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Geographic Clustering Of Diabetic Lower-Extremity Amputations In Low-Income Regions Of California

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ABSTRACT For patients suffering from diabetes and other chronic conditions, a large body of work demonstrates income-related disparities in access to coordinated preventive care. Much less is known about associations between poverty and consequential negative health outcomes. Few studies have assessed geographic patterns that link household incomes to major preventable complications of chronic diseases. Using statewide facility discharge data for California in 2009, we identified 7,973 lower-extremity amputations in 6,828 adults with diabetes. We mapped amputations based on residential ZIP codes and used data from the Census Bureau to produce corresponding maps of poverty rates. Comparisons of the maps show amputation "hot spots" in lower-income urban and rural regions of California. Prevalence-adjusted amputation rates varied tenfold between high-income and low-income regions. Our analysis does not support detailed causal inferences. However, our method for mapping complication hot spots using public data sources may help target interventions to the communities most in need.

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For more than a century, detailed geographic analyses of illness patterns have underpinned major public health interventions, accounting in large part for the control of communicable diseases in developed countries.[1] Investigators have begun to explore similar strategies to reduce the impact of chronic diseases. The advent of geographic information systems and publicly available, population-based databases has created new opportunities to better understand causes and target interventions for chronic illness using geographic pattern analysis. We applied this approach to explore the relationship between socioeconomic status and diabetic lower-limb amputation in California.

Lower-limb amputation is a debilitating, harrowing, but often avoidable complication of diabetes. A prolonged chain of events generally precedes amputation, beginning with chronic inadequate diabetes control. This results in peripheral neuropathy and vascular disease that predispose patients to foot ulcers and infections that, if not treated, place the affected limb beyond salvage.[2]

Many opportunities exist to intervene along this pathway, and proactive team-based health care can substantially lower the incidence of amputations in patients with diabetes.[3–5] The Agency for Healthcare Research and Quality's selection of the lower-extremity amputation rate in patients with diabetes as an indicator of preventive care quality reflects an emerging consensus that amputation is avoidable with good care.[6]

Despite general consensus regarding optimal diabetes care, disparities in access to and receipt of such care persist.[7,8] Evidence shows that patients residing in low-income households receive lower-quality diabetes care, even where universal coverage for primary health care exists.[9,10]

Several studies have used mapping methods to assess diabetes-related processes and outcomes, including neurologic and renal complications,[11] diabetes prevalence and treatment resources,[12] and the effectiveness of targeted programs to improve the quality of diabetes care in ZIP codes with high minority populations.[13] Other studies have analyzed disparities in diabetic amputations but have generally focused on specific patient subgroups or settings.[10,14–17]

To our knowledge, no population-level studies have assessed the relationship between density of poverty and lower-limb amputation in the United States. We sought to understand the relationship between socioeconomic status and amputation rate among all adults with diabetes in California, using a detailed geographic analysis of existing administrative data sets.

Study Data And Methods

To achieve our objective of creating detailed, neighborhood-level maps of prevalence-adjusted diabetic amputation rates for comparison with income data, we relied on ZIP Code Tabulation Areas (ZCTAs) as the geographic unit of analysis. Defined by the Census Bureau, most such areas correspond closely to postal ZIP codes.[18]

Our study's primary outcome measure was the percentage of people with diabetes ages forty-five and older residing in each ZCTA in California who underwent one or more nontraumatic lower-extremity amputation in 2009. We chose this age group to focus our analyses on the population at greatest risk of undergoing potentially preventable amputations from complications of diabetes.

DATA We drew on three separate data sources to calculate the primary outcome measure, as described in greater detail in the online Appendix.[19] First, we identified nontraumatic amputation events associated with a diagnosis of diabetes in each ZIP code, using the California Office of Statewide Health Planning and Development's patient discharge and ambulatory surgery center databases. We used *International Classification of Diseases*, Ninth Revision (ICD-9), and *Current Procedural Terminology* codes to select relevant encounters containing amputations of interest and to exclude those associated with any indication of trauma (Appendix Section e-1).[19]

Second, to estimate diabetes prevalence, we used small-area estimates from the California Health Interview Survey, which assesses the prevalence of diabetes and other chronic illnesses in ZCTAs.[20–22] Last, we used 2003–09 American Community Survey pooled estimates of household income from the Census Bureau to obtain the percentage of households in each census tract that reported incomes below 200 percent of the federal poverty level.[23]

ANALYSIS To allow geographic linkage of the three data sets, we used previously validated crosswalk algorithms to convert ZIP codes[24] and census tracts[25] to ZCTAs. To increase the stability of the amputation rate estimates, we merged adjacent, demographically similar ZCTAs in which there were fewer than 3,000 people ages forty-five and older with diabetes (Appendix Section e-2 and Appendix Exhibit A1).[19] We successfully merged 373 of 461 low-population ZCTAs, and we dropped from the analysis the 88 ZCTAs that could not be merged. We report all further analyses, including map construction, using this final geographic unit—either a single ZCTA or merged ZCTAs—which we called a "neighborhood."

We generated maps showing prevalence-adjusted amputation rates for comparison with maps showing high poverty rates (based on the percentage of households reporting incomes below 200 percent of poverty) by applying geographic information systems analysis to the linked data sets at the neighborhood level. We constructed a map of California and separate maps for four major urban areas in the state: Los Angeles, Sacramento, San Diego, and San Francisco.

To complement the geographic analysis, we used simple linear regression to model the relationship between amputation rate and poverty at the neighborhood level, weighted by neighborhood population size. We tested more complex modeling procedures and determined that simple linear regression was appropriate (see Appendix Section e-3 and Appendix Exhibit A8).[19]

The use of confidential data for the study protocol was reviewed and approved by the Institutional Review Boards at the University of California, Los Angeles, and the Committee for the Protection of Human Subjects for the California Health and Human Services Agency.

LIMITATIONS Our analysis had several limitations. Its scope was limited to describing and quantifying the association between poverty and amputation rates based on geographic distribution. We lacked individual-level income data, and because ours was an ecological study, we could not link income and amputation event data.

We had access to data on some patient characteristics (Exhibit 1). However, we did not apply multivariate methods to model causality because the available public data sets lacked many potentially important explanatory variables at the patient, provider, and neighborhood levels. We were unable to model the likelihood of amputa-

tion at the individual level, and our analysis did not address the direct effects of the many factors that may be associated with amputation in people with diabetes. Neither our geographic analysis nor our regression results supported direct inferences about the causes of observed higher amputation rates in lower-income areas. Other work has assessed ethnic disparities in diabetes outcomes with mixed findings,[26] and there is a demonstrated association between social determinants of health and adverse diabetes outcomes.[27] These factors may contribute to the income-related disparities that our study found.

Each database used in our analysis has inherent limitations. The California Health Interview Survey and the Census Bureau's American Community Survey have limitations in accuracy that are characteristic of large, population-based surveys. Furthermore, our diabetes prevalence estimates, which are based on self-reported survey data, likely underestimated diabetes rates because of undiagnosed cases.[28] In addition, our tally of diabetic amputations using hospital discharge and ambulatory surgical data from the California Office of Statewide Health Planning and Development depended on accurate discharge coding by hospitals and ambulatory surgery centers, which could vary.

Despite our effort to deduplicate the data by limiting our analysis to the most anatomically proximal amputation for each person, our deduplication process was distinct for each of the data sets from the California Office of Statewide Health Planning and Development. Therefore, we may have included people twice if they underwent amputations in both inpatient and ambulatory surgery settings. However, the overall contribution of ambulatory procedures was small relative to the total.

Our analysis did not capture amputation procedures performed in Veterans Health Administration hospitals and freestanding surgical centers not associated with hospitals, because these facilities are not included in the California Office of Statewide Health Planning and Development data sets that we used. However, given patients' demographic characteristics and procedure volumes at these centers, we believe that the lack of data from these sources was unlikely to substantially bias our results.

In our regression analysis, we treated each neighborhood independently, not accounting for the potential correlation between neighborhoods that were in close geographical proximity. Finally, the crosswalk algorithms that allow the conversion of postal ZIP codes and census tracts to ZCTAs may contain errors, although they have been validated in other settings.[24,25]

EXHIBIT 1

Characteristics Of All People With Diabetes Ages Forty-Five And Older In California And Of Those Who Had One Or More Nontraumatic Amputation In 2009

Characteristic	All people with diabetes (%)	People with an amputation (%)
AGE (YEARS)		
45–64	69.8	53.0
65–79	22.4	32.9
80 or more	8.1	14.1
SEX		
Male	49.6	68.6
RACE OR ETHNICITY		
White	42.3	42.9
Black	5.6	12.6
Hispanic	36.8	36.7
Asian or Pacific Islander	12.4	4.8
Native American	0.6	0.6
Other	2.2	1.9
Unknown	0.0	0.5
LANGUAGE SPOKEN		
English	86.2	79.1
Spanish	9.2	17.1
Asian or Pacific Island language	1.6	1.4
Other	3.0	0.9
Unknown	0.0	1.5

SOURCE Authors' analysis of data from California Health Interview Survey, CHIS 2009 adult public use file (Note 29 in text), and from the 2009 patient discharge data set of the California Office of Statewide Health Planning and Development. **NOTES** "All people with diabetes" are adults in California ages forty-five or older who have diabetes based on self-reported survey data. "People with an amputation" are adults ages forty-five and older with at least one nontraumatic lower-extremity amputation associated with a diagnosis of diabetes in an inpatient hospital or ambulatory surgery center in California.

Study Results

We identified 7,973 diabetic lower-extremity amputations in California during 2009. Of these, 7,205 took place during an inpatient hospitalization and 768 (9.6 percent) were performed in hospital-affiliated outpatient surgery centers. We excluded 1,145 amputations in people who experienced more than one amputation during the same year, including only the most recent—most anatomically proximal—amputation in these cases. This left 6,828 people (6,094 inpatients and 734 outpatients) who experienced at least one amputation related to diabetes in the study period.

After we merged adjacent small-population ZCTAs as described above, we were left with 1,395 neighborhoods for mapping and regression analysis. These neighborhoods collectively contained a population of 1.867 million people ages forty-five and older with diabetes (80 percent of the California population of people with diabetes)[29] and 6,763 people who underwent at least one amputation. We excluded 65 people who resided in small-population ZCTAs that could not be merged into neighborhoods (Ap-

pendix Section e-2).[19]

Exhibit 1 displays the demographic characteristics of all people with diabetes ages forty-five and older in California (based on the California Health Interview Survey), and of people ages forty-five and older who underwent at least one diabetes-related nontraumatic lower-extremity amputation (as recorded in Office of Statewide Health Planning and Development data). Descriptive analysis indicated that compared to the overall population of adults with diabetes, those who underwent a nontraumatic lower extremity amputation were more commonly male, older than sixty-five, black, and non–English speaking.

A comparison of neighborhood-level maps of Los Angeles County that show prevalence-adjusted amputation rates per 1,000 people ages forty-five and older with diabetes (Exhibit 2) and low-income household density (Exhibit 3) revealed hot spots of amputation in lower-income areas (for maps of other parts of California, see Appendix Exhibits A2–A5).[19] The amputation rate for people with diabetes in low-income neighborhoods (those in which more than 40 percent of households have incomes below 200 percent of poverty) is roughly double the rate for people in higher-income neighborhoods (those in which fewer than 10 percent of households have incomes below 200 percent of poverty) (Exhibit 4).

We found similar relationships in California as a whole (Appendix Exhibit A2).[19] These relationships did not change appreciably in sensitivity analyses that excluded toe amputations or that considered only below-knee or only above-knee amputations (Appendix Exhibits A6 and A7).[19]

Discussion

Neighborhoods with high amputation rates often cluster geographically into hot spots that correspond with areas where there is a high concentration of low-income households. Our regression analysis confirmed the patterns observed on the maps, which shows a strong association between diabetic lower-extremity amputation rate and density of low-income households in neighborhoods in both urban and rural California. Amputation rates varied tenfold between the highest- and lowest-income neighborhoods in the state.

Our results parallel the findings of a recent study demonstrating that poverty and diabetes each contribute independently to vision loss in the United States.[30] The results are also similar to findings from a recent observational study in Finland. That study demonstrated a significant association between diabetic lower-extremity amputation rate and socioeconomic status, with an approximately twofold increase in amputation rate from lowest to highest socioeconomic status strata, despite universal access to health services.[10]

A complex web of patient, provider, social, and delivery system factors underlies higher amputation rates in poor communities.

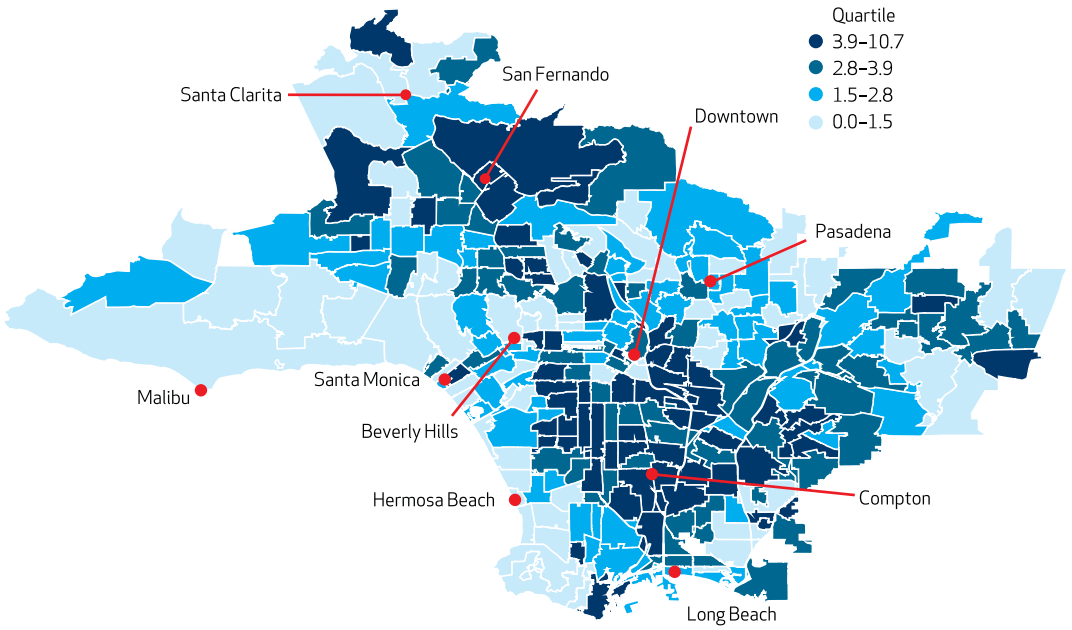
We could not determine the relative contributions of the many possible explanatory factors for the observed disparities, and future research should explore the underlying causes. Many possible sources of outcome disparities exist, including differences in patients'[31] or providers'[8] beliefs, behaviors, and characteristics; health system factors;[31,32] and social determinants of health.[27]

A substantial literature suggests that impaired access to ambulatory systems that provide comprehensive chronic disease care constitutes an important contributing factor to less favorable outcomes among low-income populations.[33] Patients living in low-income neighborhoods are more likely to be treated at safety-net hospitals, which are underresourced, compared to better-supported academic or community hospitals, and which struggle to provide high-quality care.[32]

Furthermore, there is some evidence of differing practice patterns with regard to lower-extremity amputation by setting of care and by physician specialty.[34] A study that found higher odds of amputation for black patients compared to whites identified a high degree of segregation of care and suggested that less access to vascular surgery specialists, treatment in settings without a high volume of experience with revascularization procedures, and discrepancies in provider decision making are important factors that contribute to disparities in outcomes.[34] Hospitals caring for a high volume of lower-income patients may have a greater reliance on amputation—compared to less invasive, limb-sparing treatment approaches—for a variety of reasons,

EXHIBIT 2

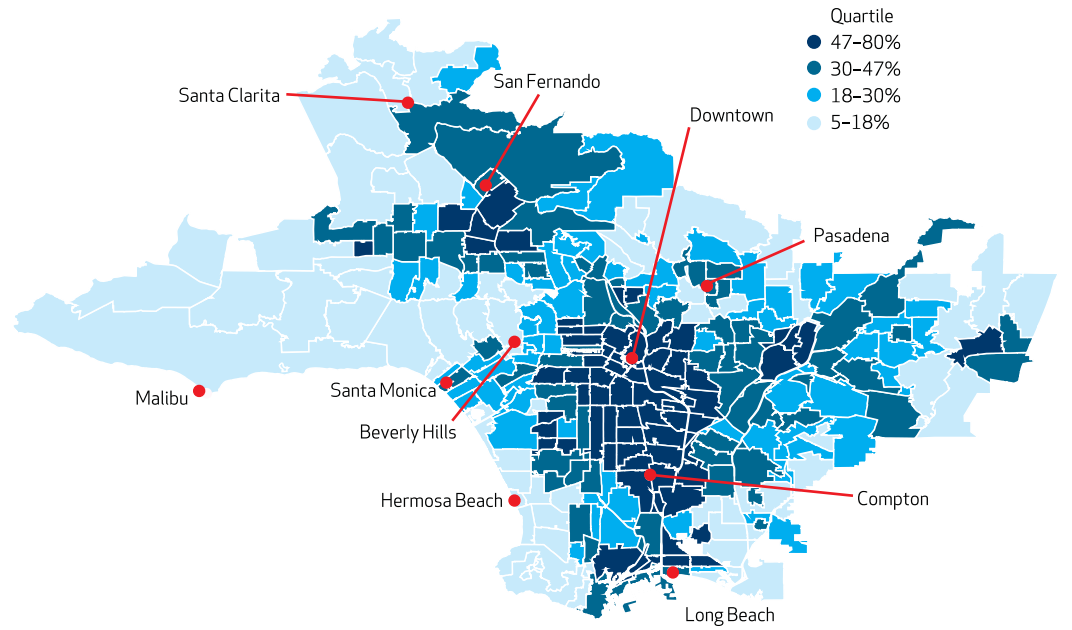
Rates Of Lower-Extremity Diabetic Amputations Per 1,000 Adults Ages Forty-Five And Older With Diabetes, Los Angeles County, 2009



SOURCE Authors' analysis of data from California Health Interview Survey, CHIS 2009 adult public use file (Note 29 in text), and from the 2009 patient discharge and ambulatory surgery center data sets of the California Office of Statewide Health Planning and Development. **NOTES** Data are mapped at the neighborhood level (each neighborhood is either a ZIP Code Tabulation Area [ZCTA] or merged ZCTAs, as explained in the text) and represent the rate of nontraumatic lower-extremity amputations associated with a diagnosis of diabetes per 1,000 people with diabetes ages forty-five and older. The rates for the region are presented in quartiles.

EXHIBIT 3

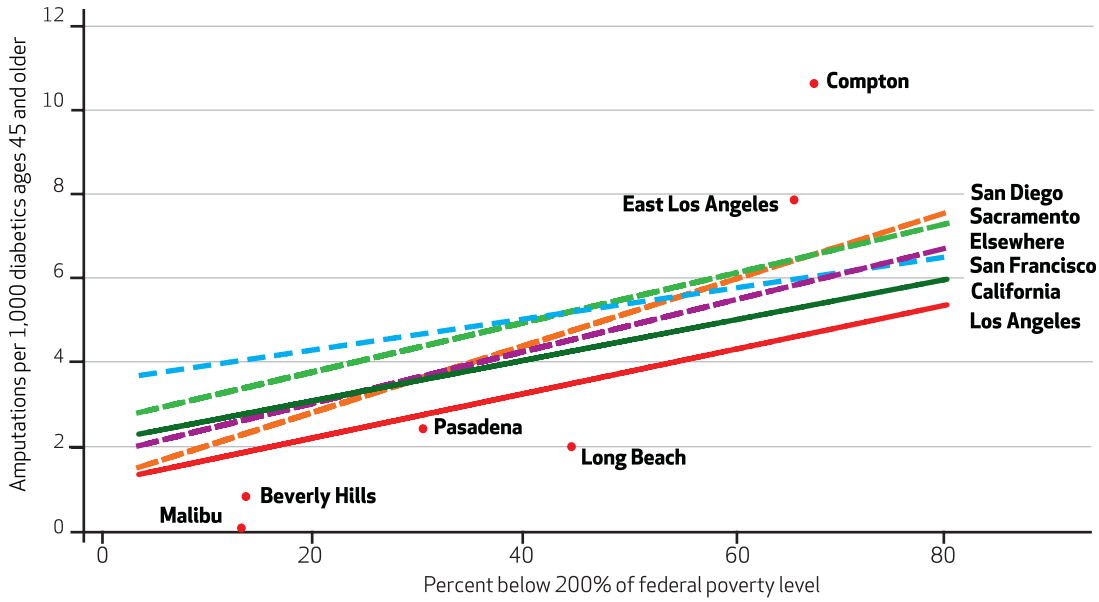
Proportion Of Households With Income Below 200 Percent Of The Federal Poverty Level, Los Angeles County, 2003–09



SOURCE Authors' analysis of data from 2003–09 American Community Survey pooled estimates of household income from the Census Bureau. **NOTES** Data are mapped at the neighborhood level (each neighborhood is either a ZIP Code Tabulation Area [ZCTA] or merged ZCTAs, as explained in the text). The proportions for the region are presented in quartiles.

EXHIBIT 4

Association Between The Low-Income Proportion Of The Population And The Amputation Rate Among Adults In California With Diabetes, 2009



SOURCE Authors' analysis of data from California Health Interview Survey, CHIS 2009 adult public use file (Note 29 in text), and from the 2009 patient discharge and ambulatory surgery center data sets of the California Office of Statewide Health Planning and Development, and 2003–09 American Community Survey pooled estimates of household income from the Census Bureau. **NOTES** Each neighborhood is either a ZIP Code Tabulation Area (ZCTA) or merged ZCTAs, as explained in the text. Fitted lines are provided for each geographic region of interest. "Elsewhere" denotes elsewhere in California besides San Diego, Sacramento, San Francisco, and Los Angeles. The plot represents a simple association and was not adjusted for possible confounders.

possibly including a lack of resources on the part of both the patients and the hospital to pursue options other than amputation.

The downward secular trends in diabetes complications that have been observed during the past two decades demonstrate that substantial gains are possible in reducing diabetes-related morbidity.[35] A recent analysis found a reduction in amputation rates per 10,000 people with diabetes in the United States from fifty-eight in 1990 to twenty-eight in 2010.[36] However, it is apparent that this decrease has not resolved disparities in this debilitating outcome.

Policy Implications

The finding that people living in lower-income areas bear a disproportionate share of disability and disfigurement from amputation is deeply disturbing in a society that espouses equality and that outspends all other nations on health care for its more affluent citizens. We believe that our findings dictate a vigorous response from the health policy community.

A complex web of patient, provider, social, and delivery system factors underlies higher amputation rates in poor communities. As a result, a successful policy response will likely need to employ multiple strategies, including addressing social determinants of health, engaging patients, and deploying multidisciplinary primary care facilities to improve access in underserved urban and rural communities.

The recent expansion of both private insurance and Medicaid enrollment under the Affordable Care Act addresses one dimension of access disparity. However, the potential benefits may be blunted by the undersupply of primary care providers in low-income neighborhoods.[37] A recent experiment in Oregon found substantial increases in primary care and pharmaceutical use among new Medicaid beneficiaries, although it did not demonstrate improvements in health outcomes.[38,39]

Our study contributes to the small but growing literature that demonstrates the utility of geographic information systems in combination with public data for identifying preventable disease hot spots and focusing interventions on these communities. In addition, the study lends urgency to the search for neighborhood-level solutions to reduce the disproportionate burden of lower-extremity amputation in low-income communities.

Conclusion

People with diabetes who live in lower-income neighborhoods in California have higher rates of lower-extremity amputation than those who reside in more affluent areas. Our hot-spot method of displaying complication rates may assist providers and public health agencies in targeting interventions to the populations that are the most affected. ■

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NOTES

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