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Neighborhood Social Vulnerability and Oral Health Outcomes Across U.S. Census Tracts: A National Ecological Analysis

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Abstract

Background: National evidence linking neighborhood social vulnerability to oral health at fine geographic resolution remains limited. We examined associations with edentulism and dental care use across U.S. census tracts, assessed vulnerability domains and geographic variation, and explored modification by state Medicaid adult dental coverage.

Methods: This ecological, cross-sectional study linked 2025 PLACES modeled prevalence estimates of edentulism (adults ≥65 years) and past-year dental visits (adults ≥18 years) with the 2022 Social Vulnerability Index (SVI) across 83,143 census tracts in all 50 states and the District of Columbia. Fractional logit models with county-clustered standard errors assessed overall associations with and without state fixed effects and mutually adjusted domain associations with state fixed effects. Multilevel models partitioned geographic variance. Exploratory analyses examined Medicaid coverage interactions. Sensitivity analyses used alternative deprivation indices and within-state SVI rankings.

Results: Each 0.10-unit increase in SVI percentile was associated with higher modeled edentulism (odds ratio [OR] 1.177, 95% confidence interval [CI] 1.169–1.184; average marginal effect +1.90 percentage points) and lower modeled dental visit prevalence (OR 0.881, 95% CI 0.878–0.884; −2.93 percentage points). From the least to most vulnerable quartile, mean edentulism prevalence increased from 7.7% to 21.9%, while dental visit prevalence decreased from 70.9% to 48.5%. Associations persisted within states. Socioeconomic vulnerability showed the strongest mutually adjusted associations with both outcomes. After accounting for SVI, residual edentulism variation occurred predominantly between tracts within counties (65%), whereas dental visit variation occurred predominantly between states (75%). More extensive Medicaid adult dental benefits were associated with higher dental visit prevalence, but vulnerability gradients did not differ significantly across coverage categories (interaction P = 0.15). Sensitivity analyses yielded consistent findings.

Conclusions: Greater neighborhood social vulnerability, particularly socioeconomic vulnerability, was associated with higher modeled edentulism and lower modeled dental utilization. Tract-level vulnerability measures can help identify communities requiring detailed

assessment beyond state and county averages. Because outcomes were modeled and the design ecological and cross-sectional, findings do not establish individual-level relationships or causal policy effects.

Keywords: social vulnerability; edentulism; dental care utilization; census tract; Medicaid; oral health disparities; small-area estimation

Background

Oral health inequalities in the United States extend beyond individual circumstances to reflect the social and economic conditions in which people live (1,2). Tooth loss remains an important marker of these inequalities, particularly among older adults, while access to routine dental care continues to be constrained by financial barriers (3,4). Because preventive dental services can reduce the risk of oral diseases that lead to tooth loss, patterns of dental care utilization and accumulated oral disease provide complementary perspectives on oral health disparities (5,6). Examining both outcomes can help distinguish inequalities in access to care from differences in oral health accumulated over time.

Neighborhood conditions are an important part of this broader context. Economic disadvantage, housing conditions, transportation barriers, and limited access to services may shape residents' opportunities to maintain oral health and obtain dental care (7,8). The Centers for Disease Control and Prevention and the Agency for Toxic Substances and Disease Registry developed the Social Vulnerability Index (SVI) to characterize communities according to their capacity to prepare for and respond to external stresses (9). Derived from American Community Survey data, the SVI combines 16 indicators into an overall measure and four domains covering socioeconomic conditions, household characteristics and disability, racial and ethnic minority status and language, and housing and transportation (10). Although originally developed for disaster preparedness, the index has increasingly been used to examine geographic differences in health outcomes (11–13). Its multidimensional structure offers a framework for investigating how distinct aspects of neighborhood vulnerability relate to oral health.

However, the evidence connecting neighborhood social vulnerability to oral health remains limited in geographic scope and analytical detail. Previous studies have been conducted at the county or state level or within single states, have focused almost exclusively on tooth loss, and have rarely examined the independent contributions of the four SVI domains (14–19). County-level analyses can obscure differences between neighborhoods within the same county, while composite scores do not establish which dimensions of vulnerability are independently associated with oral health outcomes (20,21). In addition, the relationship between neighborhood vulnerability and dental care utilization has received limited attention at the national scale (18,21,22). Understanding these associations at the census tract level, and distinguishing the

contributions of individual vulnerability domains, could provide a more precise basis for identifying geographic and social patterns of unmet oral health needs.

State policy may further shape these patterns, particularly through Medicaid adult dental coverage. Unlike many medical benefits, adult dental benefits are optional under Medicaid, and the scope of coverage varies across states (23,24). Previous research has associated more generous adult dental benefits with greater dental care utilization among low-income adults (25,26). However, it remains unclear whether more extensive coverage changes the relationship between neighborhood social vulnerability and dental care use or whether utilization disparities persist across neighborhoods with different levels of vulnerability (27). Examining this potential interaction can help distinguish an overall association between coverage generosity and dental visits from a possible difference in the vulnerability gradient across state policy contexts. Edentulism provides a useful comparison outcome in this analysis because tooth loss reflects oral disease and care experiences accumulated over many years and would not be expected to respond directly to Medicaid benefits in place in a single year (6).

Nationally available small-area health estimates make it possible to investigate these questions across the United States while retaining census tract resolution (28,29). In this study, we linked tract-level estimates of edentulism among adults aged 65 years and older and past-year dental visits among adults aged 18 years and older to the 2022 SVI across all 50 states and the District of Columbia. We aimed to quantify the associations between neighborhood social vulnerability and each outcome, determine which SVI domains were independently associated with these outcomes, and estimate the extent to which geographic variation occurred between states, between counties within states, and between census tracts within counties. We also examined whether state Medicaid adult dental coverage modified the association between neighborhood vulnerability and dental care utilization, using edentulism as a comparison outcome. Finally, we assessed the robustness of the findings using alternative neighborhood deprivation indices and an alternative SVI ranking framework.

Methods

Design and geographic scope

This ecological, cross-sectional study used the census tract as the unit of analysis and included all 50 states and the District of Columbia. Census tracts represent the smallest geographic unit at which nationwide oral health estimates and neighborhood vulnerability measures could be merged for this analysis. When delineating census tracts, the U.S. Census Bureau targets populations of approximately 4,000 residents, although tract populations may range from approximately 1,200 to 8,000 residents (30). Because all source datasets were published using 2020 census tract boundaries, records were linked using the 11-digit Federal Information Processing Standards (FIPS) code, and no geographic interpolation was required. Only aggregated, de-identified, publicly available data were analyzed; therefore, this study did not constitute human subjects research and did not require institutional review board approval.

Oral health measures

Outcome data were obtained from the 2025 release of PLACES: Local Data for Better Health, a Centers for Disease Control and Prevention (CDC) initiative that provides small-area health estimates for all U.S. census tracts (28). PLACES estimates are generated using multilevel regression with poststratification (MRP) applied to 2022 Behavioral Risk Factor Surveillance System (BRFSS) data. This approach combines individual-level BRFSS responses with census tract sociodemographic characteristics from the American Community Survey (ACS) and population counts from the U.S. Census to generate tract-level estimates of health outcomes (28,31).

Two oral health outcomes were examined: complete tooth loss (edentulism) among adults aged 65 years and older and a history of a dental visit during the preceding 12 months among adults aged 18 years and older. The published PLACES estimates represent modeled crude prevalence percentages and are not adjusted for differences in age structure across census tracts.

Measurement of neighborhood social vulnerability

Neighborhood social vulnerability was measured using the 2022 Social Vulnerability Index (SVI) developed by the Centers for Disease Control and Prevention (CDC) and the Agency for

Toxic Substances and Disease Registry (ATSDR) (9). The SVI incorporates 16 indicators derived from the 2018–2022 American Community Survey (ACS) five-year estimates into an overall composite score and four vulnerability domains: socioeconomic vulnerability, household characteristics and disability vulnerability, racial and ethnic minority status and language vulnerability, and housing type and transportation vulnerability.

Because this analysis included all U.S. census tracts, tracts were ranked nationally against all other U.S. tracts rather than within individual states. This approach generated percentile scores ranging from 0 to 1, with higher values indicating greater social vulnerability. The same national ranking framework was applied to the overall SVI and each of the four vulnerability domains. Census tracts that were not assigned an SVI percentile because of insufficient data (coded as −999 by the CDC) were excluded from the analysis. For purposes of interpretation, the four domains are referred to throughout as vulnerability dimensions rather than by their original CDC labels, such that the CDC theme "socioeconomic status" is reported as socioeconomic vulnerability. Higher values on each dimension indicate greater vulnerability.

Alternative deprivation measures and ranking frame

To evaluate whether findings were sensitive to the choice of neighborhood disadvantage measure, we conducted sensitivity analyses using two alternative indices: the Area Deprivation Index (ADI) and the Social Deprivation Index (SDI). The ADI (2024, version 4.0.1) incorporates 17 census-derived indicators of neighborhood disadvantage and is available at the census block group level (32,33). National percentile scores were aggregated to the census tract level by calculating the mean value across block groups within each tract, without population weighting. Block groups with suppressed values were excluded from this calculation. The SDI is a seven-indicator measure of social deprivation developed by the Robert Graham Center (34). Because the original SDI is available only using 2010 census tract boundaries, we used the version reconstructed by Stanford Population Health Sciences from 2016–2020 American Community Survey data and aligned to 2020 census tract boundaries (35).

Both alternative indices were converted to national percentile rankings ranging from 0 to 1 to facilitate comparison with the SVI. A separate sensitivity analysis examined whether the ranking framework influenced results by replacing national SVI percentiles with within-state SVI percentiles. Comparisons across neighborhood disadvantage measures were restricted to census

tracts with complete data for all indices, ensuring that each model was estimated using the same analytic sample.

State Medicaid adult dental coverage

State Medicaid adult dental coverage was examined as a potential policy modifier of the association between neighborhood social vulnerability and oral health outcomes. Adult dental benefits are an optional component of state Medicaid programs and vary substantially in scope across states. Each state's 2022 Medicaid dental benefit for the general adult population was classified into one of four categories: none, emergency-only, limited, or extensive, based on the National Academy for State Health Policy tracker as summarized by KFF (24). Because only three states provided no adult dental benefit and eight provided emergency-only coverage, these categories were combined for the primary analysis, resulting in three levels of coverage: none or emergency-only, limited, and extensive.

Construction of the analytic sample

Outcome, exposure, and alternative index datasets were merged using the census tract FIPS code. Two exclusion criteria were then applied. Census tracts with fewer than 500 residents were excluded because these tracts fall substantially below the population size typically targeted during census tract delineation and are largely composed of institutional or special-purpose areas, where modeled estimates of population prevalence may be less representative of residential populations (30). Tracts missing either oral health outcome estimate or the composite SVI score were also excluded.

Fractional logit models and primary association analyses

Both outcomes were proportions bounded between 0 and 1, a property that makes ordinary linear regression inappropriate, since predicted values may fall outside the feasible range. We therefore used the fractional logit approach proposed by Papke and Wooldridge (36), specifying generalized linear models with a logit link and quasibinomial variance. This approach accommodates continuous proportion outcomes while constraining predicted values to the valid range. Because census tracts within the same county may share unmeasured contextual factors, standard errors were estimated using a county-level cluster-robust variance estimator.

Effect estimates are reported as odds ratios corresponding to a 0.10-unit increase in the exposure percentile, with 95% confidence intervals. To improve interpretability, average marginal effects were additionally calculated and presented as the percentage-point change in outcome prevalence associated with a 0.10-unit increase in SVI.

Primary models were estimated with and without state fixed effects. Models without state fixed effects describe the overall national association between neighborhood vulnerability and oral health outcomes, whereas models with state fixed effects estimate associations among census tracts within the same state.

Dose-response and vulnerability domain analyses

To verify that the assumed shape of the association between SVI and each outcome was appropriate, census tracts were divided into 20 equally sized groups ranked by SVI percentile, and the observed mean prevalence within each group was compared against the values predicted by the fractional logit model. Close agreement between observed and predicted values indicates that the model adequately captured the shape of the relationship across the range of vulnerability. Associations were additionally summarized by SVI quartiles to aid interpretation.

To evaluate the independent associations of specific dimensions of vulnerability, the four SVI domains were entered simultaneously into a single mutually adjusted model for each oral health outcome. Each domain estimate therefore represents the association between that dimension of vulnerability and the outcome while holding the remaining three domains constant. These models also included state fixed effects, with standard errors clustered at the county level.

Geographic variance decomposition

To identify the geographic level at which variation in oral health outcomes was concentrated, we estimated multilevel linear models using the logit transformation of tract-level prevalence estimates. The models specified a three-level hierarchical structure, with census tracts nested within counties and counties nested within states. Each model included the SVI percentile as a fixed effect, such that the variance components represent geographic variation remaining after accounting for neighborhood social vulnerability. Variance components were extracted from the fitted models and expressed as proportions of total variance, representing the share of outcome variation attributable to differences between states, differences between counties within states,

and residual differences among census tracts within the same county.

Medicaid effect modification and **policy variance analysis**

To evaluate whether state Medicaid adult dental coverage modified the association between neighborhood social vulnerability and oral health outcomes, models included interaction terms between continuous SVI percentile and Medicaid dental coverage category. Because Medicaid coverage varies only at the state level, these models could not include state fixed effects. Standard errors were therefore clustered at the state level, and interaction effects were evaluated using a joint Wald test. In addition to the interaction models, associations between SVI and each outcome were estimated separately within each Medicaid coverage category. Outcome prevalence by coverage category was summarized as the population-weighted mean of tract-level estimates.

Edentulism was examined as a comparison outcome because Medicaid adult dental benefits available in 2022 would not be expected to influence cumulative tooth loss occurring over previous decades. Finally, the multilevel variance decomposition models were refitted with Medicaid coverage category included as a state-level predictor. The change in the state-level variance component was used to estimate the extent to which Medicaid dental coverage accounted for differences in oral health outcomes across states.

All analyses were conducted in R version 4.5.1.

Results

Derivation of the analytic sample

The 2022 CDC/ATSDR Social Vulnerability Index (SVI) dataset contained 84,120 U.S. census tracts. Of these, 778 tracts were not assigned an SVI percentile because of insufficient data and were excluded. Among the remaining 83,342 tracts, 55 had no published PLACES estimate for either outcome and 9 had a published estimate for past-year dental visits but not for edentulism; a further 135 had populations of fewer than 500 residents. The final analytic sample comprised 83,143 census tracts, distributed across all 50 states and the District of Columbia and representing approximately 330.5 million U.S. residents.

Association between neighborhood social vulnerability and oral health outcomes

Higher neighborhood social vulnerability was associated with a higher prevalence of edentulism among adults aged 65 years and older and a lower prevalence of past-year dental visits among adults (Table 1, Figure 1). Each 0.10-unit increase in SVI percentile was associated with 17.7% higher odds of edentulism (OR 1.177, 95% CI 1.169–1.184), corresponding to an average increase of 1.90 percentage points in tract-level edentulism prevalence. Each 0.10-unit increase in SVI percentile was also associated with 11.9% lower odds of a past-year dental visit (OR 0.881, 95% CI 0.878–0.884), corresponding to an average decrease of 2.93 percentage points in tract-level dental visit prevalence.

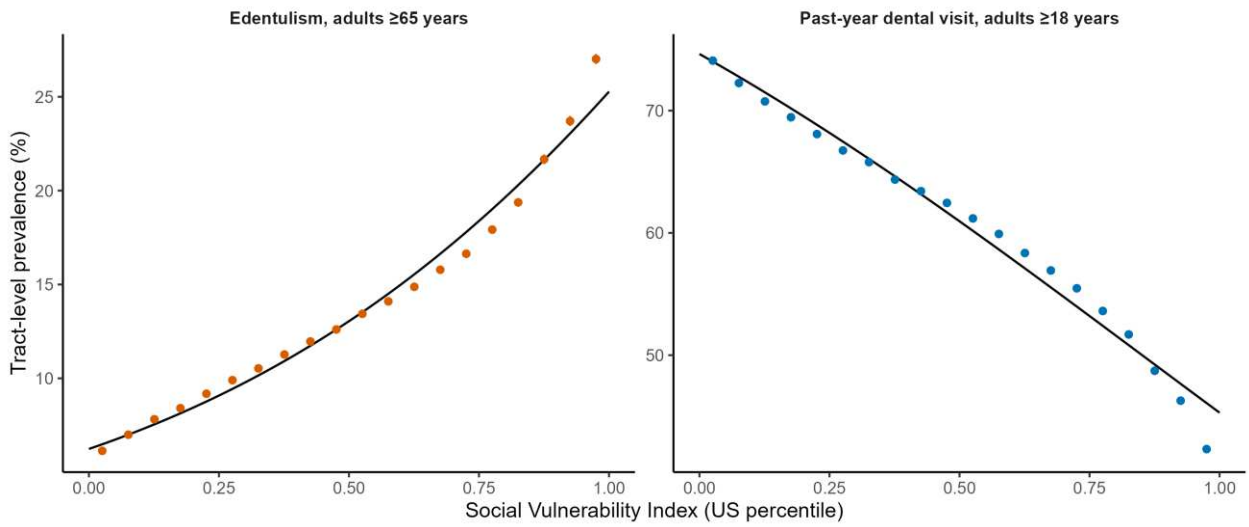
Visual inspection of the binned means demonstrated a smooth, monotonic association across the full range of SVI values for both outcomes (Figure 1). Across SVI quartiles, mean edentulism prevalence increased from 7.7% in the least vulnerable neighborhoods to 21.9% in the most vulnerable neighborhoods, whereas the prevalence of past-year dental visits decreased from 70.9% to 48.5%. Quartile summaries and tract-level scatterplots are presented in Figures S1 and S2. Adjustment for state fixed effects produced nearly identical estimates for both outcomes (Table 1).

Table 1. Association between neighborhood social vulnerability and oral health outcomes

Outcome	National OR per 0.10 (95% CI)	AME, pp per 0.10	Within-state OR per 0.10 (95% CI)
Edentulism, adults ≥65 years	1.177 (1.169–1.184)	+1.90	1.188 (1.184–1.193)
Past-year dental visit, adults ≥18 years	0.881 (0.878–0.884)	−2.93	0.884 (0.882–0.887)

Fractional logit models with county-clustered standard errors. The final column includes state fixed effects and therefore estimates associations among census tracts within the same state. AME, average marginal effect expressed as percentage-point (pp) change in outcome prevalence per 0.10-unit increase in SVI percentile; CI, confidence interval; OR, odds ratio.

Figure 1. Association between neighborhood social vulnerability and tract-level prevalence of edentulism and past-year dental visits across U.S. census tracts.



Markers represent the mean prevalence within 20 equally sized groups of census tracts ranked by SVI percentile; error bars indicate 95% confidence intervals and are narrower than the plotted markers owing to the large number of tracts per group. The solid line represents the fitted fractional logit model. Based on 83,143 U.S. census tracts.

Independent associations of SVI vulnerability domains

When all four SVI vulnerability domains were included simultaneously in the same model, socioeconomic vulnerability was the domain most strongly associated with both outcomes, independent of the others (Table 2, Figure 2). Each 0.10-unit increase in socioeconomic vulnerability was associated with 18.2% higher odds of edentulism (OR 1.182, 95% CI 1.178–1.186) and 10.6% lower odds of a past-year dental visit (OR 0.894, 95% CI 0.892–0.895). For dental visits, racial and ethnic minority status and language vulnerability showed an independent inverse association (OR 0.983, 95% CI 0.980–0.985), while its association with edentulism was close to null (OR 0.996, 95% CI 0.992–1.000). Household characteristics and disability vulnerability, and housing type and transportation vulnerability showed comparatively modest associations with both outcomes (Table 2).

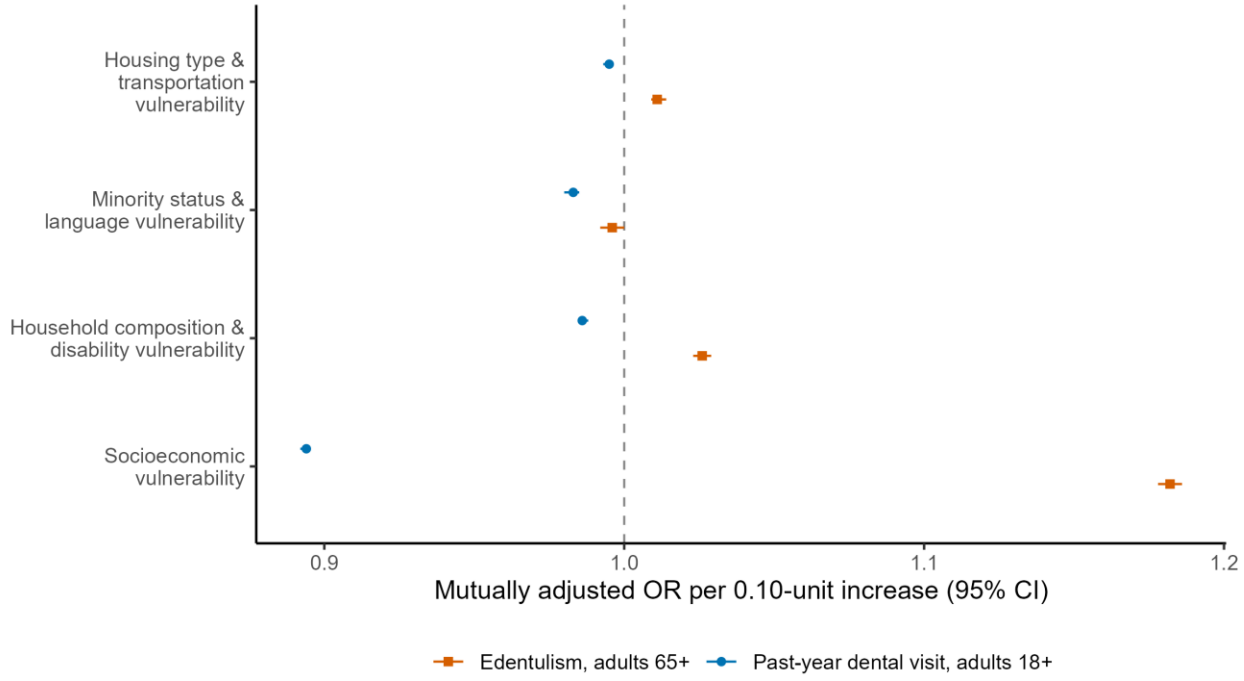
Table 2. Independent associations of Social Vulnerability Index domains with oral health outcomes

Vulnerability dimension	Edentulism, OR per 0.10 (95% CI)	Past-year dental visit, OR per 0.10 (95% CI)
Socioeconomic	1.182 (1.178–1.186)	0.894 (0.892–0.895)

Household composition & disability	1.026 (1.023–1.029)	0.986 (0.985–0.988)
Minority status & language	0.996 (0.992–1.000)	0.983 (0.980–0.985)
Housing type & transportation	1.011 (1.009–1.014)	0.995 (0.993–0.996)

All four SVI domains were entered simultaneously into a single mutually adjusted fractional logit model for each outcome, together with state fixed effects and county-clustered standard errors. Domains represent national percentile ranks of the corresponding CDC/ATSDR themes, with higher values indicating greater vulnerability. CI, confidence interval; OR, odds ratio.

Figure 2. Odds ratios per 0.10-unit increase, with 95% confidence intervals, for each vulnerability dimension and each outcome.



Estimates derive from one model per outcome containing all four dimensions. The dashed vertical line marks an odds ratio of 1.

Geographic variation in oral health outcomes

Variance decomposition demonstrated markedly different geographic patterns for the two oral health outcomes. The reported percentages represent the proportion of total variance attributable to each geographic level, after accounting for neighborhood social vulnerability. For edentulism, 65% of the total variance occurred between census tracts within the same county, compared with

9% between counties within the same state and 26% between states. In contrast, variation in past-year dental visits occurred predominantly between states, which accounted for 75% of the total variance, whereas 22% occurred between census tracts within the same county and 2% between counties within states (percentages may not sum to 100 because of rounding).

Robustness analyses

Alternative measures of neighborhood deprivation and alternative SVI ranking frameworks yielded results that were consistent with the primary analysis (Table 3). Models using the Social Deprivation Index (SDI) produced estimates that were very similar to those obtained using the primary SVI measure. Models using the Area Deprivation Index (ADI) also demonstrated associations in the same direction. Re-ranking census tracts using within-state rather than national SVI percentiles likewise produced estimates that were similar to those of the primary analysis.

Table 3. Sensitivity analyses using alternative neighborhood deprivation measures and SVI ranking frameworks

Measure and ranking frame	Edentulism, OR per 0.10 (95% CI)	Past-year dental visit, OR per 0.10 (95% CI)
SVI, ranked nationally (primary)	1.177 (1.170–1.185)	0.881 (0.878–0.884)
SDI, ranked nationally	1.179 (1.171–1.188)	0.884 (0.880–0.888)
ADI, ranked nationally	1.158 (1.143–1.173)	0.912 (0.900–0.923)
SVI, ranked within state	1.179 (1.173–1.184)	0.891 (0.887–0.894)

Fractional logit models were fitted to census tracts with complete data across all deprivation measures (n = 81,846; 98.4% of the analytic sample), with county-clustered standard errors. The primary SVI estimates in this table are re-estimated on this complete-case sample so that all rows are compared on identical tracts. ADI, Area Deprivation Index; SDI, Social Deprivation Index; SVI, Social Vulnerability Index.

Association of state Medicaid adult dental coverage with utilization and disease

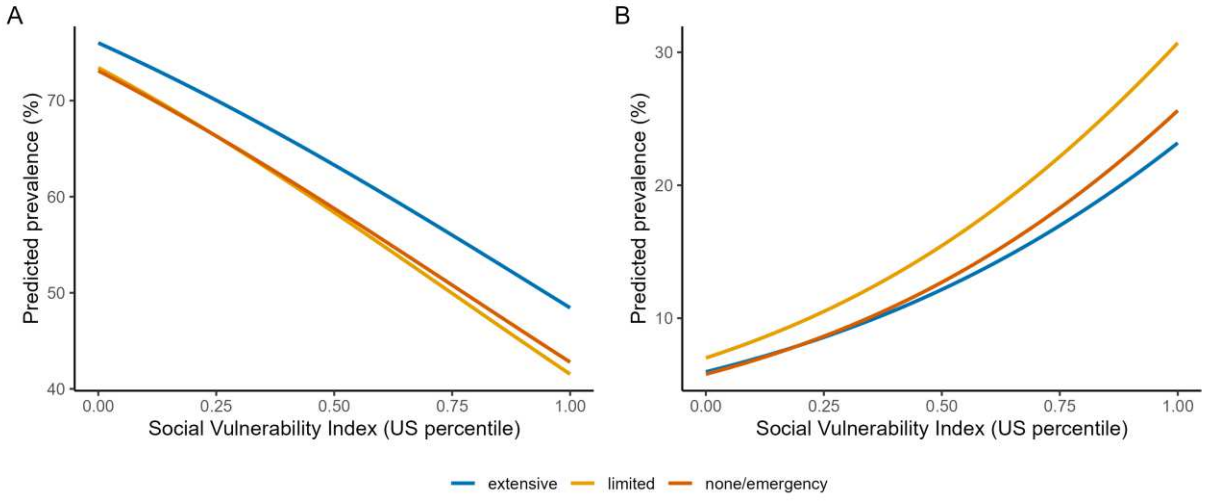
More generous state Medicaid adult dental benefits were associated with higher overall dental care utilization. Population-weighted prevalence of past-year dental visits increased from 57.8% in states providing no benefit or emergency-only coverage, to 60.3% in states with limited benefits, to 63.5% in states with extensive benefits. However, there was no statistically

significant evidence that the association between neighborhood social vulnerability and past-year dental visits differed across coverage categories (joint interaction P = 0.15); odds ratios per 0.10-unit increase in SVI percentile were 0.879, 0.873, and 0.886 in states with no or emergency-only, limited, and extensive benefits, respectively (Figure 3).

We also examined edentulism in relation to coverage. Because Medicaid benefits available in 2022 would not be expected to affect tooth loss accumulated over prior decades, edentulism served as a comparison outcome. A modest interaction was observed for edentulism (joint interaction P = 0.013); this association is unlikely to reflect an effect of current coverage and may instead reflect other differences between states.

Finally, state Medicaid coverage category accounted for only a small share of the substantial between-state variation identified above, explaining 7.2% of the between-state variance in past-year dental visits and 9.5% for edentulism.

Figure 3. Model-predicted prevalence of (A) past-year dental visits and (B) edentulism across the Social Vulnerability Index, by 2022 state Medicaid adult dental coverage category.



Lines represent model-predicted prevalence from fractional logit models. Separate lines correspond to states with no or emergency-only, limited, and extensive Medicaid adult dental coverage.

Discussion

In this national analysis of 83,143 U.S. census tracts, greater social vulnerability was associated with higher modeled prevalence of edentulism among older adults and lower modeled prevalence of past-year dental visits among adults. These gradients persisted after adjustment for state fixed effects, and socioeconomic vulnerability showed the strongest associations when the four SVI domains were considered together. Residual variation in edentulism occurred predominantly among tracts within counties, whereas variation in dental visits was concentrated between states. More extensive Medicaid adult dental benefits were associated with higher overall utilization, but there was no statistically significant evidence that the vulnerability gradient in dental visits differed across coverage categories.

Our findings agree with earlier research linking neighborhood disadvantage to tooth loss. Chong and Gansky reported a strong inverse correlation between neighborhood advantage, measured using the Healthy Places Index, and edentulism among California seniors (17). Nationally, Liu and colleagues found that greater cumulative environmental burden was associated with higher edentulism prevalence, particularly in more socially vulnerable neighborhoods (16). Examining dental visits alongside edentulism distinguishes recent contact with services from accumulated tooth loss. Vulnerable neighborhoods had less favorable outcomes in both respects, although the different age groups and time periods represented by these measures preclude interpreting current nonattendance as the cause of observed tooth loss.

The continuous gradients suggest that oral health inequalities extend beyond a small group of exceptionally disadvantaged neighborhoods. Directing resources toward the most vulnerable communities may address the greatest apparent need, but a single eligibility threshold could overlook differences elsewhere in the distribution. The persistence of these gradients within states also means that statewide averages provide an incomplete picture of inequality. Monitoring should examine the distribution of utilization and disease burden across communities, alongside overall levels.

The socioeconomic findings point to affordability as an important consideration in assessing these communities. Financial barriers may affect whether residents seek care, complete recommended treatment, or can afford tooth-preserving alternatives (4,7). Our analysis did not

measure those decisions, but the association with both utilization and edentulism supports examining barriers throughout treatment, beyond initial attendance. The tract-level data cannot determine how much of the observed pattern reflects residents' individual resources and how much reflects neighborhood conditions.

Racial and ethnic minority status and language vulnerability remained associated with lower dental utilization, but its association with edentulism was close to null after adjustment. This differs from the positive associations between racial segregation and edentulism reported in California (17). However, population composition and language are not equivalent to residential segregation, and our estimates condition on socioeconomic vulnerability and the other SVI domains. Adjustment may account for some pathways through which structural inequities are expressed. The household characteristics and disability domain and the housing type and transportation domain showed smaller associations after mutual adjustment. Tract-level indicators such as vehicle access may not fully capture travel burden, which also depends on provider locations (8). The domain estimates therefore describe conditional associations rather than rank the causal importance of racial inequities, disability, transportation, or economic conditions.

For edentulism, the substantial residual variation among tracts within the same county shows how county summaries can conceal local differences in accumulated tooth loss. Dental visits had a different pattern, with a larger share of residual variation between states. Neighborhood vulnerability alone therefore does not capture the geographic distribution of utilization, raising questions about the broader insurance and service environments in which care is obtained. These variance shares describe modeled outcomes after adjustment for SVI; they do not identify the causes of geographic differences or establish where interventions would be most effective.

Higher dental visit prevalence in states with extensive Medicaid benefits was consistent in direction with Decker and Lipton's finding that adult dental coverage was associated with increased attendance, with larger associations at higher payment rates to dentists (26). We found no statistically significant interaction between coverage category and vulnerability for dental visits. This result concerns differences in the association on the modeled logit scale. It does not

establish that absolute disparities were equivalent across coverage categories or that coverage expansion cannot improve equity.

Wehby and colleagues found that Medicaid expansions with extensive dental benefits narrowed racial and ethnic disparities among newly eligible low-income adults (27). Their analysis examined policy changes among adults directly affected, whereas ours compared neighborhood gradients in utilization among all adults across states grouped by their 2022 benefit categories. Effects concentrated among beneficiaries could be diluted in a population-wide outcome. Broad benefit categories also do not measure enrollment, provider participation, or whether covered services are available where residents seek care. These differences help explain why the analyses need not produce the same conclusions about disparities.

Current Medicaid coverage is particularly difficult to interpret in relation to edentulism, which reflects experiences accumulated over decades. Its association with coverage category may reflect historical benefits, population composition, or other state characteristics. The edentulism comparison raises these possibilities but cannot distinguish among them. Similarly, the modest reductions in between-state variance after adding coverage category indicate that the classification captured only a small portion of the remaining state differences. They do not estimate how much inequality would be eliminated by expanding benefits.

For service planning, local information on untreated disease, treatment completion, provider capacity, and residents' experiences is needed to establish what prevents people from obtaining care. Such information can help distinguish a shortage of services from difficulties accessing existing services. Vulnerability measures can guide that assessment but cannot determine whether a community's principal needs are preventive, restorative, or prosthodontic. A higher overall attendance rate also does not necessarily indicate that care is reaching those with the greatest need.

Strengths and Limitations

The study combines national coverage at census tract resolution with two complementary outcomes and comparisons of national and within-state associations. Similar findings using SDI, ADI, and alternative SVI rankings suggest that the overall pattern was not specific to one index

or ranking framework. These measures contain overlapping socioeconomic information, however, so their agreement does not provide independent validation. Unweighted aggregation of ADI block-group percentile ranks also masks within-tract differences and gives equal weight to block groups with different populations.

The principal limitation is the use of modeled outcomes. PLACES incorporates sociodemographic characteristics related to SVI, together with state and county effects (28). Associations with vulnerability may partly reflect shared inputs and estimation assumptions, while the geographic decomposition may partly reflect the structure of the source models. Alternative deprivation indices do not resolve these concerns. Our analyses also treated published prevalence estimates as observed outcomes without propagating their estimation uncertainty. Cluster-robust standard errors address specified geographic dependence but not this additional uncertainty, and spatial dependence may remain. Narrow confidence intervals therefore should not be taken as equivalent certainty about the underlying population relationships. The Medicaid comparisons are exploratory, consistent with CDC's caution against using PLACES estimates to evaluate policy or program effects (29).

The ecological, cross-sectional design also prevents individual-level or causal inference. Current residence may poorly represent the lifetime circumstances relevant to edentulism, and crude prevalence estimates may reflect differences in age composition. Neither outcome fully measures dental need: attendance does not establish that needed treatment was received, and edentulism excludes disease among adults retaining teeth. The Medicaid models remain susceptible to unmeasured state differences and lack information on individual eligibility, enrollment, and access to covered services. Longitudinal studies using individual utilization and clinical outcomes would help evaluate the mechanisms and policy questions raised by these findings.

Conclusions

Greater neighborhood social vulnerability was associated with lower dental utilization and higher edentulism across U.S. census tracts, with socioeconomic vulnerability showing the strongest mutually adjusted associations. These gradients remained evident within states and across alternative deprivation measures. Assessing oral health inequalities requires looking beyond state and county averages to the communities within them. Tract-level vulnerability measures can help

identify where more detailed assessment is needed, while local evidence is necessary to determine how best to improve access and address unmet care needs.

Abbreviations

ACS, American Community Survey; ADI, Area Deprivation Index; AME, average marginal effect; ATSDR, Agency for Toxic Substances and Disease Registry; BRFSS, Behavioral Risk Factor Surveillance System; CDC, Centers for Disease Control and Prevention; CI, confidence interval; FIPS, Federal Information Processing Standards; GAM, generalized additive model; MRP, multilevel regression with poststratification; OR, odds ratio; pp, percentage points; SDI, Social Deprivation Index; SVI, Social Vulnerability Index.

Declarations

Ethics approval and consent to participate

This study used publicly available, aggregate, de-identified data and did not involve human participants or identifiable private information. Therefore, it did not constitute human subjects research and ethics committee approval and informed consent were not required.

Consent for publication

Not applicable.

Availability of data and materials

All data analyzed in this study are publicly available from the sources described in the Methods. The corresponding URLs are provided in the reference list. The analysis code used in this study is publicly available on GitHub at https://github.com/cogaba/svi-oral-health-national. A permanently archived version of the repository is available on Zenodo: https://doi.org/10.5281/zenodo.21708856. Redistribution restrictions apply to the Area Deprivation Index, which is freely obtainable from the Neighborhood Atlas following registration (33).

Use of AI tools

AI-assisted tools were used to refine the language and clarity of the manuscript. The authors reviewed all content and take responsibility for the final text.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

CG: Conceptualization, methodology, data analysis, data curation, visualization, writing – original draft; writing – review and editing.

ALA: Conceptualization, interpretation of data, writing – original draft; writing – review and editing.

Both authors read and approved the final manuscript.

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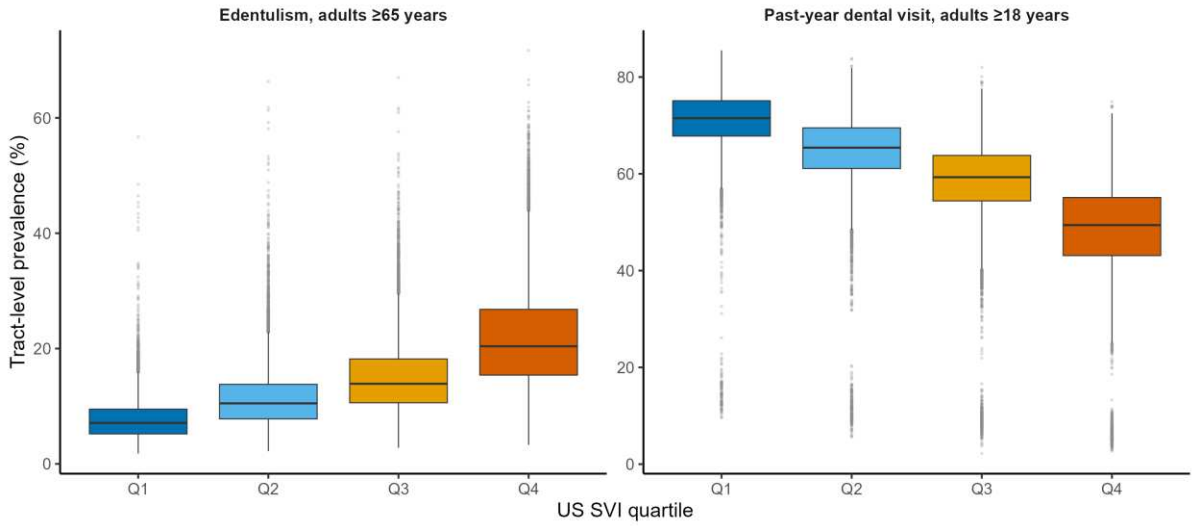
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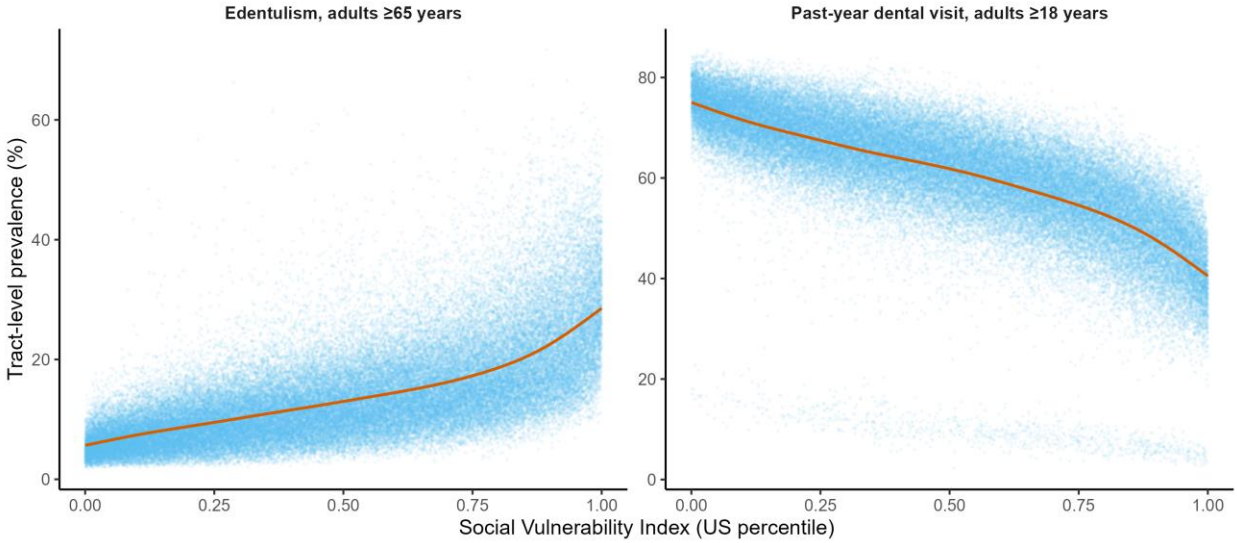
Supplementary figures

Figure S1. Distribution of tract-level prevalence of edentulism (adults aged ≥65 years) and past-year dental visits (adults aged ≥18 years) across national Social Vulnerability Index quartiles.



Quartile 1 includes census tracts at or below the 25th percentile of the national Social Vulnerability Index (SVI), quartile 2 includes tracts above the 25th through the 50th percentile, quartile 3 includes tracts above the 50th through the 75th percentile, and quartile 4 includes tracts above the 75th percentile. Boxes represent the interquartile range, the horizontal line within each box represents the median, whiskers extend to 1.5 times the interquartile range, and points represent observations beyond the whiskers. Q1, least vulnerable quartile; Q4, most vulnerable quartile

Figure S2. Tract-level prevalence of edentulism (adults aged ≥65 years) and past-year dental visits (adults aged ≥18 years) plotted against national Social Vulnerability Index percentile across 83,143 U.S. census tracts.



Each point represents one U.S. census tract. The solid line represents a generalized additive model (GAM) smooth, and the shaded band indicates the 95% confidence interval.