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ORIGINAL RESEARCH

Geographic and Socioeconomic Disparities in Major Lower Extremity Amputation Rates in Metropolitan Areas

Alexander C. Fanaroff, MD, MHS; Lin Yang, MS; Ashwin S. Nathan, MD, MS; Sameed Ahmed M. Khatana, MD, MPH; Howard Julien, MD, MPH; Tracy Y. Wang, MD, MSc, MHS; Ehrin J. Armstrong, MD; Diane Treat-Jacobson, PhD, RN; Julia D. Glaser, MD; Grace Wang, MD, MSCE; Scott M. Damrauer, MD; Jay Giri, MD, MPH; Peter W. Groeneveld, MD, MS

BACKGROUND: Rates of major lower extremity amputation in patients with peripheral artery disease are higher in rural communities with markers of low socioeconomic status, but most Americans live in metropolitan areas. Whether amputation rates vary within US metropolitan areas is unclear, as are characteristics of high amputation rate urban communities.

METHODS AND RESULTS: We estimated rates of major lower extremity amputation per 100 000 Medicare beneficiaries between 2010 and 2018 at the ZIP code level among ZIP codes with ≥100 beneficiaries. We described demographic characteristics of high and low amputation ZIP codes, and the association between major amputation rate and 3 ZIP code–level markers of socioeconomic status—the proportion of patients with dual eligibility for Medicaid, median household income, and Distressed Communities Index score—for metropolitan, micropolitan, and rural ZIP code cohorts. Between 2010 and 2018, 188 995 Medicare fee-for-service patients living in 31 391 ZIP codes with ≥100 beneficiaries had a major lower extremity amputation. The median (interquartile range) ZIP code–level number of amputations per 100 000 beneficiaries was 262 (75–469). Though nonmetropolitan ZIP codes had higher rates of major amputation than metropolitan areas, 78.2% of patients undergoing major amputation lived in metropolitan areas. Compared with ZIP codes with lower amputation rates, top quartile amputation rate ZIP codes had a greater proportion of Black residents (4.4% versus 17.5%, $P<0.001$). In metropolitan areas, after adjusting for clinical comorbidities and demographics, every $10 000 lower median household income was associated with a 4.4% (95% CI, 3.9–4.8) higher amputation rate, and a 10-point higher Distressed Communities Index score was associated with a 3.8% (95% CI, 3.4%–4.2%) higher amputation rate; there was no association between the proportion of patients eligible for Medicaid and amputation rate. These findings were comparable to the associations identified across all ZIP codes.

CONCLUSIONS: In metropolitan areas, where most individuals undergoing lower extremity amputation live, markers of lower socioeconomic status and Black race were associated with higher rates of major lower extremity amputation. Development of community-based tools for peripheral artery disease diagnosis and management targeted to communities with high amputation rates in urban areas may help reduce inequities in peripheral artery disease outcomes.

Key Words: amputation ■ healthcare disparities ■ peripheral artery disease

Major limb amputation is a late and serious complication of peripheral artery disease (PAD) with substantial associated morbidity and mortality.[1–3] Adverse clinical events such as lower extremity amputation can be delayed and/or prevented by timely and aggressive medical and behavioral change therapies, as well as revascularization. However, lack of access to subspecialty PAD care may both delay PAD

Correspondence to: Alexander C. Fanaroff, MD, MHS, Perelman Center for Advanced Medicine, 3400 Civic Center Blvd, Philadelphia, PA 19104. E-mail: alexander.fanaroff@pennmedicine.upenn.edu

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CLINICAL PERSPECTIVE

What Is New?

- Though amputation rates are higher in rural areas, more than three quarters of patients with peripheral artery disease undergoing lower extremity amputation live in metropolitan areas.
- In metropolitan areas, ZIP codes with markers of low socioeconomic status and greater proportions of Black people had amputation rates comparable to those in rural communities.

What Are the Clinical Implications?

- Geographic proximity to subspecialty peripheral artery disease care within metropolitan areas is not adequate to ensure access to high-quality care.
- Strategies targeted to communities with high amputation rates in urban areas are needed to reduce disparities in peripheral artery disease outcomes.

Nonstandard Abbreviations and Acronyms

DCI	Distressed Communities Index

diagnosis, hindering efforts at aggressive primary and secondary prevention, and limit limb salvage efforts (including revascularization) in advanced disease.[4]

Geographic variation in amputation rate among US patients with PAD has been described on a regional and state-by-state level,[5,6] but inequities in the social determinants of health affecting PAD outcomes function at the local level. Across multiple conditions, health outcomes are worse in communities with low socioeconomic status (SES) and high proportions of Black residents.[7] Prior research has observed an association between residence in a rural community with markers of low SES and major lower extremity amputation[8–10]; however, <20% of Americans live in rural areas. If there is a similar association between community-level markers of racial composition and SES and amputation rate in metropolitan areas, then low SES urban communities with high proportions of Black residents will represent important targets for health services interventions intended to improve PAD diagnosis and treatment and reduce inequities.

In this study, we used national claims data to describe ZIP code–level variation in rates of major amputation among Medicare beneficiaries, described characteristics of high amputation rate ZIP codes, and assessed whether selected ZIP code–level measures of low SES and racial composition were associated with higher rates of amputation, focusing on metropolitan communities.

METHODS

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Study Cohort and Definitions

Using Medicare 100% Hospital Data Claims and annual Medicare Beneficiary Summary (enrollment) files, we used *International Classification of Diseases, Ninth and Tenth Edition* (*ICD-9* and *ICD-10*) procedure codes to identify Medicare fee-for-service patients with major lower extremity amputation between 2010 and 2018 (Table S1). Major lower extremity amputation was defined as above or below the knee amputation; toe and forefoot amputations were excluded. Because we wanted to capture PAD-related amputations, including patients who did not undergo vascular testing before amputation and were thus not directly diagnosed with PAD, we limited our exclusions to patients with codes specifically indicating a non-PAD reason for amputation, such as the presence of trauma, lower extremity malignancy, pressure ulcer, or venous ulcer during the same hospitalization as their amputation.[11] As a sensitivity analysis, we also defined a "stricter" cohort with both major lower extremity amputation plus a diagnosis of PAD.[5]

Patient ZIP code of residence was obtained from Medicare enrollment files. Patients were assigned to Core-Based Statistical Areas using ZIP code classifications published by the US Department of Housing and Urban Development. Core-Based Statistical Areas are geographic areas consisting of an urban center along with surrounding counties socioeconomically linked to the urban center by commuting. The US Office of Management and Budget defines metropolitan areas as those with an urban cluster of at least 50 000 people and micropolitan areas as those with urban clusters between 10 000 and 50 000 people. ZIP codes that could not be linked to metropolitan or micropolitan Core-Based Statistical Areas were defined as rural. To avoid anomalies related to small numbers of patients, we excluded ZIP codes with <100 Medicare fee-for-service beneficiaries (n=6231); the analytic cohort thus comprised 31 391 ZIP codes with ≥100 fee-for-service beneficiaries. Core-Based Statistical Areas were used as the geographic unit defining metropolitan, micropolitan, and rural areas because they reflect commuting patterns and therefore are a reasonable surrogate for geographic access to subspecialty PAD care services.

We defined each ZIP code's SES by median household income. In secondary analyses, we defined ZIP code–level SES by Distressed Communities Index (DCI) and proportion of patients dual-eligible for Medicare and Medicaid. Median household income for each ZIP code was obtained from the Dartmouth Health Atlas (https://atlasdata.dartmouth.edu/folder/list_files/income_crosswalk). Dual-eligibility status was determined from Medicare enrollment files. DCI, a metric that combines 7 economic indicators (percent of population with high school diploma, housing vacancy rate, percent of adults not working, poverty rate, median income ratio, change in employment and change in business establishments) to generate a single index score from 0 (least distressed) to 100 (most distressed), was determined from crosswalk files (https://eig.org/dci). Unlike other composite metrics of SES, the DCI is available at the ZIP code level, the smallest geographic unit available in Medicare claims data. It is available for ZIP codes with >50 000 residents, and has been used in analyses examining the association between ZIP code–level SES and health outcomes.[12]

Statistical Analysis

We calculated the number of patients with major lower extremity amputations unrelated to trauma, malignancy, or venous/pressure ulcer per 100 000 Medicare fee-for-service beneficiaries for each ZIP code, and generated descriptive statistics. We then described ZIP code characteristics by quartile of amputation rate.

To visualize the location of high amputation ZIP codes, we divided ZIP codes into quartiles by amputation rate and plotted choropleth maps showing amputation rate by ZIP code and median income by ZIP code for metropolitan statistical areas with >2 million inhabitants as of 2010. We also plotted maps of amputation rate by ZIP code and majority Black resident ZIP codes for the county corresponding to the anchor city of each metropolitan statistical area with >2 million inhabitants.

To determine whether ZIP code–level racial characteristics and markers of SES were associated with major amputation, we first determined the association between proportion of Black residents in each ZIP code and amputation rate using a zero-inflated negative binomial model. We then performed multivariable zero-inflated negative binomial regressions with major amputations per 100 000 beneficiaries as the dependent variable and median household income, DCI, and proportion dual eligible as alternative SES independent variables in 3 distinct analyses. Analyses were performed at the ZIP code level, and additional independent variables included US census region (Midwest, Northeast, South, and West) and demographic and clinical characteristics of all beneficiaries within each ZIP code (including age, sex, self-reported race, and the proportion of patients with heart failure, hypertension, diabetes mellitus, prior stroke, and peripheral vascular disease). We repeated these analyses separately in metropolitan, micropolitan, and rural ZIP codes. We translated the negative binomial rate ratio outcomes into difference in amputations per 100 000 by setting all covariates aside from SES markers to their median values, using the negative binomial model output to calculate the model's predicted number of amputations per 100 000 in ZIP codes with median values for SES markers and values 1 unit higher than the median ($10 000 decrease in median income, 10-point increase in DCI, 1% increase in dual-eligible patients), and subtracting these values. We repeated this process, subtracting predicted number of amputations in ZIP codes with fifth percentile SES markers from those with 95th percentile markers. For all analyses, $P<0.05$ was considered statistically significant.

Statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC) and R Studio 1.3.959. The University of Pennsylvania institutional review board designated this study as exempt from review.

RESULTS

Characteristics of High Amputation Rate ZIP Codes

Between 2010 and 2018, 188 995 Medicare fee-for-service beneficiaries living in 31 391 ZIP codes with ≥100 Medicare beneficiaries underwent 222 956 major lower extremity amputations not associated with trauma, malignancy, or venous/pressure ulcers. The ZIP code mean (SD) number of amputations per

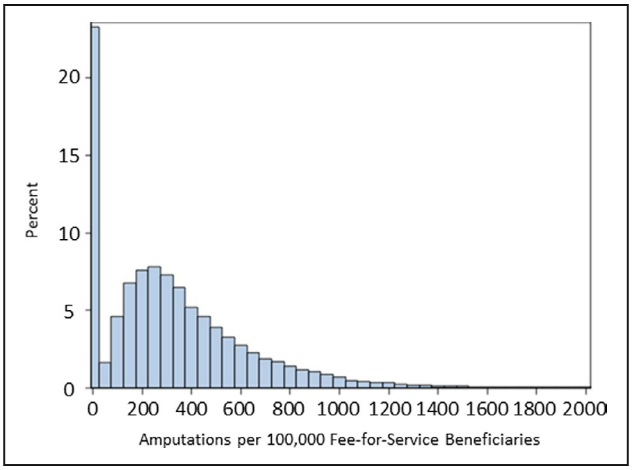

Figure 1. Distribution of amputation rates by ZIP code. ZIP code–level amputation rates ranged from 0 to 7080 major amputations per 100 000 Medicare fee-for-service beneficiaries. The mean number of amputations per 100 000 beneficiaries was 328; median was 262.

100 000 beneficiaries was 329 (331); the median number of amputations per 100 000 beneficiaries was 268 (interquartile range 83–472), and 20% of ZIP codes had no Medicare beneficiaries who underwent a major lower extremity amputation (Figure 1). A sensitivity analysis specifically including secondary codes denoting PAD revealed similar results (mean, 328; SD, 337; median, 262; 25th, 75th percentiles: 75, 469).

Compared with ZIP codes in the bottom quartile of amputation rate, top quartile ZIP codes were more often located in the South region of the United States (55.9% versus 26.1%; P<0.001), had a higher mean proportion of Black residents (17.5% versus 4.4%; P<0.001), a lower average median income ($42 046 versus $55 448; P<0.001), a greater mean proportion of residents with dual eligibility for Medicaid (16.1% versus 10.7%; P<0.001), and a higher mean DCI score (68.9 versus 42.2; P<0.001) (Table 1). ZIP codes in the highest amputation rate quartile also had higher rates of hypertension, diabetes mellitus, stroke, and peripheral vascular disease than those in the lowest amputation rate quartile. Among 7852 ZIP codes with top quartile amputation rates, 4477 (57.0%) were located in metropolitan areas, 1839 (23.4%) in micropolitan areas, and 1536 (19.6%) in rural areas.

In the 20 208 metropolitan ZIP codes, the unadjusted mean (SD) number of amputations per 100 000 beneficiaries was 315 (299), compared with 351 (354) in 6332 micropolitan ZIP codes and 363 (412) in 4851 rural ZIP codes (P<0.001). After adjusting for demographic, clinical, and socioeconomic characteristics of beneficiaries, amputations per 100 000 beneficiaries was 14.6% (95% CI, 14.4%–14.8%) lower in metropolitan areas and 4.0 (95% CI, 3.8%–4.3%) lower in micropolitan areas compared with rural areas. However, because there are more metropolitan ZIP codes and

Table 1. Characteristics of ZIP Codes by Quartile of Amputation Rate

	Lowest Quartile (7844 ZIP Codes; 0–82 Amputations per 100 000 Beneficiaries)	Second Quartile (7855 ZIP Codes; 83–268 Amputations per 100 000 Beneficiaries)	Third Quartile (7840 ZIP Codes; 269–471 Amputations per 100 000 Beneficiaries)	Top (7852 ZIP Codes; 472–7080 Amputations per 100 000 Beneficiaries)
US census region, n (%)				
Midwest	2509 (32.0)	2150 (27.4)	2293 (29.2)	1802 (22.9)
Northeast	1529 (19.5)	1783 (22.7)	1340 (17.1)	855 (10.9)
South	2049 (26.1)	2114 (26.9)	3117 (39.8)	4391 (55.9)
West	1757 (22.4)	1808 (23.0)	1090 (13.9)	804 (10.2)
Age, y	65.8 (2.8)	66.1 (2.3)	65.4 (2.3)	64.8 (2.5)
Male (%)	50.4 (4.6)	47.9 (3.3)	48.3 (3.4)	49.1 (4.0)
White (%)	87.7 (16.9)	86.0 (15.4)	83.2 (19.8)	71.9 (28.4)
Black (%)	4.35 (11.4)	3.74 (7.13)	7.60 (13.4)	17.5 (24.1)
Asian (%)	1.23 (3.87)	2.62 (6.28)	1.42 (4.02)	0.77 (2.74)
Hispanic (%)	3.61 (8.91)	4.52 (8.69)	5.10 (11.1)	6.14 (15.1)
Congestive heart failure (%)	22.6 (5.6)	22.9 (4.0)	24.5 (4.1)	25.9 (4.9)
Hypertension (%)	76.2 (6.3)	77.3 (4.4)	78.7 (4.3)	80.0 (5.0)
Diabetes mellitus (%)	31.5 (7.7)	31.6 (5.6)	35.2 (5.6)	38.5 (7.1)
Stroke (%)	7.9 (2.7)	8.1 (1.4)	8.4 (1.6)	8.8 (2.4)
Peripheral vascular disease (%)	15.0 (4.2)	15.6 (2.8)	16.6 (3.0)	17.3 (3.6)
Renal failure (%)	23.4 (5.7)	24.1 (4.0)	25.4 (4.2)	26.9 (5.3)
Ischemic heart disease (%)	38.8 (7.6)	39.2 (5.6)	40.9 (5.7)	41.5 (6.6)
Chronic kidney disease (%)	40.3 (6.8)	41.5 (4.8)	43.2 (5.1)	45.2 (6.5)
Hyperlipidemia (%)	55.9 (7.9)	57.9 (6.1)	57.5 (6.1)	56.4 (6.6)
Tobacco (%)	17.3 (7.9)	16.0 (6.1)	19.6 (6.2)	21.9 (7.2)
No. of Elixhauser comorbidities	4.8 (0.6)	4.9 (0.5)	5.1 (0.5)	5.3 (0.6)
Weighted AHRQ comorbidity score	11.6 (1.9)	11.9 (1.4)	12.2 (1.5)	12.7 (1.8)
Dual eligibility for Medicaid (%)	10.7 (8.6)	10.7 (8.2)	12.8 (8.3)	16.1 (10.1)
Median household income	$55 448 ($24 050)	$61 665 ($24 227)	$49 474 ($16 305)	$42 046 ($14 422)
Distressed Communities Index score	42.2 (27.3)	36.5 (26.5)	53.3 (26.2)	68.9 (24.5)

For all variables, unless otherwise indicated, shown is the ZIP code–level mean and SD. P for all row comparisons <0.001. Distressed Communities Index is a metric that combines 7 economic indicators (percent of population with high school diploma, housing vacancy rate, percent of adults not working, poverty rate, median income ratio, change in employment, and change in business establishments) to generate a single index score from 0 (least distressed) to 100 (most distressed). AHRQ indicates Agency for Healthcare Research and Quality.

metropolitan ZIP codes have more residents (ZIP code mean [SD] number of fee-for-service Medicare beneficiaries: metropolitan, 2387 [2600]; micropolitan, 1203 [1708]; rural, 641 [788]), 78.5% of patients undergoing amputations during the study period (n=148 327) resided in metropolitan ZIP codes.

Association Between Amputation Rate and Markers of Racial Composition

Of 1133 ZIP codes with ≥50% Black residents, 860 (75.9%) had top quartile amputation rates, compared with 5816 (21.9%) of 26 544 nonmajority Black ZIP codes; the mean (SD) amputation rate in majority Black ZIP codes was 712 (387) per 100 000 beneficiaries compared with 310 (299) per 100 000 beneficiaries in nonmajority Black ZIP codes (P<0.001).

On unadjusted analysis, for every 5 percentage point increase in a ZIP code's proportion of Black residents, there was a 5.9% (95% CI, 5.6%–6.1%) increase in number of amputations per 100 000 Medicare beneficiaries, corresponding to a difference of 22 amputations per 5 percentage point increase in proportion of Black residents, and a difference of 257 amputations between ZIP codes with fifth and 95th percentile proportions of Black residents. With the inclusion of demographic and clinical characteristics, as well as a marker of SES, the association between a ZIP code's proportion of Black residents and amputation rate was attenuated compared with the unadjusted analysis of the association between proportion of Black residents and amputation rate: In the model including median income, for example, each 5 percentage point increase in the proportion of Black residents was associated with a 2.7% (95% CI, 2.5%–3.0%) increase in number of amputations per 100 000 Medicare beneficiaries, corresponding to a difference of 10 amputations (Table 2). Results were similar for the models using DCI and proportion of patients dual eligible for Medicaid as the marker of SES.

There was similarly an association between proportion of Black residents and unadjusted amputation rate when metropolitan, micropolitan, and rural ZIP codes were examined separately, and these associations were again attenuated when demographic variables and markers of SES were included in the model. Looking specifically at cities anchoring metropolitan statistical areas with >2 million inhabitants, high amputation rate ZIP codes colocalized with majority Black ZIP codes (Figure 2 and Figures S1 through S3).

Association Between Amputation Rate and Markers of SES

When we examined the association between markers of SES and amputation, after adjusting for clinical and demographic comorbidities, a \$10 000 decrease in household income was associated with a 5.8% (95% CI, 5.4%–6.3%) increase in amputations per 100 000 beneficiaries, corresponding to a difference of 23 amputations per \$10 000 decrease in household income,

Table 2. Association Between Proportion of Residents of Black Race and Amputation Rate

	Change in Amputation Rate (95% CI) per 5% Change in Proportion of Black Residents, Unadjusted	Change in Amputation Rate (95% CI), per 5% Change in Proportion of Black Residents Adjusting for Demographic and Socioeconomic Characteristics
Overall	5.9% (5.6–6.1)	2.7% (2.5–3.0)
Metropolitan	6.8% (6.6–7.1)	2.5% (2.2–2.8)
Micropolitan	6.3% (5.7–7.0)	4.1% (3.3–4.9)
Rural	5.2% (4.4–5.9)	3.5% (2.6–4.4)

We used US Office of Management and Budget definitions of metropolitan, micropolitan, and rural areas: Metropolitan areas have an urban cluster of at least 50 000 people, micropolitan areas have urban clusters between 10 000 and 50 000 people, and rural areas lack an urban cluster with ≥10 000 people. In the adjusted model, covariates included US region (Midwest, Northeast, South, and West), median beneficiary age, median household income, and the proportion of beneficiaries with male sex, congestive heart failure, hypertension, diabetes mellitus, stroke, peripheral vascular disease, ischemic heart disease, chronic kidney disease, hyperlipidemia, and tobacco use. Results were similar when Distressed Communities Index and proportion of beneficiaries dual-eligible for Medicaid were entered into the model instead of median household income.

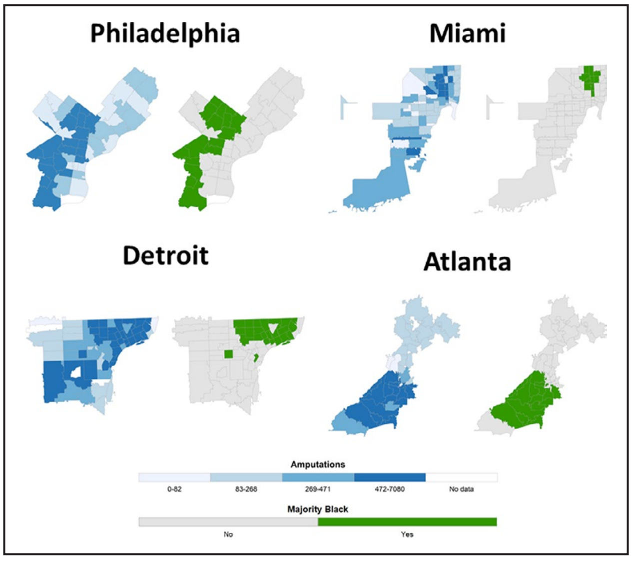

Figure 2. Colocalization of majority Black race and high amputation rate ZIP codes in 4 selected US cities.
Shown are ZIP code–level maps of amputations per 100 000 Medicare beneficiaries (unadjusted) in Philadelphia, Dade (Miami), Wayne (Detroit), and Fulton (Atlanta) counties with parallel maps indicating ZIP codes with ≥50% Black inhabitants. Majority Black ZIP codes colocalize with high amputation rate ZIP codes. Maps for all 29 cities anchoring metropolitan statistical areas with >2 million inhabitants are shown in Figures S5 through S8.

and a difference of 137 amputations between a ZIP codes with fifth and 95th percentile median household incomes (Table 2). A 10-point increase in DCI was associated with a 4.3% (95% CI, 3.9%–4.6%) increase in amputations per 100 000 beneficiaries, corresponding to a difference of 12 amputations. Each percentage point increase in the proportion of patients dual eligible for Medicaid was associated with a 0.1% (95% CI, 0.0%–0.3%) increase in amputations per 100 000 beneficiaries, corresponding to a difference of 0 amputations.

In metropolitan ZIP codes, the associations between ZIP code–level markers of SES and amputation rate were similar to the associations identified in all ZIP codes. After adjusting for clinical and demographic comorbidities, a $10 000 decrease in household income was associated with a 4.4% (95% CI, 3.9%–4.8%) increase in amputations per 100 000 beneficiaries, corresponding to a difference of 15 amputations, and a difference of 108 amputations between a ZIP codes with fifth and 95th percentile median household incomes. A 10-point increase in DCI was associated with a 3.8% (95% CI, 3.4%–4.3%) increase in amputations per 100 000 beneficiaries, corresponding to a difference of 12 amputations. Each percentage point increase in the proportion of dual-eligible patients was associated with a 0.1% (95% CI, 0.0%–0.2%) decrease in amputations per 100 000 beneficiaries, corresponding to a difference of 0 amputations. In micropolitan and rural ZIP codes, these associations were directionally similar but mostly smaller in magnitude (Table 3).

Across 30 metropolitan areas with populations >2 million people in 2010, 1287 ZIP codes had top quartile amputation rates, accounting for 28.8% of all top quartile ZIP codes, and all such metropolitan areas had at least 1 ZIP code in the top quartile. There was substantial ZIP code–level variability in amputation rates within individual large metropolitan areas. In many of these large metropolitan areas, there were 1 or more clusters of high-amputation rate ZIP codes colocalized with low SES neighborhoods within the urban core (Figure 3 and Figures S4 through S8).

DISCUSSION

In this analysis of a nationwide administrative database, we found substantial small-area geographic variation in rates of major lower extremity amputation, even within individual metropolitan areas. ZIP codes with a greater proportion of Black residents had higher amputation rates than ZIP codes with lower proportions of Black residents, and 76% of majority Black ZIP codes had top quartile amputation rates. ZIP codes with markers of lower SES had higher amputation rates than those with higher SES, even after adjusting for

Table 3. Association Between ZIP Code–Level Markers of SES and Amputation Rate in Metropolitan, Micropolitan, and Rural ZIP Codes

	Change in Amputation Rate (95% CI)	Difference in Amputations per 100 000 Beneficiaries per Unit Change (from Median) in SES Metric	Difference in Amputations per 100 000 Beneficiaries from Fifth Percentile to 95th Percentile SES Metric
Median household income (per $10 000 decrease)			
Overall	5.8% (5.4–6.3)	23	137
Metropolitan	4.4% (3.9–4.8)	15	108
Micropolitan	3.5% (1.7–5.4)	9	52
Rural	0.9% (−1.8 to 3.4)	4	12
DCI score (per 10 points)			
Overall	4.3% (3.9–4.6)	12	105
Metropolitan	3.8% (3.4–4.2)	12	106
Micropolitan	2.5% (1.6–3.4)	10	80
Rural	−0.4% (−1.6 to −0.7)	−2	−13
% Dual eligible for Medicaid (per 1%)			
Overall	0.1% (0.0–0.3)	0	12
Metropolitan	−0.1% (−0.2 to 0.0)	0	−8
Micropolitan	0.1% (0.1–1.2)	3	81
Rural	0.1% (0–0.4)	0	9

We used US Office of Management and Budget definitions of metropolitan, micropolitan, and rural areas: Metropolitan areas have an urban cluster of at least 50 000 people, micropolitan areas have urban clusters between 10 000 and 50 000 people, and rural areas lack an urban cluster with ≥10 000 people. In each model, covariates included US region (Midwest, Northeast, South, and West), median beneficiary age, and the proportion of beneficiaries with male sex, Black race, congestive heart failure, hypertension, diabetes mellitus, stroke, peripheral vascular disease, ischemic heart disease, chronic kidney disease, hyperlipidemia, and tobacco use. DCI indicates Distressed Communities Index; and SES, socioeconomic status.

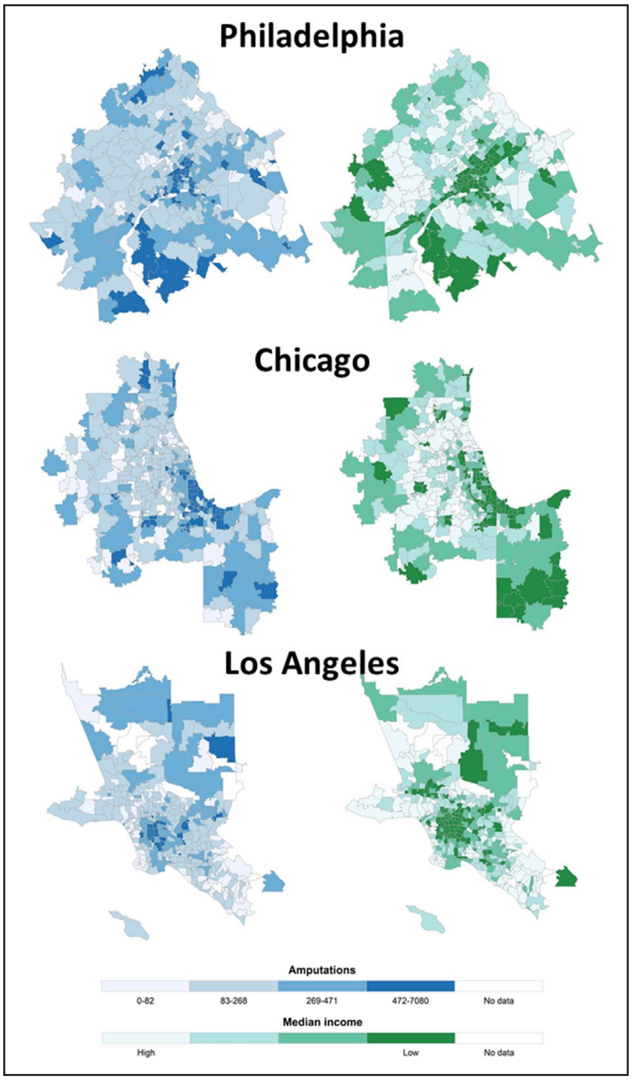

Figure 3. Geographic variation in ZIP code–level amputation rates and median income in 3 selected metropolitan statistical areas.
Shown are ZIP code–level maps of amputations per 100 000 Medicare beneficiaries and median income in the Philadelphia, Chicago, and Los Angeles metropolitan statistical areas (MSAs); darker colors represent higher rates of amputation and lower median income. Each of the 3 large, representative MSAs shown have multiple ZIP codes with top quartile amputation rates, with many colocalized to ZIP codes with low median income. Maps for all 30 MSAs with >2 million inhabitants are shown in Figures S1 through S5.

clinical and demographic characteristics. Though rural and micropolitan ZIP codes had higher amputation rates than metropolitan ZIP codes, the vast majority of patients undergoing amputations lived in metropolitan areas and most large metropolitan areas had at least 1 cluster of high amputation rate ZIP codes located in an under-resourced area of the urban core. These findings highlight the burden of major lower extremity amputation in urban areas with large Black populations and markers of low SES, and the need to identify and test health services interventions targeting the populations and specific barriers in these communities.

National quality improvement efforts have improved the care of patients with cardiovascular disease, but care for patients with PAD lags behind.[13] Compliance with guideline recommendations regarding pharmacotherapy, including antiplatelet and statin therapy, is associated with a 65% lower mortality risk and a lower risk of amputation than noncompliance,[14–16] and smoking cessation is associated with 60% lower mortality and amputation-free survival.[17,18] However, in a nationally representative assessment of office-based practice, only 36% of outpatients with PAD received antiplatelet therapy, 33% a statin, and 36% of smokers received smoking cessation counseling.[19] In clinical trials, supervised exercise therapy improves functional capacity and quality of life,[20] but in a registry of patients with PAD followed at subspecialty PAD clinics in 3 countries, only 2% of US patients were referred to supervised exercise therapy.[4] Lack of access to care is not limited solely to primary and secondary prevention therapies: 32% of patients with Medicare who ultimately underwent lower extremity amputation did not receive any diagnostic arterial testing (eg, ankle–brachial index, computed tomography, magnetic resonance imaging, or invasive angiography) in the 12 months before the amputation, implying no formal investigation into the possibility of revascularization for limb salvage.[21]

Among people of color and lower SES, gaps in quality care are amplified. Black and Native American patients, and those of lower SES, admitted to the hospital with critical limb ischemia are approximately two- to threefold more likely to undergo amputation than White patients,[22] and Black patients with critical limb ischemia are less likely to have attempts at limb salvage.[11] Structural racism is an important contributor to inequities in these cardiovascular health outcomes.[23] One of the principal ways by which structural racism affects health outcomes is by creating racial residential segregation, or the occupancy of different neighborhood environments by race.[7] Functionally, in the United States, racial residential segregation results in a disproportionate number of Black people living in areas of concentrated poverty. In these areas, concentrated poverty leads to fewer job and educational opportunities, increased exposure to chemical and psychosocial stressors, and less investment by government and the private sector. These features make it more difficult for residents to practice healthy behaviors and more difficult to access primary care, subspecialty care, and pharmacy services, leading to inadequate treatment of chronic illnesses and subsequent disparities in health outcomes.[7] Prior studies have shown associations between segregation and worse perinatal and cancer outcomes for Black individuals.[24,25] In this study, we found that ZIP codes with top quartile amputation rates had a mean proportion of Black residents 10% higher than bottom quartile ZIP codes, and that 75% of majority Black ZIP codes had top quartile amputation rates. The proportion of Black residents living in a ZIP code was directly associated with amputation rate; this relationship was attenuated but not eliminated by the addition of markers of SES and clinical comorbidities.

Analyses in Texas, North Carolina, and Ontario, Canada have shown higher rates of lower extremity amputation in underserved rural communities,[9,10,26] and national analyses looking at amputation rates within Dartmouth Health Atlas hospital referral regions appeared to show higher rates in rural regions.[6] Such analyses of amputation rates in rural areas have focused on lack of geographic proximity to PAD specialists as a mediator of poor outcomes in rural communities with low SES. By reporting ZIP code–level amputation rates per 100 000 Medicare beneficiaries, our study shows that the association between SES and amputation rate is not limited to rural regions, but extends to major metropolitan areas as well. Major amputation rates in urban communities with low SES approximate rates in rural communities despite urban patients' geographic proximity to vascular subspecialists,[27,28] suggesting that geographic proximity is not sufficient to ensure access to care in these communities. This extends, to the national level, work showing amputation "hot spots" in lower-income urban and rural regions of California.[29]

There are multiple potential explanations for gaps in quality care for patients with PAD, including fragmented care delivery with multiple subspecialties clinically managing patients with PAD; suboptimal management of modifiable PAD risk factors such as tobacco use, hypertension, diabetes mellitus, and hyperlipidemia; a subclinical early disease course with failure of patients and nonspecialist clinicians to recognize and treat PAD early in the disease process; and limited availability of vascular subspecialty diagnostic and treatment services. In urban communities, access to PAD care is not limited by geography, but may be limited by inadequate diagnosis and suboptimal referral rates to PAD specialists. Regardless of the reason for lower access to PAD care in these communities, investment in the development and implementation of scalable community-based resources for PAD diagnosis and management—potentially including community screening programs, reliable oscillometric ankle–brachial index screening techniques, home-based walking programs, and collaborative efforts to measure and improve the quality of medical management of patients with PAD seen in primary care practices—may help improve outcomes and lower amputation rates. The fact that nearly 4 in 5 Americans who underwent major lower extremity amputation lived in metropolitan areas highlights the importance of developing programs specifically targeted to improving PAD outcomes among individuals living in urban areas with low SES.

Our study has limitations. Administrative data are subject to miscoding, which could lead amputations to be under- or over-counted; however, we used the same *ICD-9* and *ICD-10* codes that prior studies of similar nature have used, and the overall amputation rate is similar to that in prior studies. The nature of administrative data prevents us from understanding reasons for inequities in amputation rates with any certainty; however, the presence of these inequities and their association with markers of SES reflect gaps in management of patients with PAD that require further study. Additionally, we measured rates of amputation not associated with lower extremity malignancy, trauma, or pressure/venous ulcers. Hence, not all of the amputations included in our analysis were definitively associated with PAD, and may therefore not be preventable with measures to improve PAD care quality or offer community resources for PAD management. However, we used this definition to avoid potential biases related to differential rates of PAD diagnosis before amputation results; furthermore, our results were similar when we examined amputations associated with a PAD diagnosis. Furthermore, we used proportion of Black residents as our racial explanatory variable, which simplifies the complex interaction between race, ethnicity, SES, and amputation rate. Such simplification is necessary to describe this relationship on the national level, but more granular descriptions of this complex problem on a regional or local level would facilitate public health interventions. Lastly, early-onset PAD is more common in Black patients,[30] and patients with early-onset PAD may have been excluded from this Medicare beneficiaries cohort, potentially leading us to undercount amputations in ZIP codes with high proportions of Black residents.

CONCLUSIONS

In this analysis of a nationwide administrative claims database, >3 in 4 major lower extremity amputations occurred in patients living in metropolitan areas. Within metropolitan areas, ZIP code–level markers of low SES were associated with higher rates of major lower extremity amputation. Development of community-based tools for PAD diagnosis and management targeted to communities with high amputation rates in urban areas may help reduce inequities in PAD outcomes.

ARTICLE INFORMATION

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Affiliations

Penn Cardiovascular Outcomes, Quality and Evaluative Research Center (A.C.F., L.Y., A.S.N., S.A.K., H.J., G.W., S.M.D., J.G., P.W.G.), Leonard Davis Institute of Health Economics (A.C.F., A.S.N., S.A.K., G.W., S.M.D., J.G., P.W.G.), and Division of Cardiovascular Medicine (A.C.F., A.S.N., S.A.K., H.J., J.G.), University of Pennsylvania, Philadelphia, PA; ; Division of Cardiology and Duke Clinical Research Institute, Duke University, Durham, NC (T.Y.W.); Division of Cardiology, University of Colorado, Aurora, CO (E.J.A.); School of Nursing, University of Minnesota, Minneapolis, MN (D.T.); Division of Vascular Surgery and Endovascular Therapy, University of Pennsylvania, Philadelphia, PA (J.D.G., G.W., S.M.D.); Corporal Michael J. Crescenz Veterans Affairs Medical Center, Philadelphia, PA (S.M.D., J.G., P.W.G.); and Division of General Internal Medicine, University of Pennsylvania, Philadelphia, PA (P.W.G.).

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Supplementary Material

Table S1
Figures S1–S8

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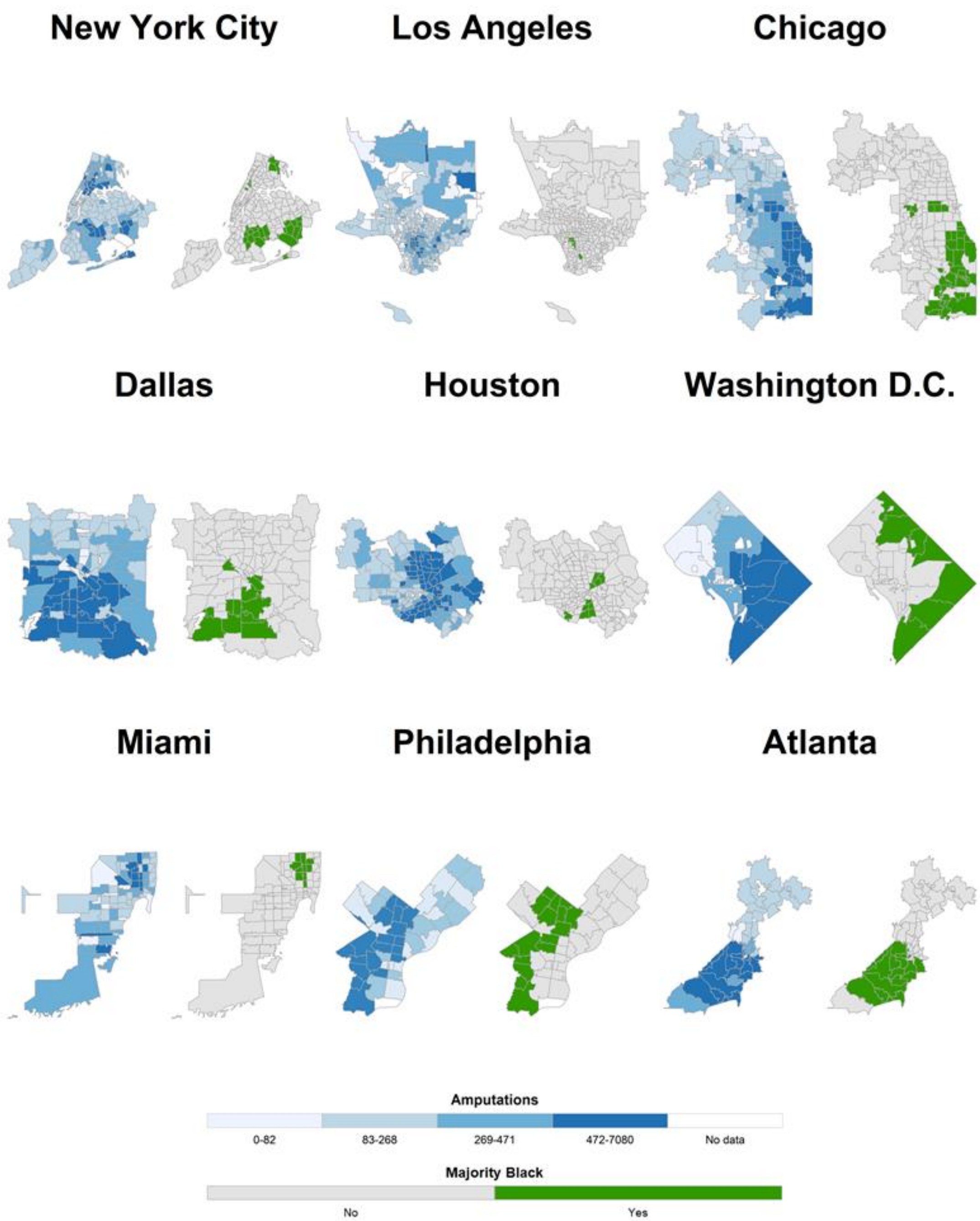
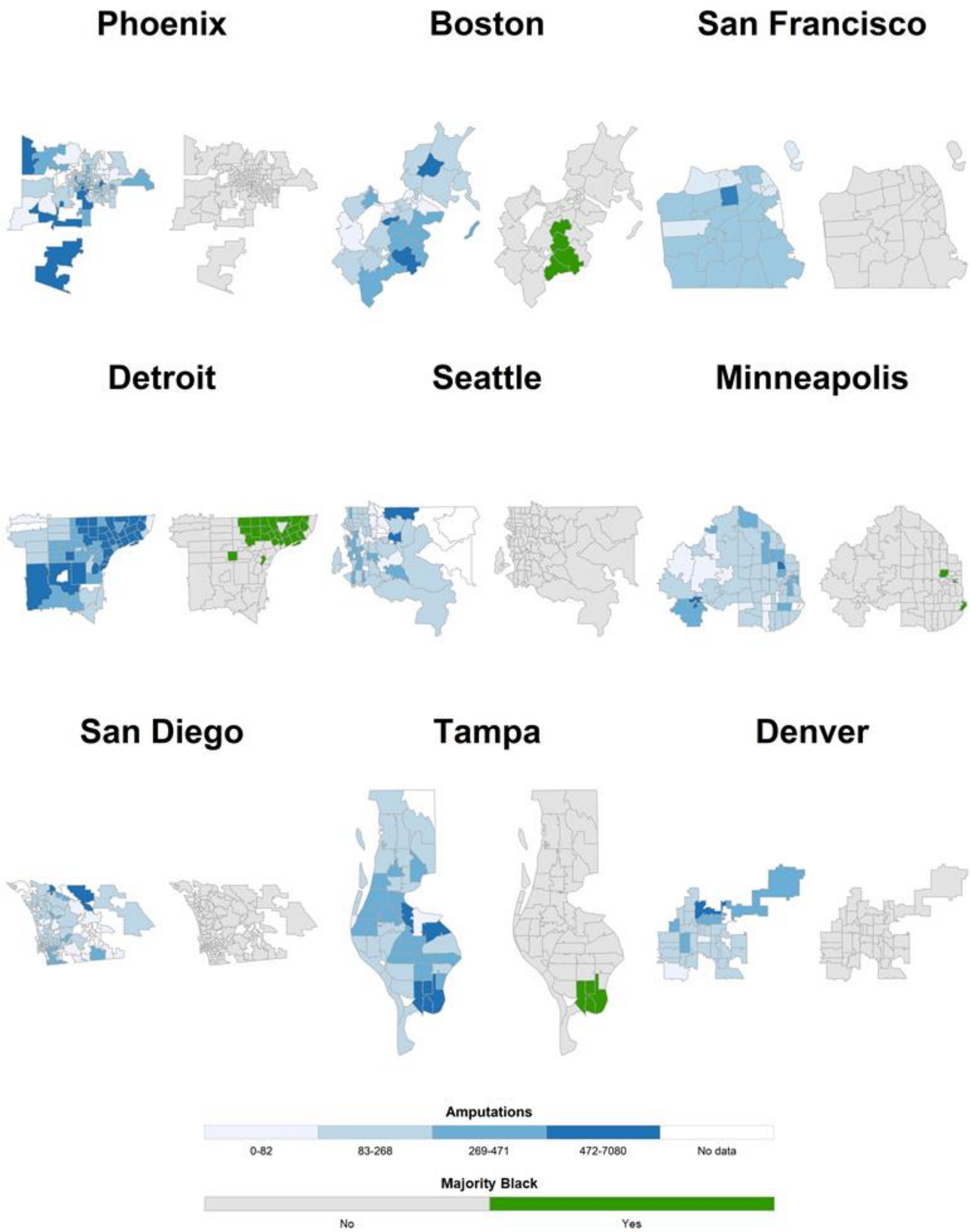
SUPPLEMENTAL MATERIAL

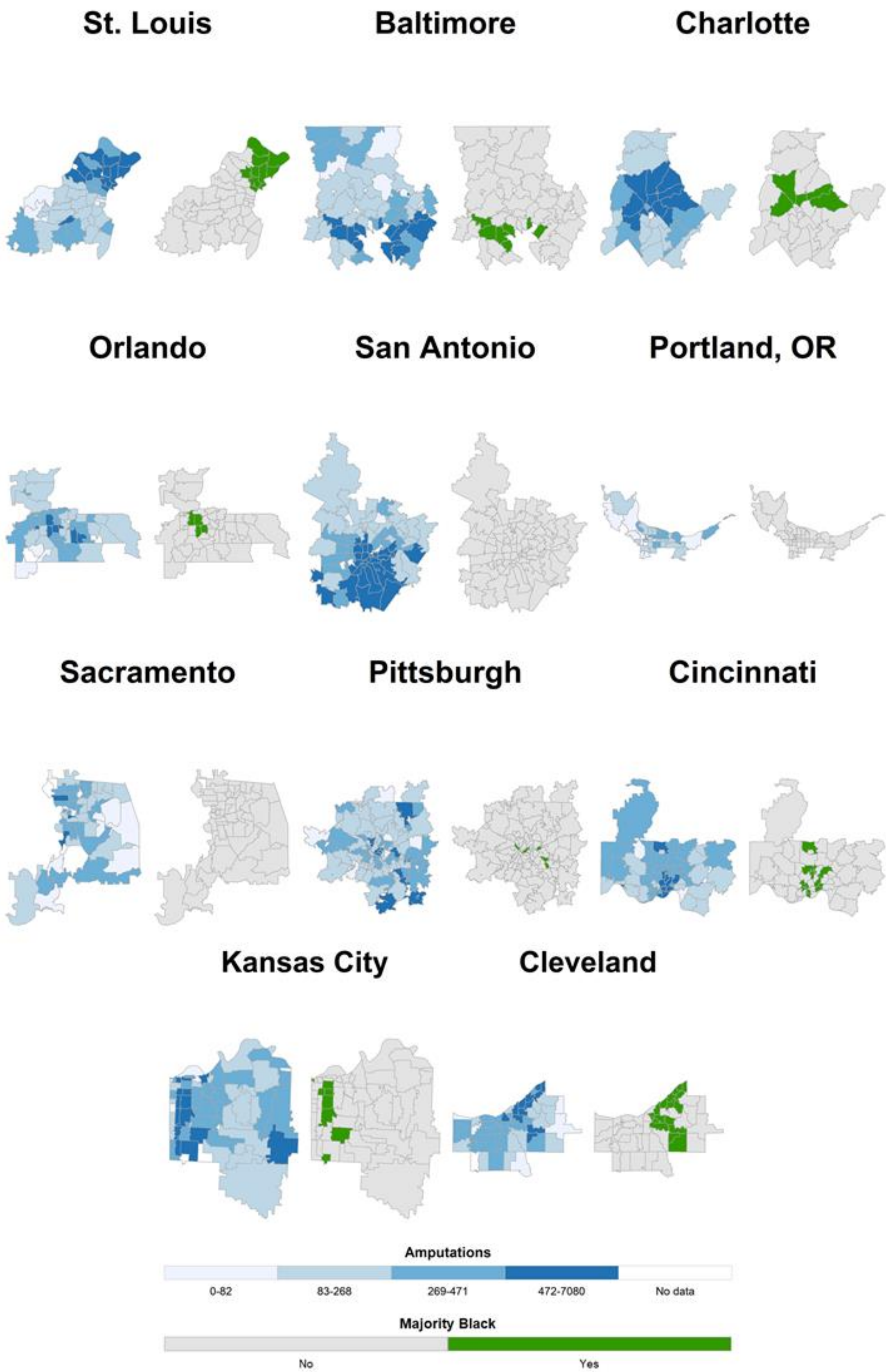
Table S1. International Classification of Diseases, Ninth and Tenth Edition, codes used to define the study cohort.

Condition	ICD-9	ICD-10
Major lower extremity amputation	84.13 to 84.18	0Y06M0Z0, 0Y6N0Z0, 0Y6H0Z3, 0Y6J0Z3, 0Y6H0Z1, 0Y6H0Z2, 0Y6H0Z3, 0Y6J0Z1, 0Y6J0Z2, 0Y6J0Z3, 0Y6F0ZZ, 0Y6G0ZZ, 0Y6C0Z1, 0Y6C0Z2, 0Y6C0Z3, 0Y6D0Z1, 0Y6D0Z2, 0Y6D0Z3, 0Y670ZZ, 0Y680ZZ
Pressure ulcer	707.00, 707.04, 707.05, 707.06, 707.07, 707.09, 707.23, 707.24, 707.25, 707.8	L89.2x, L89.3x, L89.4x, L89.5x, L89.6x, L89.8x, L89.9x
Venous ulcer	459.31, 459.33	I87.2, I87.31x, I87.32x, I87.33x, I87.8, I87.9
Trauma	820.x, 821.x, 822.x, 823.x, 824.x, 825.x, 826.x, 827.x, 828.x, 945.0x, 945.3x, 945.4x, 945.5x, 897.x	S71.x, S72.x, S73.x, S74.x, S75.x, S76.x, S77.x, S78.x, S79.x, S81.x, S82.x, S83.x, S84.x, S85.x, S86.x, S87.x, S88.x, S89.x, S91.x, S92.x, S93.x, S94.x, S95.x, S96.x, S97.x, S98.x, S99.x, T34.6, T34.7, T34.8, T34.9, T24.3x, T24.7x T25.3x, T25.7x, T79.A2
Lower extremity malignancy	170.7-8, 172.7, 173.7, 195.5, 209.34	C40.2x, C40.3x, C41.4, C43.7, C44.7, C76.5x, C4A.7x
Peripheral artery disease	444.0, 440.2x, 440.3x, 440.4, 440.9, 443.9, 444.2, 444.22, 444.8, 444.81, 447.1, 445.0, 445.02, 250.7, 250.70, 250.71, 250.72, 250.73, 707.1x	I70.0, I70.2x, I70.3x-I70.7x, I70.9x, I73.9, I74.0x, I74.1x, I74.3, I74.4, I74.5, I74.8, I74.9, I75.02x, I77.1, E10.5x, E11.5x, E08.5x, E09.5x, E13.5x, L97.1x, L97.2x, L97.3x, L97.4x, L97.5x, L97.8x, L97.9x

Figures S1, S2, and S3. Co-localization of majority Black and high amputation rate ZIP codes in cities anchoring 29 metropolitan statistical areas with > 2 million inhabitants.



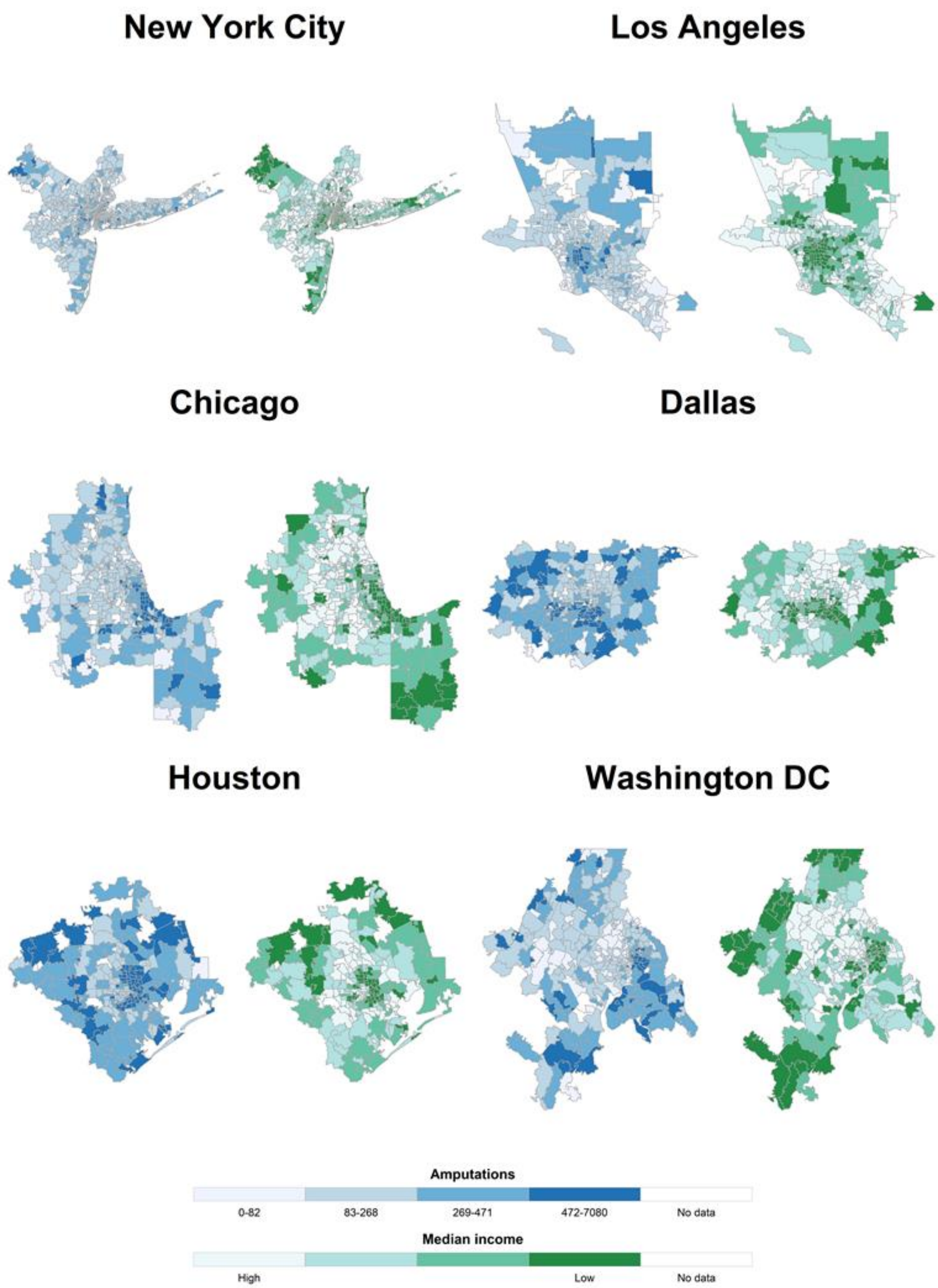

Phoenix
Boston
San Francisco
Detroit
Seattle
Minneapolis
San Diego
Tampa
Denver
Amputations
0-82
83-268
269-471
472-7080
No data
Majority Black
No
Yes

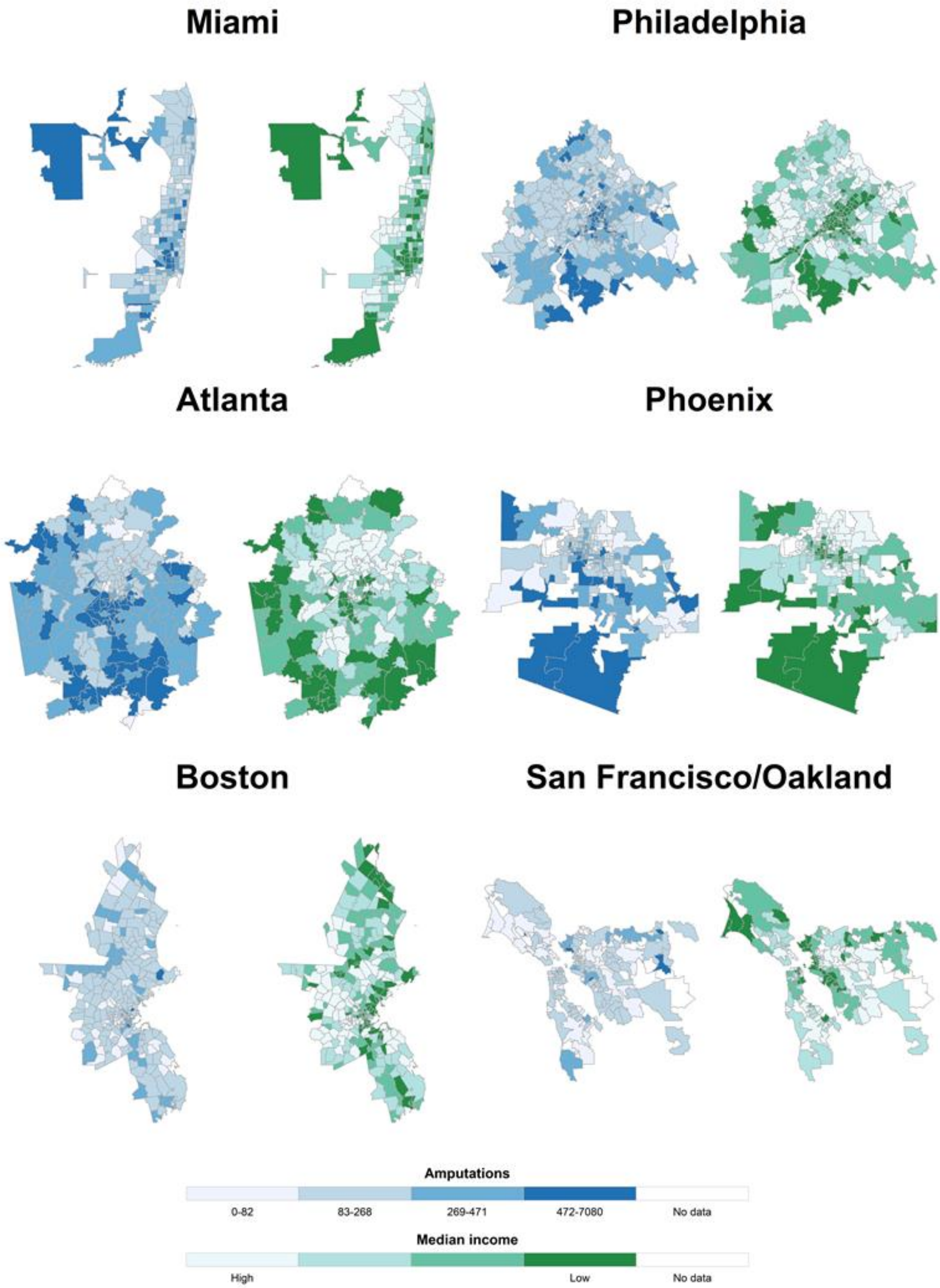


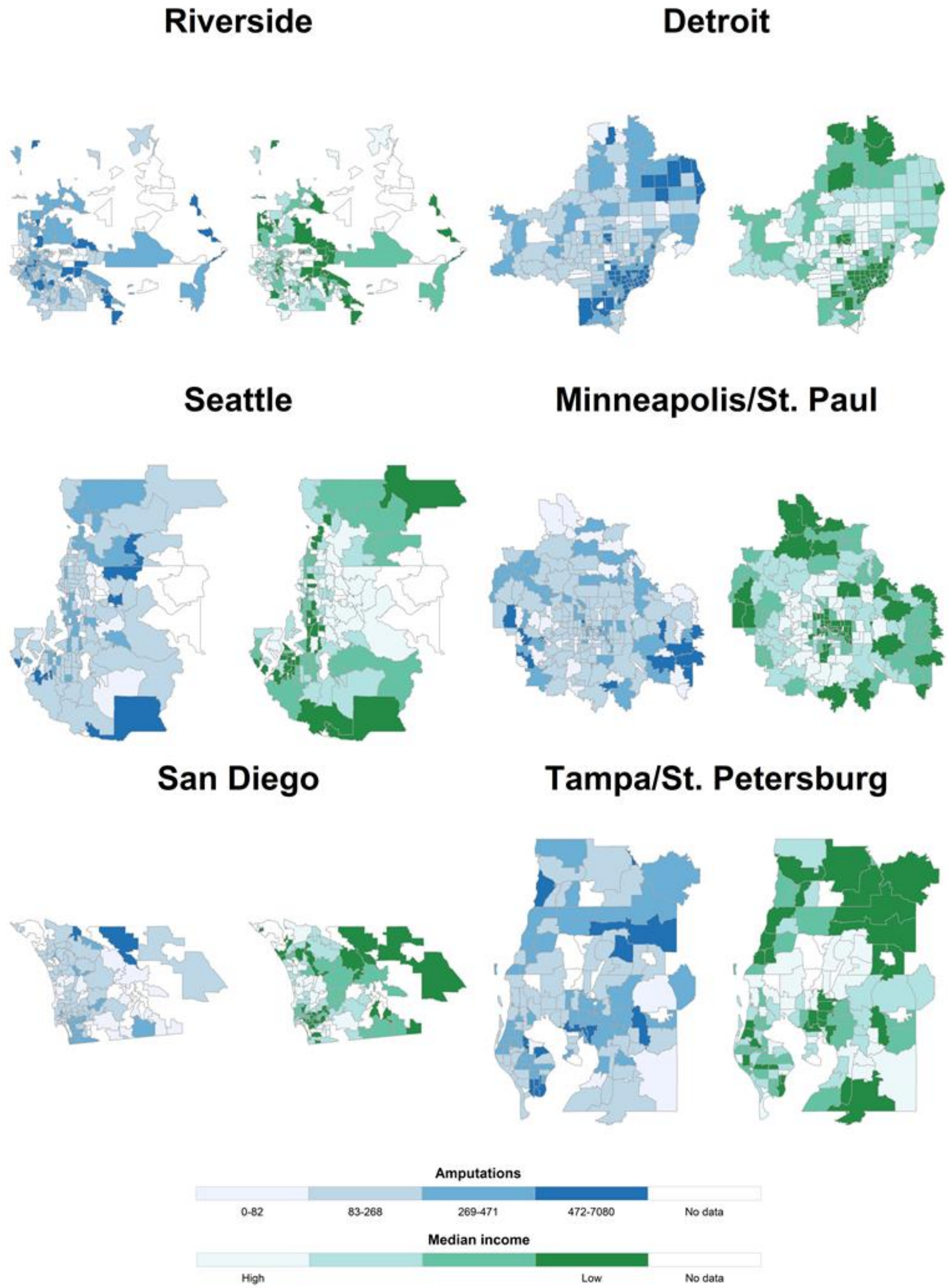
St. Louis
Baltimore
Charlotte
Orlando
San Antonio
Portland, OR
Sacramento
Pittsburgh
Cincinnati
Kansas City
Cleveland
Amputations
0-82
83-268
269-471
472-7080
No data
Majority Black
No
Yes

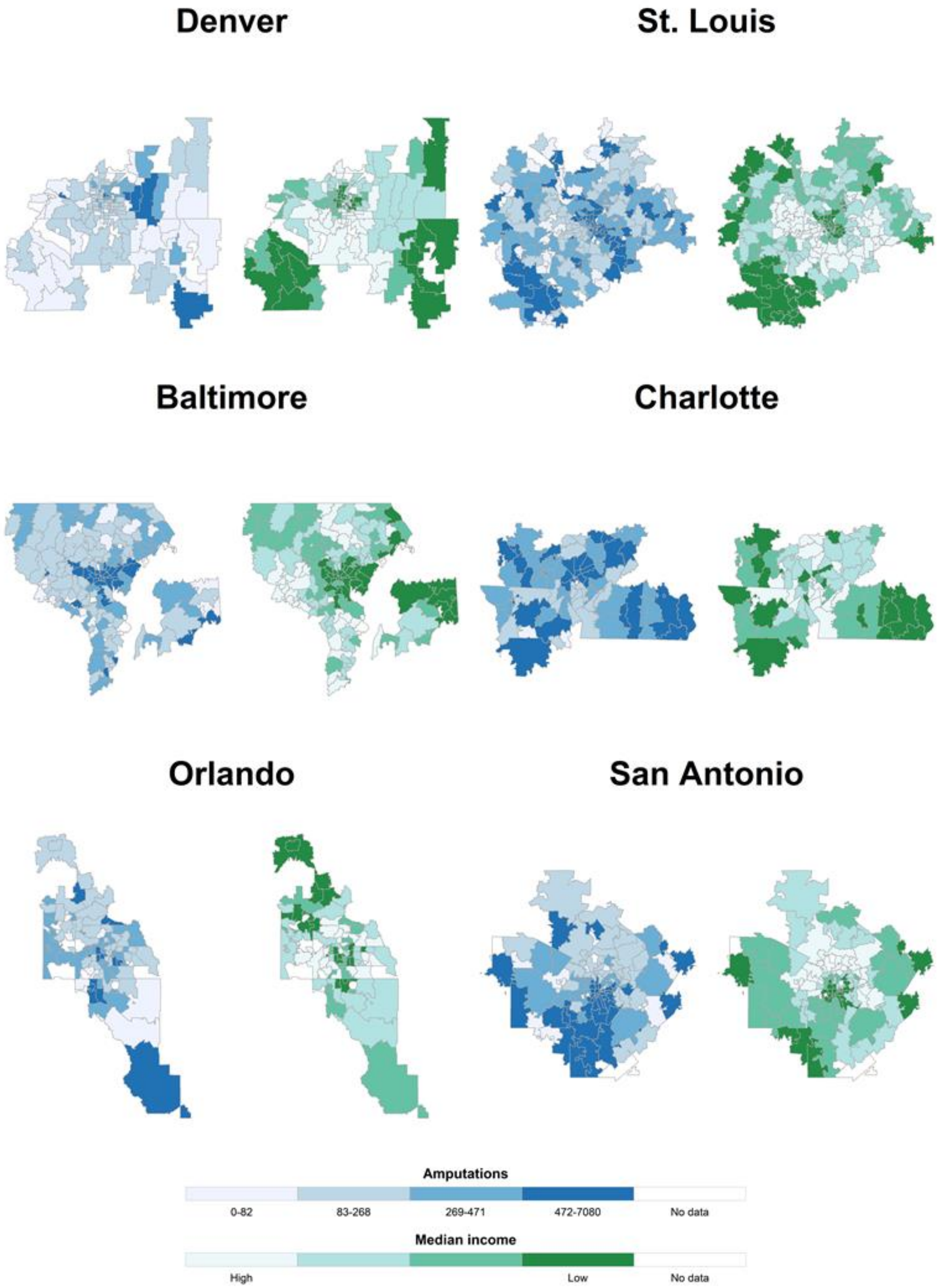
Shown are ZIP code level maps of amputations per 100,000 Medicare beneficiaries in Bronx, New York, Kings, Queens, and Richmond (New York City), Los Angeles, Cook (Chicago), Dallas, Harris (Houston), Dallas, Washington D.C., Dade (Miami), Philadelphia, Fulton (Atlanta), Maricopa (Phoenix), Suffolk (Boston), San Francisco, Wayne (Detroit), Kings (Seattle), Hennepin (Minneapolis), San Diego, Pinellas (Tampa), Denver, St. Louis, Baltimore, Mecklenberg (Charlotte), Orange (Orlando), Bexar (San Antonio), Multnomah (Portland, OR), Sacramento, Allegheny (Pittsburgh), Hamilton (Cincinnati), Jackson (Kansas City), and Cuyahoga (Cleveland) counties with parallel maps indicating ZIP codes with ≥ 50% Black inhabitants. Majority Black ZIP codes co-localize with high amputation rate ZIP codes.

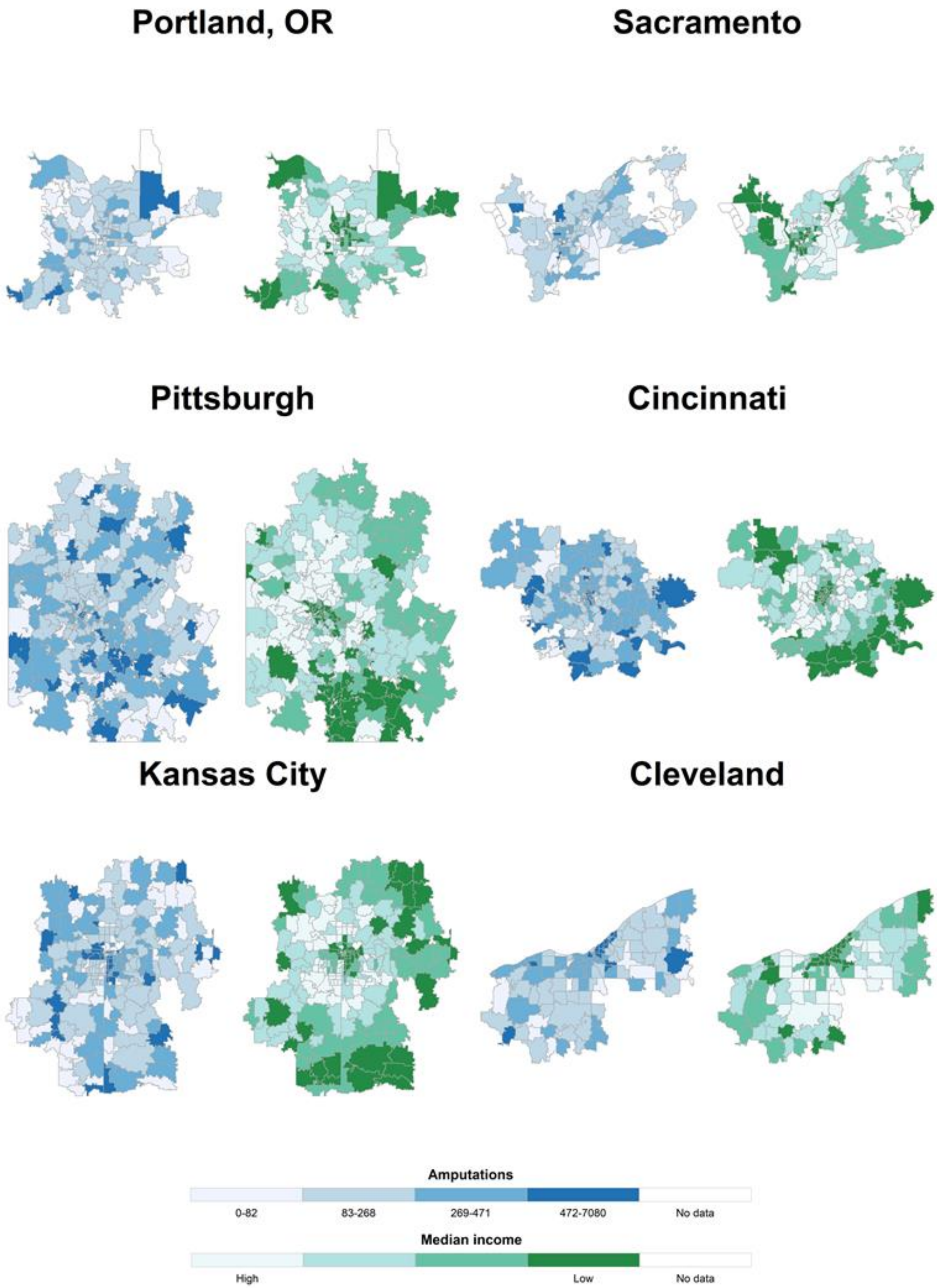
Figures S4, S5, S6, S7, and S8. Geographic variation in ZIP code-level amputation rates in 30 metropolitan statistical areas with > 2 million inhabitants.




Miami
Philadelphia
Atlanta
Phoenix
Boston
San Francisco/Oakland
Amputations
0-82
83-268
269-471
472-7080
No data
Median income
High
Low
No data


Riverside
Detroit
Seattle
Minneapolis/St. Paul
San Diego
Tampa/St. Petersburg
Amputations
0-82
83-268
269-471
472-7080
No data
Median income
High
Low
No data


Denver
St. Louis
Baltimore
Charlotte
Orlando
San Antonio
Amputations
0-82
83-268
269-471
472-7080
No data
Median income
High
Low
No data


Portland, OR
Sacramento
Pittsburgh
Cincinnati
Kansas City
Cleveland
Amputations
0-82
83-268
269-471
472-7080
No data
Median income
High
Low
No data

Shown are maps of amputations per 100,000 Medicare beneficiaries and median income in metropolitan statistical areas (MSAs) with population > 2,000,000 in 2010; darker colors represent higher rates of amputation (in blue) and lower median income (in green). Each of the MSAs shown have multiple ZIP codes with top quartile amputation rates, with many co-localized with ZIP codes with low median income.