Cancer Causes & Control (2019) 30:697–706
https://doi.org/10.1007/s10552-019-01172-4

ORIGINAL PAPER

Socioeconomic gradients in cancer incidence by race and ethnicity in California, 2008–2012: the influence of tobacco use or screening detectable cancers

David H. Rehkopf[1] · Danielle Rodriguez[2] · Rosemary Cress[2] · Dejana Braithwaite[3] · Ingrid Oakley-Girvan[4,5] · Dee West[2,4,5] · Robert A. Hiatt[6]

Received: 12 June 2018 / Accepted: 12 April 2019 / Published online: 7 May 2019

Abstract

Purpose There are clearly documented inequalities in cancer incidence by socioeconomic position, but it is unclear whether this is due primarily to differences in tobacco exposure and screening practices or to other factors.

Methods Our study included 741,373 incident cases of invasive cancer from 2008 to 2012 in California. We calculated age-standardized incidence rates across twelve categories of census tract poverty as a measure of socioeconomic position (SEP) for (1) all cancer sites combined, (2) sites not strongly related to tobacco use, (3) sites not related to screening, and (4) sites not related to tobacco use or screening.

Results There was higher cancer incidence among those living in areas with higher levels of poverty for sites not strongly related to tobacco use or screening, among Whites, Blacks, and Asians, but not among Latinos. Among Whites there was no relationship with census tract poverty at lower levels of poverty—the relationship with cancer incidence was primarily among those in higher poverty. For Blacks and Asians, there is a more linear relationship with cancer incidence across levels of poverty.

Conclusions SEP gradients in cancer incidence remain after exclusion of cancer sites strongly related to tobacco use and screening. Our findings demonstrate a need for research on other environmental and social causes of cancer where exposures are differentially distributed by SEP.

Keywords Socioeconomic · Screening · Tobacco · Poverty · Epidemiology

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10552-019-01172-4) contains supplementary material, which is available to authorized users.

✉ David H. Rehkopf
drehkopf@stanford.edu

1 Division of Primary Care & Population Health, School of Medicine, Stanford University, 1070 Arastradero Road, Room 280, Palo Alto, Stanford, CA 94304, USA

2 Cancer Registry of Greater California, Public Health Institute, Sacramento, CA, USA

3 Department of Oncology, Lombardi Comprehensive Cancer Center, Georgetown University, Washington, DC, USA

4 Stanford Cancer Institute and the Canary Center at Stanford for Cancer Early Detection, School of Medicine, Stanford University, Stanford, CA, USA

5 Cancer Prevention Institute of California, Fremont, CA, USA

6 Division of Epidemiology & Biostatistics, University of California, San Francisco, CA, USA

Introduction

For cancer incidence in the United States, all-site and site-specific inequalities by race/ethnicity are documented and consistently reported [1, 2]. However, there is also evidence for all-site and site-specific inequalities in incidence by socioeconomic position (SEP) such that, with notable exceptions for breast and a few other cancers, persons of higher SEP generally have lower incidence [3, 4]. It is well documented that the greatest contributor to this inequality in industrialized countries is the higher rates of smoking among lower SEP individuals resulting in higher rates of lung and other cancer sites among lower SEP individuals, whether measured by income or level of education [5], and found consistently across 67 studies in a meta-analysis [6]. Conversely, SEP differences in cancer incidence in the U.S. are also influenced by screening practices. Screening for cervical cancer [7], colorectal cancer [8], breast cancer

[9], and prostate cancer [10] is all are more common for higher SEP individuals, resulting in the potential for case ascertainment bias, and thus bias in the true SEP differences in cancer incidence. Analysis of time trends in SEP differences in prostate cancer demonstrates an example of this. While there were no SEP differences in prostate cancer incidence at the time screening was introduced, after introduction higher incidence was found among higher SEP individuals [11].

Despite a longstanding interest in using descriptive epidemiology to understand SEP patterns in cancer [12], prior work has not attempted to understand SEP gradients accounting for these already well-documented reasons for SEP differences in cancer incidence. In order to move towards a better understanding of these causes of SEP inequalities in cancer incidence, it is useful to answer the following question: are these inequalities primarily due to the well-documented differences in tobacco use and cancer screening by SEP, or do other factors also contribute?

The primary descriptive hypothesis that we test is that socioeconomic inequalities in cancer incidence are influenced by other factors in addition to differential rates of screening (higher among high SEP) and tobacco use (higher among low SEP). While there is evidence for a wide range of determinants for site-specific cancers [13], it is less clear how different causes impact the population-level magnitude of SEP inequalities in cancer incidence. Inability to reject this hypothesis does not prove, but is consistent with a substantial contribution of other causes to SEP inequalities in cancer incidence.

Our secondary descriptive hypothesis is that there will be a non-linear dose–response relationship between area SEP and non-tobacco and non-screening-related cancer incidence with a stronger relationship at lower levels of SEP. We hypothesize that there will be greater SEP differences in cancer incidence between lower SEP areas as compared to higher SEP areas. While gradients differ by cancer site and racial/ethnic group [14], the extent to which inequalities in cancer incidence are evenly distributed (i.e., in a linear manner) across SEP is unknown. Prior analyses suggest this is the case for mortality [15] and other outcomes, such as cardiovascular diseases [16]. However, prior work using broad categories of SEP has not provided an answer to the nature of this gradient for cancer incidence [17, 18]. The importance of testing this descriptive hypothesis is twofold. First, it will help guide etiologic research looking into potentially causal factors that have distributions across SEP consistent with distributions of incidence. Second, it will help to clarify which populations are in greatest need of interventions and services to prevent cancer.

In this study we focused on California, a large geographic region with an ethnically and socioeconomically diverse population. We evaluated data from years 2008 to 2012 to have the most accurate denominator data from the year 2010 United States Census.

Materials and methods

Incident cancer source

Incident cancer data from 2008 to 2012 were obtained from the California Cancer Registry, for all ages, and for all 58 California counties. We selected this range of years in order to have the most accurate full-count population data when calculating incidence rates stratified by both race/ethnicity and ten categories of census tract poverty. The total number of incident cases observed in this time period was 897,277. Race/ethnicity was defined using data from the medical record, which is based on either self-report or health-care provider notes. We used the census-designated categories of white non-Hispanic, black non-Hispanic, Latino, or Hispanic, and Asian non-Hispanic (hereafter white, black, Latino, and Asian). Due to small sample size among the California Native American population, findings in this subpopulation were not presented. To be consistent with the denominator data from the census, we excluded from our analysis individuals (< 1% of the population) who identified with two or more racial/ethnic groups. When multiple sites of cancer were recorded for an individual, we included only the first recorded site (first primary), which reduced the total number of incident cases to 844,047. Fewer than 1% of cases could not be linked to census tract poverty levels ($n = 4{,}243$) resulting in a sample of 839,806. Finally, we limited our analysis to only invasive cancers, which resulted in a final analytic sample size of 741,373. Table S1 shows the number of incident cases by site-specific grouping and race/ethnicity, demonstrating that we have a sufficient sample size for our analyses. We focused our analysis on adults aged 25–64 at the time the incident cancer was identified to limit the impact of mortality selection on our estimated associations, but also present analyses for the population age 65 and older. We include ages 25 and above because our primary focus is on understanding the socioeconomic gradients in cancer in the entire population. Although for most individuals screening starts at the age of 50, we include all ages in our analysis since some individuals are screened at an earlier age if they have a family history of cancer.

We defined sites as strongly tobacco related if the average relative risk across multiple studies of cancer incidence for that site was 2.0 or greater (oral cavity and pharynx, esophagus, larynx, lung and bronchus, kidney and renal pelvis, other urinary) [19] coded as (C000-C069, C090-C159, C250-C259, C300-C349, C640-C659). Colon, rectum, breast, cervix, and prostate sites were considered commonly screen detected. For breast cancer, there were only 978 cases among men (0.69% of cases), therefore rates of breast cancer are presented among women only. These categories were defined by the following ICD-O-3 codes for cancer sites related to screening (C180-C189, C199, C209-C219, C260-C269, C500-C509, C530-C539, C619).

Population data source

Population data for calculating denominators were obtained from the SF1 files of the 2010 U.S. census [20].

Measure of socioeconomic position

We used levels of poverty obtained from the U.S. census by census tract as the measure of SEP in this analysis. In the year 2010, the federal poverty line was $10,830 for one person, $14,570 for two persons in the same household, and $22,050 for a four-person household [21]. Percent census tract poverty was used from 12 a priori defined categories (0.0–2.4%, 2.5–4.9%, 5.0–7.4%, 7.5–9.9%, 10–12.4%, 12.5–14.9%, 15–17.4%, 17.5–19.9%, 20–24.9%, 25–29.9%, 30–39.9%, ≥ 40%). Greater than 20% of residents of an area living in poverty is designated by the US Bureau of the Census as a "poverty area," and > 40% of residents living in poverty is designated as an "extreme poverty area" [22]. Figure 1 shows the distribution of poverty by these categories for the full population, Whites, Blacks, Latinos, and Asians. Online resource Figure S1 shows the population distribution of poverty for the full population, Whites, Blacks, Latinos, and Asians with a continuous measure of poverty rather than the 12 categories we used for analyses. These figures show that the categories accurately capture the distributions of poverty within racial/ethnic populations. The fact that there are a particularly large number of zero poverty census tracts and a few very high poverty census tracts demonstrates the importance of using categories in our analyses so that results will not be unduly influenced by extremely high or low values.

Prior work has validated percent poverty at the census tract level as a useful measure of area SEP [23, 24]. For descriptive epidemiologic investigation, using a census tract derived area-based socioeconomic measure has several advantages [25]. First, it reduces bias from those who refuse to report an individual-level socioeconomic measure, or for those who misreport, which may be common [26]. Secondly, it avoids conflating cohort and age differences that occur when using individual measures of SEP. For example, household earnings do not capture SEP in an equivalent way for older individuals who are not in the paid labor force as compared to individuals in the paid labor force, and a high school diploma has a different economic meaning for individuals from different birth cohorts [27]. These may be part of the reason that individual-level education, for example, has been associated with smaller differences in mortality than census tract-based measures [28].

Statistical methods

Cancer incidence rates were age standardized to the year 2000 (US standard million) within race and SEP strata. Smoothed models of age-standardized incidence rates across levels of SEP were fit with a generalized additive model based on penalized splines [29]. The advantage of this method as compared to a fully categorical approach to examining socioeconomic differences in cancer rates is that the smoothed model borrows strength from adjacent categories, allowing a more robust and stable analysis of socioeconomic differences over categories with relatively smaller numbers of events. These models also allow us to relax the assumption that there is a linear relationship of cancer incidence across the 12 poverty categories. 95% confidence intervals (CI) were obtained using the inverse probability of the standard error. Age standardization was performed using the ageadjust.direct function from the EpiTools R package [30]. Smoothed generalized additive models were fit using the mgcv package in R, version 2.9.2 [31].

We also present models using a general linear model with age-standardized cancer incidence as the dependent variable and poverty category as the independent variable, weighted by population size across poverty strata. While these models have the limitation of assuming a linear relationship across categories of poverty with cancer incidence, they have the advantage of allowing us to estimate coefficients of the differences in incidence rates across categories of census tract poverty, along with 95% CI.

Results

Figure 1 shows the population distribution of poverty for the full population, Whites, Blacks, Latinos, and Asians. For the black and the Latino populations, there is a relatively even population distribution across poverty categories, except for the population in the highest poverty category [12], which is the population living in areas with 40% or more households in poverty. For Whites and Asians, the most individuals live in the lowest poverty areas and we observed a generally monotonically decreasing prevalence of individuals living in each category of higher poverty levels. While there is an adequate number of individuals across categories to estimate relatively stable incidence rate ratios, the wider confidence intervals in some parts of poverty distributions reflect the smaller populations in some of these categories.

Figure 2 presents age-standardized incidence rates (per 100,000) for cancer incidence smoothed across poverty category, by cancer site category, among Asian, black, Latino,

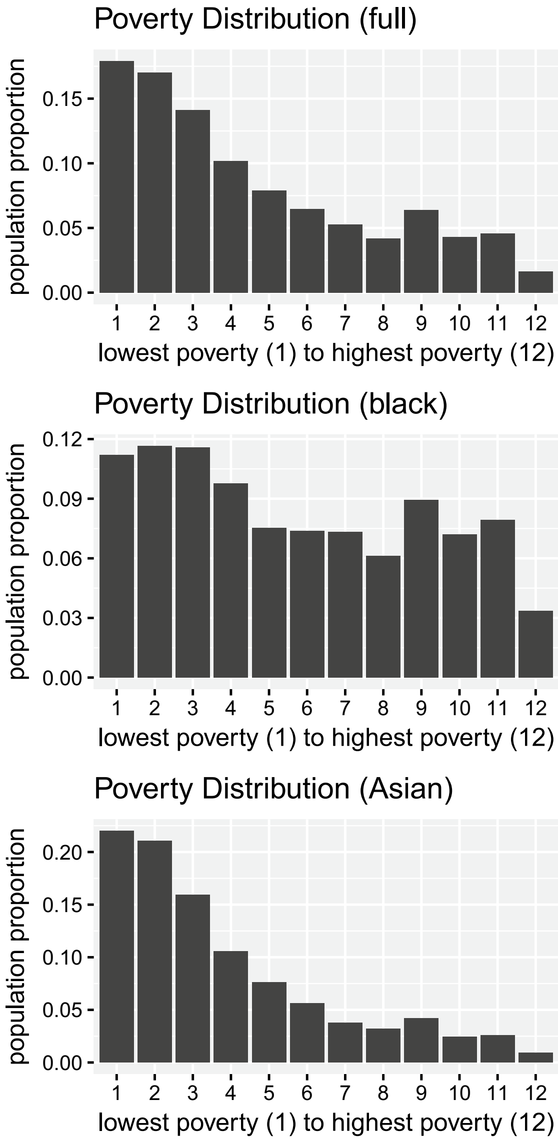

Fig. 1 Population distribution of poverty by category, California 2000, for the full population and for racial/ethnic categories, U.S. Census. Poverty categories are 1) < 2.5% census tract poverty, 2) 2.5 to < 5% census tract poverty, 3) 5 to < 7.5% census tract poverty, 4) 7.5 to < 10% census tract poverty, 5) 10 to < 12.5% census tract poverty, 6) 12.5 to < 15% census tract poverty, 7) 15 to < 17.5% census tract poverty, 8) 17.5 to < 20% census tract poverty, 9) 20 to < 25% census tract poverty, 10) 25 to < 30% census tract poverty, 11) 30 to < 40% census tract poverty, 12) 40 to 100% census tract poverty

and white populations, aged 25–64 in California from 2008 to 2012. The X axis on each plot differs because the focus is on the relative comparisons across levels of poverty within classifications of cancer sites. For all sites of cancer (upper left panel), in terms of absolute levels, rates are much higher for Whites (light gray solid line) and Blacks (medium gray-dashed line) than for Asians (black dot-dash line) and Latinos (dark gray-dotted line). In considering differences by level of poverty, the largest differences in incidence by poverty are observed for Whites, followed by Blacks, and Asians. All-site cancer incidence among Latinos has the opposite relationship, higher levels in lower poverty census tracts. Our primary hypothesis is to compare these relationships with those sites not related to screening or strongly related to tobacco use (upper right panel). While the absolute level of cancer incidence is lower among this restricted group of cancer sites, the relative differences between high and low levels of poverty are similar. The plot shows higher levels of incidence among those living in higher poverty areas for Whites, Blacks, and Asians, but lower incidence in higher poverty areas among Latinos. The reasons that these associations remain similar can be understood by examining the relationships shown in the second and third rows of the figure. Cancer sites related to screening have lower level of

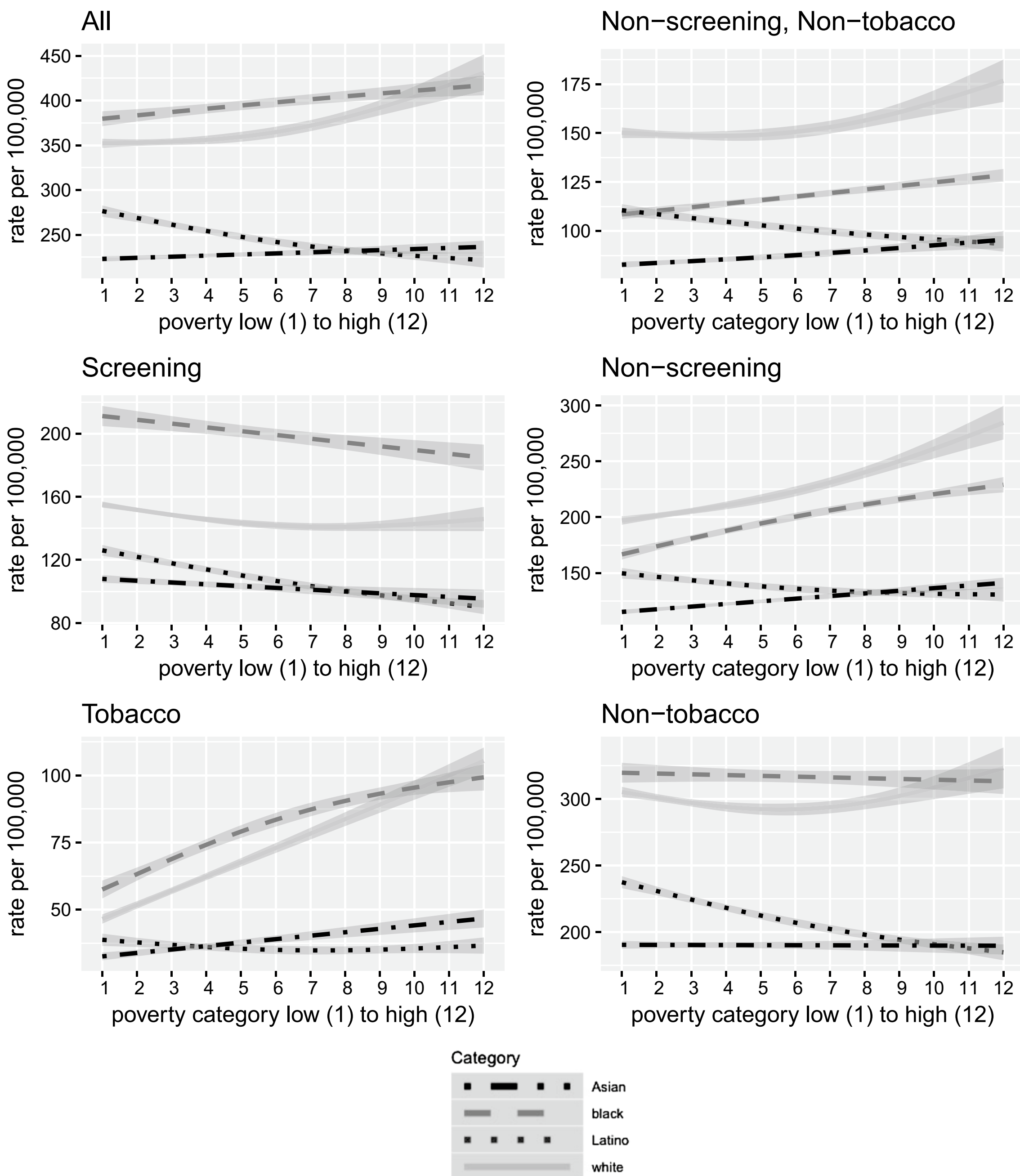

Fig. 2 Model-based age-standardized cancer incidence rate (per 100,000) by poverty category, California, 2008–2012, ages 25–64. The panels show rates by cancer site groups. The lines show rates by racial/ethnic group: Whites (light gray solid line), Blacks (medium gray-dashed line), Latinos (dark gray-dotted line), and Asians (black dot-dash line). The gray area flanking the estimates indicates the 95% CI. Note that scale and range of the vertical axes differ due to different rates between cancer site categories

incidence at higher levels of poverty, while sites strongly related to tobacco use have greater incidence among individuals living in higher poverty areas. When removing sites not related to screening (middle row right panel)—the magnitude of difference in incidence across level of poverty is greater for Blacks, Whites, and Asians, and the inverse socioeconomic gradient for Latinos is decreased in magnitude. For sites strongly related to tobacco use (lower left plot) there are much higher rates in higher poverty areas, especially for Blacks and Whites. For sites not strongly related to tobacco use (lower right panel), there remain similar gradients for Whites and Latinos as compared to all sites, but there are null associations among Blacks and Asians.

In consideration of our secondary hypothesis of the linearity of the associations, among Whites we see no relationship with census tract poverty at lower levels of poverty, and only see the relationship with cancer incidence among those in higher poverty. For Blacks and Asians, there is a more linear relationship across levels of poverty.

Figure 3 presents the same categorization of cancer sites and population stratifications by race/ethnicity, but for the population age 65 and above. While the incidence rates are higher in this older population, the shapes of the associations with level of poverty are generally similar to those aged 25–64. One difference in poverty gradients is that SEP inequalities among Blacks are diminished in the 65 and over

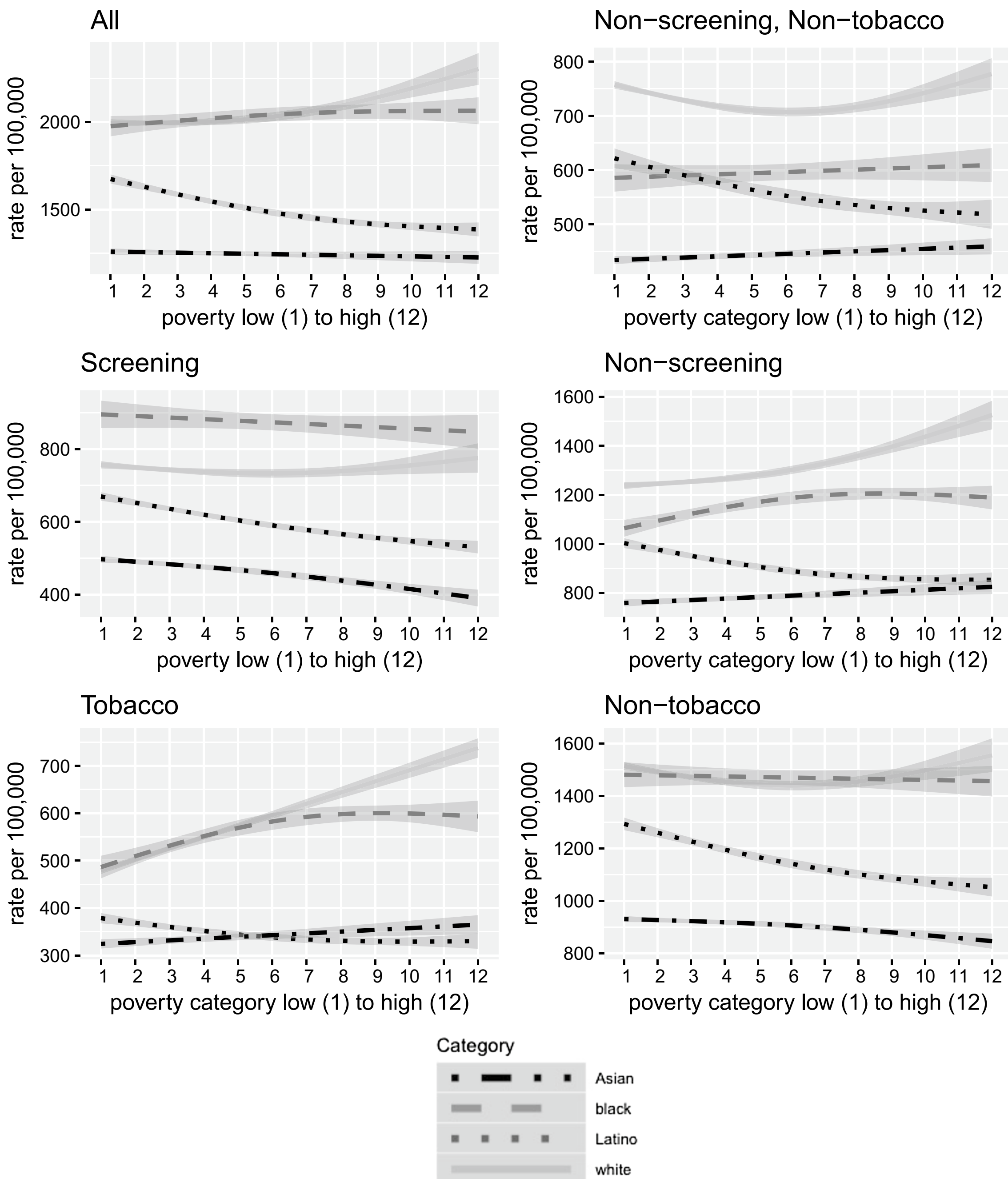

Fig. 3 Model-based age-standardized cancer incidence rate (per 100,000) by poverty category, California, 2008–2012, ages 65 and above. The panels show rates by cancer site groups. The lines show rates by racial/ethnic group: Whites (light gray solid line), Blacks (medium gray-dashed line), Latinos (dark gray-dotted line), and Asians (black dot-dash line). The gray area flanking the estimates indicates the 95% CI. Note that scale and range of the vertical axes differ due to different rates between cancer site categories

population as compared to the 25–64-year-old population. In addition, among sites not strongly related to tobacco use or screening (upper right plot), there is a U-shaped relationship with higher levels of incidence at both lower and higher levels of poverty among Whites.

As a complementary approach to quantifying the difference in cancer incidence rates by level of poverty, we fit generalized linear models to the poverty category-specific age-standardized rates, for the populations aged 25–64 and 65 and older, by racial/ethnic group (Table 1). The coefficients can be interpreted as the difference in the age-standardized incidence rate per category of poverty, with 1 the lowest category of census tract poverty and 12 the highest category of census tract poverty. We find higher rates of cancer incidence at higher levels of poverty for causes not strongly related to tobacco use or screening for Whites aged 25–64, Blacks 25–64, and for Asians 25–64 and 65 and above. We find lower rates at higher levels of poverty for Latinos 25–64 and 65 and above.

A supplemental set of analyses described relationships between cancer incidence and poverty for women only and men only among the full population, Whites, Blacks, Latinos, and Asians aged 25–64 (Online resource Tables S2 through S6). Our focus in interpreting these models was whether the confidence intervals for women and men overlapped for the relationships between poverty and non-screening/non-tobacco cancer incidence, indicating similar relationships between incidence and poverty between genders. We found evidence of differences in the relationship for black men and women aged 25–64, where there was a stronger relationship with poverty level for black men. We also found differences among Asian men and women aged 25–64 and 65 and older, where they were also stronger among men.

Discussion

There are higher incidence rates of all-site cancer in higher poverty areas among Whites, Blacks, and Asians, but higher incidence rates in lower poverty areas among Latinos. The same pattern was observed for sites not strongly associated with tobacco use and screening practices. In the total population, we found higher cancer incidence rates in lower poverty areas, but this is due to confounding by race/ethnicity primarily due to the larger population of Latinos with lower incidence rates living in higher poverty areas. This finding is consistent with there being a substantial impact of the healthy immigrant effect on Latino cancer rates [32]. Even as tobacco-related cancer incidence is an important source of higher cancer incidence in higher poverty areas, our data demonstrate additional socioeconomically related determinants of cancer incidence among Blacks, Whites, and Asian men that are not strongly related to either tobacco or screening practices. We also show that for Blacks and Asians, this non-tobacco and non-screening risk is linear across poverty

Table 1 Generalized linear model coefficients (95% CI) for poverty category and cancer incidence rates (per 100,000), California, 2008–2012

	All sites	Screening	Non-screening	Tobacco	Non-tobacco	Non-tobacco/non-screening
Total						
Age 25–64	− 3.9 (− 4.4, − 3.3)	− 3.2 (− 3.6, − 2.8)	− 0.17 (− 0.49, 0.16)	1.5 (1.2, 1.8)	− 5.4 (− 6.0, − 4.7)	− 1.6 (− 2.0, − 1.3)
Age 65+	− 20 (− 22, − 17)	− 10 (− 12, − 8.9)	− 9.0 (− 11, − 7.3)	3.7 (1.8, 5.6)	− 24 (− 27, − 20)	− 13 (− 14, − 11)
White						
Age 25–64	4.8 (2.9, 6.7)	− 1.7 (− 2.5, − 1.0)	7.1 (5.7, 8.4)	5.3 (4.8, 5.8)	− 0.50 (− 2.1, 1.1)	1.8 (0.69, 2.8)
Age 65+	17.5 (9.1, 26)	− 1.7 (− 4.9, 1.6)	20 (14, 25)	23.4 (14, 25)	− 6.0 (− 13, 0.90)	− 3.9 (− 8.0, 0.15)
Black						
Age 25– 64	3.4 (2.0, 4.8)	− 2.4 (− 3.5, − 1.3)	6.4 (5.6, 7.1)	− 2.4 (− 3.5, − 1.3)	− 0.58 (− 1.9, 0.73)	2.3 (1.8, 2.8)
Age 65+	8.7 (− 0.41, 18)	− 4.4 (− 11, 2.1)	13 (6.5, 20)	11 (6.5, 15)	− 2.2 (− 10, 6.0)	2.2 (− 2.3, 6.7)
Latino						
Age 25–64	− 5.2 (− 6.2, − 4.1)	− 3.3 (− 3.9, 2.8)	− 1.5 (− 2.2, − 0.73)	− 0.26 (− 0.63, 0.11)	− 4.9 (− 5.7, − 4.1)	− 1.2 (− 1.6, − 0.76)
Age 65+	− 28 (− 34, − 23)	− 13 (− 15, 11)	− 14 (− 19, − 10)	− 5.0 (− 6.9, − 3.0)	− 23 (− 28, − 19)	− 9.5 (− 13, − 6.3)
Asian						
Age 25–64	1.2 (0.43, 2.0)	− 1.1 (− 1.8, − 0.48)	2.8 (2.3, 3.3)	1.3 (0.90, 1.7)	− 0.061 (− 0.84, 0.71)	1.5 (1.1, 2.0)
Age 65+	− 3.0 (− 7.3, 1.3)	− 9.0 (− 11, − 6.9)	6.3 (3.0, 9.7)	3.7 (1.3, 6.0)	− 6.7 (− 9.3, − 4.1)	2.7 (1.0, 4.2)

Age standardization was done to the year 2000 standard million population by 5-year age category. Data are from the full California population aged 25 and older. Lowest level of poverty is one, highest level of poverty is 12 categories, but among Whites the increased risk is primarily among those living in higher poverty areas.

Strengths of our analysis include the fact that our data are from the entire California population, thus minimizing sample selection bias. This large population-based data set also provided a large sample size to test racial/ethnic strata and many categories of census tract poverty with sufficient statistical power. A further strength of our analysis was the use of generalized additive models to test the non-linear dependence of cancer incidence on census tract percent poverty. Further, our findings justified the simultaneous consideration of race/ethnicity and SEP on cancer incidence. Studies examining only one of these factors are likely to produce misleading results, as was the case with the analysis of poverty differences in cancer incidence in the total population. We specifically focused on cancer incidence rather than mortality because this provides a perspective on etiologic factors and screening rather than on treatment, long-term survivor care, and comorbidity that would introduce health system-related factors into socioeconomic gradients in mortality. Our findings are not likely due to differential access to medical care or other health services because we also performed analyses by removing sites of cancer for which screening is performed.

One possible weakness of the current study is the use of an area-based rather than individual-level measure of SEP. The limitation is not one of ecologic fallacy because we do not attribute causes to individual-level exposures and we do analyze individual-level demographic and incidence data [33]. However, some prior work has shown that there may be a weaker association between area-based socioeconomic measures and disease as compared to individual-based measures [25, 34]. Moreover, advantages of this measure are comparability between studies using this common metric for evaluating socioeconomic gradients, and elimination of measurement error due to misreporting of socioeconomic data (e.g., level of education) or missing data due to individuals unwilling to report socioeconomic information. The use of percent poverty as our metric as compared to a composite measure of area SEP also has the advantage of interpretability with little loss in predictive value [35]. Finally, area-based SEP allows for the comparison of findings across age groups, when the meaning of individual-level SEP measures such as education, income, and occupation may differ in their meaning to age and cohort differences. A further limitation of our analysis is that we only have census tract of residence at the time of cancer diagnosis, and residence in earlier life may be relevant to cancer development [36, 37]. Again, this would most likely bias our results towards the null if conceptualized as non-directional measurement error of SEP over the life course. We also recognize that although we excluded the cancers sites most strongly related to tobacco use, recent evidence suggests a small magnitude of impact on other cancer sites, including the pancreas and stomach. These may have an impact on our results such that tobacco use may still account for part of the observed SEP difference in incidence.

While no other studies of socioeconomic differences in cancer incidence have tested as many socioeconomic categories or restricted analysis for non-screening non-tobacco-related cancer sites, our findings may be compared to the small number of studies that have tested socioeconomic gradients in cancer incidence by race/ethnicity. The 1998 Report on the Health of the United States: Socioeconomic Status and Health included only one cancer outcome stratified by socioeconomic status—showing higher rates of lung cancer among lower socioeconomic status men, but not women, using data from 1979 to 1989 [38]. The more recent monograph published by the National Cancer Institute, Surveillance Epidemiology, and End Result (SEER) program, used data from the late 1990s, and found similar socioeconomic gradients for all cancer sites for the total population, Whites, and Blacks but did not report data for Latinos or Asians [17]. This prior study used percent of county population living below poverty—which does not capture the substantial differences in social and economic conditions within many large metropolitan counties. Secondly, higher percent poverty counties tend to be rural counties, and lower percent poverty counties tend to be urban counties, so county poverty is highly associated with urban–rural cancer differences, whereas census tract poverty measures are not [39]. In addition, Latinos and Asians in California may be more likely to be recent immigrants as compared to the rest of the country, and thus differentially impact race/ethnicity specific socioeconomic gradients in cancer [32]. Both this prior study and other more recent data show socioeconomic gradients for lung cancer like what we find for cancer site incidence related to tobacco use [6, 17]. Other work specifically in California shows similar findings to ours for colorectal cancer among Latinos, although in our study we did not disaggregate by country of origin [40]. Finally, the analysis of differences in cancer incidence by four categories of poverty across 39 cancer sites shows similar gradients for sites related to tobacco, although this study controlled for race/ethnicity rather than presenting race/ethnicity-stratified results as in our analysis [41].

We found that for all cancer site incidence, for sites related to tobacco use, for screening, and for non-screening/non-tobacco cancers, socioeconomic differences for Whites and Blacks are similar. This is consistent with work using national SEER data [4]. However, in our analyses looking explicitly at incidence rates by socioeconomic strata within different race/ethnic groups (rather than just controlling for SES), some differences were observed. Our findings are also consistent with findings from all of California examining five specific cancer incidence sites using a composite measure of SEP with five categories [18].

Our results offer some suggestions for understanding the underlying mechanisms by which socioeconomic and racial/ethnic differences in cancer incidence emerge. First, for Whites, Blacks, and Asians, individuals living in census tracts with a higher percentage of residents living in poverty are more likely to develop cancer, even after accounting for sites that are related to two well-known factors associated with SEP—tobacco use and screening practices. Understanding the relationship between SEP and cancer incidence is relevant to improve our understanding of the etiology of socioeconomic gradients in cancer incidence and support deeper investigation into the material and psychosocial pathways that lead from adverse socioeconomic conditions to the development of cancer. For cancer sites not related to tobacco or screening, inequalities were found to exist in a generally linear manner across area SEP for Whites, Blacks, and Asians. A number of potential underlying mechanisms exist that may explain our findings including poor diet, in part driven by healthy food access [42] and the cost of healthy food [43], lower rates of physical activity, and contextual factors [44]. Living in a higher poverty area may also lead to greater exposure to environmental hazards [45] and individual psychological stress associated with higher levels of area poverty [46], as well as increased exposure to infections associated with cancer [41]. These speculations, however, warrant future investigation, in particular with combined data sources that provide a larger sample size for differentiating among different countries of origin among the broad Asian and Latino categories used in our analysis [47], and for place of birth [32]. Place of birth is a critical factor for capturing life course exposures not only for Asians and Latinos, but also for U.S. Blacks [48].

From a policy perspective, our results showing substantial socioeconomic gradients for tobacco-related causes highlight the important role of socioeconomic inequalities in cancer incidence for all groups except Latinos. Resources and policies encouraging smoking cessation among lower SEP individuals are clearly well directed.

Some important questions remain unanswered. We have in the current analysis focused on incidence for all stages of each cancer combined, but considerations of how stage of diagnosis related to SEP and race/ethnicity are critical to consider given their impact on racial/ethnic and socioeconomic inequalities in cancer survival [49] and the impact of screening on stage at diagnosis. It is also critical to understand if similar patterns exist in other areas outside California—differences or similarities with other regions of the United States may provide important guidance as to why the observed racial/ethnic and socioeconomic differences are found. A further important direction for research is to determine the extent to which these relationships differ depending on percent poverty at different points in the life course. Finally, the role of place of birth and timing of immigration should be tested in relation to the observed higher incidence rates of cancer among Latinos and Asians living in lower poverty areas.

Acknowledgments We thank the Robert Wood Johnson Foundation Health & Society Scholars program for salary support for DHR at the time this work was initiated, as well as a pilot project grant from the University of California San Francisco/University of California Robert Wood Johnson Foundation Health & Society Scholars site to DHR and RAH for specific funding for this project. DHR is supported by a grant from the National Institute of Aging (Grant No. K01 AG047280). All authors thank Scarlett Lin Gomez for helpful comments on an earlier version of the manuscript. DHR would like to acknowledge funding support from NIH AG047280 and the Robert Wood Johnson Health and Society Scholars Program UC San Francisco/UC Berkeley.

References

1. Ward E, Jemal A, Cokkinides V et al (2004) Cancer disparities by race/ethnicity and socioeconomic status. CA: A Cancer J Clin 54:78–93
2. Siegel RL, Miller KD, Jemal A (2015) Cancer statistics 2015. CA: A Cancer J Clin 65:5–29
3. Ward E, Jemal A, Cokkinides V et al (2004) Cancer disparities by race/ethnicity and socioeconomic status. CA Cancer J Clin 54:78–93
4. McWhorter WP, Schatzkin AG, Horm JW, Brown CC (1989) Contribution of socioeconomic status to black/white differences in cancer incidence. Cancer 63:982–987
5. Devesa S, Grauman D, Blot W, Pennello G, Hoover R, Fraumeni J (1999) Atlas of cancer mortality in the United States 1950-94. Am J Epidemiol. https://doi.org/10.2307/2669813
6. Sidorchuk A, Agardh EE, Aremu O, Hallqvist J, Allebeck P, Moradi T (2009) Socioeconomic differences in lung cancer incidence: a systematic review and meta-analysis. Cancer Causes Control 20:459–471
7. Coughlin SS, King J, Richards TB, Ekwueme DUJCE, Biomarkers P (2006) Cervical cancer screening among women in metropolitan areas of the United States by individual-level and area-based measures of socioeconomic status, 2000 to 2002. Cancer Epidemiol Biomark Prev 15:2154–2159
8. Frederiksen B, Jørgensen T, Brasso K, Holten I, Osler M (2010) Socioeconomic position and participation in colorectal cancer screening. Br J Cancer 103:1496
9. Dailey AB, Brumback BA, Livingston MD et al (2011) Area-level socioeconomic position and repeat mammography screening use: results from the 2005 National Health Interview Survey. Cancer Epidemiol Biomark Prev 20(11):2331–2344
10. Rapiti E, Fioretta G, Schaffar R et al (2009) Impact of socioeconomic status on prostate cancer diagnosis, treatment, and prognosis. Cancer 115:5556–5565
11. Liu L, Cozen W, Bernstein L, Ross RK, Deapen D (2001) Changing relationship between socioeconomic status and prostate cancer incidence. J Natl Cancer Inst 93:705–709
12. Smith GD, Leon D, Shipley MJ, Rose G (1991) Socioeconomic differentials in cancer among men. Int J Epidemiol 20:339–345
13. Hiatt RA, Porco TC, Liu F et al (2014) A multilevel model of postmenopausal breast cancer incidence. Cancer Epidemiol Biomarkers Prev 23:2078–2092

14. Krieger N, Quesenberry C Jr, Peng T et al (1999) Social class, race/ethnicity, and incidence of breast, cervix, colon, lung, and prostate cancer among Asian, Black, Hispanic, and White residents of the San Francisco Bay Area, 1988-92 (United States). Cancer Causes Control 10:525–537
15. Backlund E, Sorlie PD, Johnson NJ (1996) The shapes of the relationship between income and mortality in the United States: evidence from the National Longitudinal Mortality Study. Ann Epidemiol 6:12–20
16. Rehkopf DH, Berkman LF, Coull B, Krieger N (2008) The nonlinear risk of mortality by income level in a healthy population: US National Health and Nutrition Examination Survey mortality follow-up cohort, 1988-2001. BMC Public Health 8:383
17. Singh GK, Miller BA, Hankey BF, Edwards BK (2003) Area socioeconomic variations in U.S. cancer incidence, mortality, stage, treatment, and survival. Bethesda. NIH, Bethesda, MD, pp 1975–1999
18. Yin D, Morris C, Allen M, Cress R, Bates J, Liu L (2010) Does socioeconomic disparity in cancer incidence vary across racial/ethnic groups? Cancer Causes Control 21:1721–1730
19. Vineis P, Alavanja M, Buffler P et al (2004) Tobacco and cancer: recent epidemiological evidence. J Natl Cancer Inst 96:99–106
20. Bureau USC (2010) Census. U.S. Government Publishing Office, Washington, DC
21. Sebelius K (2010) Delayed update of the HSS poverty guidelines for the remainder of 2010. Fed Reg 75(148):45628–45629
22. Lamison-White L (1995) Poverty Areas. In: Bureau CU (ed) Statistical briefs: Department of Commerce. Maryland, Economics and Statistics Administration
23. Krieger N, Chen JT, Waterman PD, Rehkopf DH, Subramanian SV (2005) Painting a truer picture of US socioeconomic and racial/ethnic health inequalities: the public health disparities Geocoding project. Am J Public Health 95:312–323
24. Krieger N, Chen JT, Waterman PD, Rehkopf DH, Yin R, Coull BA (2006) Race/ethnicity and changing US socioeconomic gradients in breast cancer incidence: California and Massachusetts, 1978-2002 (United States). Cancer Causes Control 17:217–226
25. Rehkopf DH, Haughton LT, Chen JT, Waterman PD, Subramanian SV, Krieger N (2006) Monitoring socioeconomic disparities in death: comparing individual-level education and area-based socioeconomic measures. Am J Public Health 96:2135–2138
26. Sorlie PD, Johnson NJ (1996) Validity of education information on the death certificate. Epidemiology 7(4):437–439
27. Everett BG, Rehkopf DH, Rogers RG (2013) The nonlinear relationship between education and mortality: an examination of Cohort, race/ethnic, and gender differences. Popul Res Policy Rev. https://doi.org/10.1007/s11113-013-9299-0
28. Rehkopf DH, Haughton LT, Chen JT, Waterman PD, Subramanian SV, Krieger N (2006) Monitoring socioeconomic disparities in death: comparing individual-level education and area-based socioeconomic measures. Am J Public Health 96:2135–2138
29. Wood S (2006) Generalized additive models: an introduction with R. Chapman & Hall/CRC, Boca Raton
30. Aragon TJ, Fay MP, Wollschlaeger D, Omidpanah A. (2017) epitools. 0.5-9 ed
31. R-Development-Core-Team (2008) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria
32. Singh GK, Hiatt RA (2006) Trends and disparities in socioeconomic and behavioral characteristics, life expectancy, and cause-specific mortality of native-born and foreign-born populations in the United States, 1979-2003. Int J Epidemiol 35:903–919
33. Robinson WS (1950) Ecological correlations and the behavior of individuals. Am Sociol Rev 15:351–357
34. Rehkopf DH, Buka SL (2006) The association between suicide and the socio-economic characteristics of geographical areas: a systematic review. Psychol Med 36:145–157
35. Krieger N, Chen JT, Waterman PD, Rehkopf DH, Subramanian SV (2003) Race/ethnicity, gender, and monitoring socioeconomic gradients in health: a comparison of area-based socioeconomic measures—the public health disparities geocoding project. Am J Public Health 93:1655–1671
36. Davey Smith G, Hart C, Blane D, Hole D (1998) Adverse socioeconomic conditions in childhood and cause specific adult mortality: prospective observational study. BMJ 316:1631–1635
37. Naess O, Strand BH, Smith GD (2007) Childhood and adulthood socioeconomic position across 20 causes of death: a prospective cohort study of 800,000 Norwegian men and women. J Epidemiol Community Health 61:1004–1009
38. Pamuk E, Makuc DM, Heck K, Reuben C, Lochner K (1998) Socioeconomic status and health chartbook. US Department of Health and Human Services, Hyattsville
39. Krieger N, Rehkopf DH, Chen JT, Waterman PD, Marcelli E, Kennedy M (2008) The fall and rise of US inequities in premature mortality: 1960-2002. PLoS Med 5:e46
40. Stern MC, Zhang J, Lee E, Deapen D, Liu L (2016) Disparities in colorectal cancer incidence among Latino subpopulations in California defined by country of origin. Cancer Causes Control 27:147–155
41. Boscoe FP, Johnson CJ, Sherman RL, Stinchcomb DG, Lin G, Henry KA (2014) The relationship between area poverty rate and site-specific cancer incidence in the United States. Cancer 120:2191–2198
42. Dubowitz T, Heron M, Bird CE et al (2008) Neighborhood socioeconomic status and fruit and vegetable intake among whites, blacks, and Mexican Americans in the United States. Am J Clin Nutr 87:1883–1891
43. Drewnowski A, Specter SE (2004) Poverty and obesity: the role of energy density and energy costs. Am J Clin Nutr 79:6–16
44. Grzywacz JG, Marks NF (2001) Social inequalities and exercise during adulthood: toward an ecological perspective. J Health Soc Behav 42:202–220
45. Evans GW, Kantrowitz E (2002) Socioeconomic status and health: the potential role of environmental risk exposure. Annu Rev Public Health 23:303–331
46. Yen IH, Syme SL (1999) The social environment and health: a discussion of the epidemiologic literature. Annu Rev Public Health 20:287–308
47. Kwong SL, Chen MS Jr, Snipes KP, Bal DG, Wright WE (2005) Asian subgroups and cancer incidence and mortality rates in California. Cancer 104:2975–2981
48. Krieger N, Jahn JL, Waterman PD (2017) Jim Crow and estrogen-receptor-negative breast cancer: US-born black and white non-Hispanic women, 1992–2012. Cancer Causes Control 28:49–59
49. Clegg LX, Reichman ME, Miller BA et al (2009) Impact of socioeconomic status on cancer incidence and stage at diagnosis: selected findings from the surveillance, epidemiology, and end results: National Longitudinal Mortality Study. Cancer Causes Control 20:417–435