*
Income category[a]				
Low	1630 (36.2)	19.4	403 (34.4)	23.3
Medium	1906 (42.3)	15.6	483 (41.2)	17.8
High	827 (18.3)	11.9*	199 (17.0)	19.1

[a]Income categories were race specific: <$35 000, $35 000–$74 999, and ≥$75 000 for Whites and <$16 000, $16 000–$49 999, and ≥$50 000 for African Americans.
*P<.0001 (χ^2 test).

severe periodontitis were older and more likely to have low incomes (P<.0001).

In general, Whites and African Americans with severe periodontitis tended to reside in more disadvantaged neighborhoods than their peers without severe disease, as can be seen in Table 3 in the lower values for each of the neighborhood SES characteristics assessed. In addition, Whites and African Americans with severe periodontitis were more likely to report annual family incomes of less than $35 000 and $50 000 and less likely to have graduated from college or professional school.

Individual and neighborhood SES indicators were both associated with prevalence of severe periodontitis among Whites (Table 4). However, after adjustment for age, gender, recruitment center, education, and income, education level and neighborhood SES score were not significantly associated with severe periodontitis. Whites with low incomes were 1.5 times (95% confidence interval [CI]=1.2, 2.0) more likely than their high-income peers to have severe periodontitis. There was no evidence of an interaction between individual- and neighborhood-level SES. Moreover, associations did not differ according to gender.

Education level was associated with prevalence of severe periodontitis among African Americans (Table 4), and this association remained significant after adjustment for age, gender, recruitment center, and neighborhood SES score. Odds of having severe periodontitis were 2.0 times (95% CI=1.4, 2.9) higher among those without a high school diploma than among those with a college degree or postgraduate education. After adjustment for age, gender, recruitment center, and neighborhood SES score, low-income African Americans were 2.2 times (95% CI=1.3, 3.7) more likely to have severe periodontitis than their high-income peers. These associations did not differ according to either neighborhood SES or gender. There was no association between neighborhood SES and severe periodontitis.

Low-income Whites residing in neighborhoods in the lowest SES score tertile were more likely than high-income Whites residing in the most advantaged neighborhoods to have severe periodontitis (Table 4). After adjustment for age, gender, recruitment center, and education, the joint effect of individual income and neighborhood SES score was significantly associated with higher odds of severe periodontitis among Whites (OR=1.8; 95% CI=1.2, 2.7).

We also compared adjusted prevalences of severe periodontitis to determine independent effects of neighborhood SES and individual income (data not shown). After adjustment for age, gender, recruitment center, and education, statistically significant independent associations between prevalence of severe periodontitis and neighborhood SES (P=.05) and individual income (P<.04) were found only among Whites. In the case of both Whites and African Americans, there was no difference in periodontal disease prevalences between the group with high individual incomes and low neighborhood SES scores and the group with low individual incomes and high neighborhood SES scores. However, although the magnitude of the difference between the low-income/low-neighborhood-SES group and the high-income/high-neighborhood-SES group was nearly the same for both Whites and African Americans (7.0% and 7.6% higher for those in the low-income/low-neighborhood-SES group, respectively), the difference achieved statistical significance among Whites only (P=.003).

When income categories based on the entire sample were examined (data not shown), the association between low income and prevalence of severe periodontitis was weaker and nonsignificant (OR=1.3; 95% CI=0.9, 1.8) among Whites. Among African Americans, the association (OR=2.0; 95% CI=1.2, 3.3) was similar to that observed in the analyses of the race-specific income categories (OR=2.2; 95% CI=1.3, 3.7).

DISCUSSION

We found associations between individual socioeconomic indicators and prevalence of severe periodontitis. Low income was associated with presence of severe periodontitis

TABLE 3—Adjusted Race-Specific Neighborhood and Individual Socioeconomic Characteristics at Baseline, According to Severe Periodontitis Status: Dental ARIC Study, 1996–1998

	Whites		African Americans	
	Severe Periodontitis (n = 683)	No Severe Periodontitis (n = 3823)	Severe Periodontitis (n = 130)	No Severe Periodontitis (n = 1041)
Neighborhood				
Neighborhood score	2.7	2.9	−3.2	−2.8
Median household income, $	38 219	39 085	21 310	22 245
Median value of housing units, $	92 084	93 705	45 883	47 639
Households with interest, dividends, or rental income, %	51	51	15	15
Adult residents with high school diploma, %	82	82	64	65
Adult residents with college degree, %	23	24	19	21
Employed residents in executive, managerial, or professional occupations, %	29	30	21	22
Individual level, %				
Annual income ≥ $35 000	60	66*	28	36*
Annual income ≥ $50 000	35	42*	15	20
College degree	42	44	30	44*
Graduate or professional school	8	11*	13	19*

Note. Values were adjusted for age, gender, and recruitment center.
*$P \leq .05$ (for comparison between participants with and without severe periodontitis).

among Whites, and low education and income levels were associated with severe periodontitis among African Americans. In addition, low-income Whites residing in disadvantaged neighborhoods had higher odds of experiencing severe periodontitis than high-income Whites living in high-SES neighborhoods.

Although previous studies have documented differences in periodontal health according to socioeconomic indicators (i.e., income and education),[3–9,26,35–37] these indicators have rarely been investigated as the independent variables of primary interest. In fact, earlier studies can be summarized as follows: those reporting higher rates of disease among individuals of low SES in cross tabulations between outcomes and socioeconomic indicators[3–9,35] and those reporting persistence in racial/ethnic differences after adjustment for socioeconomic indicators in multivariable analyses.[3,8,9,26,36,37] In contrast to previous studies, we investigated associations between income and education and severe periodontitis before and after adjusting for age, gender, recruitment site, and neighborhood SES characteristics. Our results showed associations between individual SES indicators and severe periodontitis.

To our knowledge, this is the first study to investigate neighborhood effects on periodontal disease. It has been postulated that area of residence influences an individual's health behaviors and health-related norms.[14,16] In the case of periodontal disease, social contexts could promote or prevent behaviors, such as oral health habits and cigarette smoking, that affect periodontal health. Our study did not reveal statistically significant associations between neighborhood SES and severe periodontitis among either Whites or African Americans. This null finding could reflect misspecifications of neighborhood- and area-level SES constructs or the association between individual- and aggregate-level measures of SES.

In most US studies evaluating neighborhood effects on health and mortality, census tracts (mean population: 4000) or clusters of census tracts have been used as proxies for relevant areas.[15,38–44] Consistent with previous studies,[38,39] we used block groups in our analyses because they represent smaller areas more akin to neighborhoods than census tracts. However, we repeated our analyses using census tracts, and the results were nearly unchanged.

We used aggregate US census measures to assess neighborhood SES characteristics. It has been suggested that such measures represent summaries of individual characteristics and that their effects are difficult if not impossible to separate from those of individual-level SES indicators.[45] However, we did not find strong correlations between neighborhood SES score and individual income (Spearman $r=0.22$) or education (Spearman $r=0.30$), suggesting that these variables may be tapping into constructs not captured by neighborhood SES conditions.

Furthermore, we found appreciable variability in study participants' income and education levels across neighborhood SES score tertiles. Because of this variability, we also investigated the combined effects of neighborhood SES score and individual income. In the case of Whites only, we found high odds of severe periodontal disease among individuals with low incomes who resided in the most disadvantaged neighborhoods. Possible reasons for the absence of a significant association among African Americans included the small size of the sample (n=1171, compared with n=4406 among Whites) and the fact that 92% of African Americans were recruited from a single community (Jackson).

Because we were interested in quantifying the associations between severe periodontitis and individual-level and neighborhood-level SES indicators, we did not adjust for risk factors considered to be (at least in part) intervening variables in the pathway between SES and periodontal disease. Notable examples are cigarette smoking and type 2 diabetes, which have plausible and well-documented associations with SES (distal) and extent and severity of periodontal disease (proximal). Adjustments for such covariates would not provide valid estimates of independent effects.[46] Although easy to implement, such adjustments are likely to be misleading as a result of the large degree of residual confounding associated with both cigarette smoking and type 2 diabetes, particularly in the context of the chronic process assessed here. We repeated the analyses, adjusting for marital status, smoking status, presence of diabetes, time

TABLE 4—Race-Specific Odds Ratios for Severe Periodontitis, According to Individual and Neighborhood Socioeconomic Indicators: Dental ARIC Study, 1996–1998

Indicator	Crude OR (95% CI)	Adjusted[a] OR (95% CI)	Adjusted[b] OR (95% CI)
Whites			
Education			
Less than high school	1.6 (1.3, 2.1)	1.2 (0.9, 1.6)	1.2 (0.9, 1.5)
High school/vocational school	1.1 (0.9, 1.4)	1.1 (0.9, 1.3)	1.1 (0.9, 1.3)
College or higher	1.0	1.0	1.0
P for trend	.0004	.10	.20
Income, $			
< 35 000	1.8 (1.4, 2.2)	1.6 (1.2, 2.0)	1.5 (1.2, 2.0)
35 000–74 999	1.4 (1.1, 1.7)	1.3 (1.0, 1.7)	1.3 (0.9, 1.6)
≥ 75 000	1.0	1.0	1.0
P for trend	<.0001	.001	.002
Neighborhood score			
Low	1.7 (1.4, 2.0)	1.2 (0.9, 1.5)	1.1 (0.8, 1.3)
Medium	1.4 (1.1, 1.7)	1.2 (0.9, 1.4)	1.1 (0.9, 1.3)
High	1.0	1.0	1.0
P for trend	<.0001	.13	.68
Joint effect of neighborhood score and individual income[c]			
Low–low	2.7 (1.9, 3.8)	1.9 (1.3, 2.8)	1.8 (1.2, 2.7)
High–high	1.0	1.0	1.0
African Americans			
Education			
Less than high school	2.0 (1.4, 2.9)	2.0 (1.4, 3.0)	2.0 (1.4, 2.9)
High school/vocational school	1.6 (1.1, 2.3)	1.3 (1.1, 2.4)	1.6 (1.1, 2.4)
College or higher	1.0	1.0	1.0
P for trend	<.0001	.001	.0003
Income, $			
< 16 000	1.3 (0.8, 1.9)	2.3 (1.4, 3.7)	2.2 (1.3, 3.7)
16 000–49 999	0.9 (0.6, 1.4)	1.2 (0.7, 1.9)	1.2 (0.7, 1.9)
≥ 50 000	1.0	1.0	1.0
P for trend	.08	.001	.002
Neighborhood score			
Low	1.1 (0.8, 1.5)	1.3 (0.9, 1.9)	1.0 (0.7, 1.5)
Medium	1.0 (0.7, 1.4)	1.1 (0.7, 1.6)	0.9 (0.9, 1.3)
High	1.0	1.0	1.0
P for trend	.58	.14	.93
Joint effect of neighborhood score and individual income[c]			
Low–low	1.1 (0.6, 1.9)	2.1 (1.2, 3.8)	1.6 (0.8, 3.2)
High–high	1.0	1.0	1.0

Note. OR = odds ratio; CI = confidence interval.
[a]Adjusted for age, gender, and recruitment site.
[b]Adjusted in addition for neighborhood score for income and education ORs, and vice versa. For the joint effect of neighborhood score and individual income, the OR was adjusted for age, gender, recruitment center, and education.
[c]Refers to the effect of cross-classified categories of neighborhood socioeconomic score tertiles and individual income categories.

since most recent dental visit, and number of teeth (data not shown). Although the estimates were of slightly lower magnitude, the results were nearly identical.

A strength of our study was the population-based nature of the sample in contrast to most studies involving periodontal patient samples. An important limitation is that observational studies, such as the present investigation, are often unable to tease out compositional effects (i.e., individual effects) and contextual effects (i.e., neighborhood effects). Although we used standard multivariable approaches to controlling individual-level socioeconomic indicators in our assessment of the association between neighborhood-level SES and periodontal disease (and vice versa), such variables may well be mediators of this association rather than confounders.[14,16] In addition, the cross-sectional nature of the data and the lack of information on the length of time individuals had been disadvantaged precluded us from making inferences regarding directionality between exposure and disease.

Another limitation to note is that African Americans were drawn predominantly from a single geographic locale (Jackson, Miss), whereas Whites were drawn from all of the other 3 communities. This limitation prevented us from making direct racial/ethnic comparisons, in that such analyses would have inevitably been confounded by recruitment site. In addition, the large numbers of participants excluded for medical reasons or because their address could not be appended to census data, along with the exclusion of participants who were eligible but refused to participate in the study, could have led to either underestimations or overestimations in our findings. For example, those excluded for medical reasons may have been more likely to have systemic diseases (e.g., diabetes) and, therefore, more likely to have periodontal disease. As a consequence, their exclusion may have led to underestimations in our results.

Furthermore, participants without census data were more likely to be young, male, and White; more likely to have been recruited from Forsyth County and Minnesota; and more likely to have a high income. However, there was no difference in periodontal disease status. Finally, participants who were eligible but refused to participate in the dental

examination were less likely to have a high school diploma (21% in ARIC vs 14% of Dental ARIC participants; $P<.05$) and more likely to smoke (22% vs 14%; $P<.05$). However, there were no differences in terms of age, race, gender, or diabetes status between those who participated and those who were eligible but refused to participate. Thus, it is likely that if exclusions indeed had an impact on our results, it would have been one of lessening the magnitudes of the associations observed.

Our study shows that individual income and education are important factors in periodontal health independent of neighborhood SES circumstances. Although neighborhood SES did not emerge as an attribute associated with periodontal disease to an important degree, being poor and living in a disadvantaged neighborhood increased the odds of periodontal disease among Whites. Determinations of whether neighborhood SES plays a role in population levels of periodontal disease would benefit from investigations of specific processes through which neighborhood characteristics act upon or interact with individual-level SES indicators and the behaviors that affect periodontal disease. Specifically, such research could help elucidate the features of neighborhoods that influence health-related behaviors of particular segments of the population, including less educated and low-income individuals. ■

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Contributors

L.N. Borrell planned the study, analyzed the data, interpreted the results, and wrote the article. J.D. Beck and G. Heiss contributed to interpreting the analyses and reviewing and writing the article.

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Human Participant Protection

The institutional review board at each study center approved the study protocol, and informed consent was obtained from all participants. In addition, the analysis was approved by the institutional review board at Columbia University.

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