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Cancer Incidence and Multilevel Measures of Residential Economic and Racial Segregation for Cancer Registries

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Abstract

Background: The handful of studies (<30) on cancer and residential segregation have focused on racial segregation, primarily at the city/town level. We tested a priori hypotheses about choice of measure and level by extending use of the Index of Concentration at the Extremes (ICE) to quantify both economic and racial residential segregation, singly and combined, and conducted analyses for the total population and stratified by race/ethnicity.
Methods: Outcomes comprised Massachusetts incidence rates (2010–2014) for invasive breast, cervical, and lung cancer, analyzed in relation to census tract and city/town ICE measures for income, race/ethnicity, race/ethnicity + income, and the federal poverty line. Multilevel Poisson regression modeled observed counts of incident cases.
Results: Both choice of metric and level mattered. As illustrated by cervical cancer, in models including both the census tract and city/town levels, the rate ratio for the worst to best quintile for the total population was greatest at the census tract level for the ICE for racialized economic segregation (3.0, 95% confidence interval [CI] = 2.1 to 4.3) and least for the poverty measure (1.9, 95% CI = 1.4 to 2.6), with null associations at the city/town level. In analogous models with both levels for lung cancer, however, for the non-Hispanic black and Hispanic populations, the rate ratios for, respectively, the ICE and poverty measures, were larger (and excluded 1) at the city/town compared with the census tract level.
Conclusions: Our study suggests that the ICE for racialized economic segregation, at multiple levels, can be used to improve monitoring and analysis of cancer inequities.

Growing use of multilevel frameworks, methods, and measures in cancer and other health research is advancing understanding of how places' societal and physical conditions shape population health (1–4), including health inequities, that is, differences in health status between social groups that are unfair, unnecessary, and in principle preventable (4–6). One crucial impetus to this work in the United States has been rising income inequality, growing concentrations of low- and high-income neighborhoods, and persistent racial/ethnic residential segregation (7–10).

However, despite increasing interest in geospatial aspects of cancer occurrence and control (3,4) and growing awareness of the need to analyze segregation at multiple levels (2,11–13), including jointly in relation to racial/ethnic and economic segregation (2,13), fewer than 30 studies, to our knowledge, have focused on cancer and residential segregation (14–41). Notably, all of these studies were conducted within the United States and focused solely on racial/ethnic residential segregation at a single level, typically that of the city or higher (14–44). Among these studies, 18 focused on health care access, stage of diagnosis, screening, treatment, or survival (14–31), five on mortality (19,32–35), four on exposure to carcinogenic pollutants (36–39), one on tumor biomarkers (40), and only one on incidence (41). Compounding the invisibility of cancer risks associated with

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residential segregation, neither the US Surveillance, Epidemiology, and End Results (SEER) program nor the National Association of American Cancer Registries (NAACR) includes any measures of residential segregation among their public access place-based data, which are available only at the county level (45,46), and the only census tract data provided by SEER (by special request) is for a "socioeconomic status (SES) composite" variable (47). Yet, residential segregation warrants consideration as a standard metric for monitoring cancer inequities, given its role as a population driver of cancer risk across the cancer continuum and life course via pathways involving the physical and social contexts in which people live and their access to education, health care, affordable nutritious food, recreation, transportation, and employment opportunities (4,42–44).

We accordingly designed our study to test associations between cancer incidence and a new measure of racialized economic segregation that we have recently introduced, one that can be meaningfully used at multiple geographic levels (13,40,48–53). The measure is based on the Index of Concentration at the Extremes (ICE) (54), which was developed in 2001 by one of the foremost US scholars of US racial segregation, Douglas Massey (7,54), to quantify how rising income and wealth inequalities were leading to growing spatial and social economic polarization (54). The ICE quantifies the extent to which the residents of a specified place are concentrated into the top vs bottom categories of variables that measure a specified dimension of privilege or deprivation (54).

Our innovations have been to extend use of the ICE to quantify both racial segregation and racialized economic segregation, and to do so at multiple levels (thus addressing the well-known "Modifiable Areal Unit Problem," whereby effect size can depend on choice of geographic level) (13,40,48–53). Our studies have found that 1) the ICE, and especially the ICE for racialized economic segregation, is more sensitive to detecting inequities than the commonly employed US poverty measure and 2) there is evidence of stronger associations, in multilevel models, at the census tract compared with city/town or county level for the total and non-Hispanic white populations, but with city/town effects still evident for the black and Hispanic populations, likely reflecting how city-level segregation structures health inequities above and beyond immediate residential context (53). Outcomes have included preterm birth (50–52), hypertension (49), premature and cause-specific mortality (50,52,53), fatal and nonfatal weapons-related assaults (13), and exposure to air pollution (48). Our study using SEER data, however, found that the county-level ICE measures and poverty measure were similarly associated with the proportion of breast cancer cases that were estrogen receptor positive (40).

To build on this research, we newly focus on incidence rates for three cancer sites that exhibit distinct and well-documented social gradients: 1) cervical and lung cancer (higher rates positively associated with deprivation) (55–60) and 2) breast cancer (higher rates positively associated with privilege) (55–57,61,62). Our a priori hypotheses were 1) the ICE for racialized economic segregation is more sensitive for detecting health inequities as compared with both the US poverty measure and also solely income or racial/ethnic ICE measures; and 2) census tract compared with city/town ICE measures will show stronger associations, in multilevel models, with incidence rates for the total and white non-Hispanic populations, but city/town effects will remain for the US black and Hispanic populations.

Methods

Study Population and Outcomes

The study base for our observational cross-sectional population-based investigation comprised all residents of the US state of Massachusetts (2010–2014) and incident cases of invasive cancer diagnosed between January 1, 2010, and December 31, 2014, that were recorded by the Massachusetts Cancer Registry (63). The study was approved by the Institutional Review Boards of the Harvard T.H. Chan School of Public Health (HSPH protocol IRB16-1325) and the Massachusetts Cancer Registry (MDPH protocol 946302-2). Available sociodemographic data pertained to age at diagnosis, gender (classified solely as women and men, with no option for transgender), and race/ethnicity, classified using the federal criteria employed by the US census (63,64). The total numbers of invasive cancer cases by site were 28 152 breast (women only), 958 cervix (women only), and 24 372 lung.

Place-Based Measures

We employed three types of place-based measures, pertaining to residential segregation, poverty, and urbanicity (measured using the US National Center for Health Statistics definitions for large metro, small and medium metro, or nonmetro places) (65). To compute the ICE and poverty variables at the census tract and city/town levels, we used data from the five-year 2010–2014 estimate from the American Community Survey (ACS) (66). We did not employ county level because within Massachusetts the primary political and public health jurisdictions are at the city/town, not county, level (67,68).

We employed ArcMap 10.4.1 (69) to geocode the residential address of each case to its latitude and longitude, allowing assignment to census tract and city/town codes; across the study outcomes, only 2.6% to 2.7% of cases could not be geocoded to this level of precision. To create a multilevel data structure in which all city/towns contained at least one census tract, we aggregated the 59 small towns (out of the state's 351 city/towns) that were nested within census tracts that contained two or more towns into 21 "super towns" containing one census tract each; the population in these small towns accounted for 1.1% of the total population. The analytic study base comprised 1478 census tracts nested within 313 city/towns.

We computed the ICE as follows (54):

$$ICE_i = (A_i - P_i)/T_i$$

where A_i, P_i and T_i correspond, respectively, to the number of persons in the ith geographic area who are categorized as belonging to: the most privileged extreme, the most deprived extreme, and the total population whose privilege level was measured. For example, for the ICE for income, A_i = number of persons in the top income households (80^{th} percentile) in neighborhood i; P_i = number of persons in the bottom income households (20^{th} percentile) in neighborhood i; and T_i = total population across all income percentiles in neighborhood i. The ICE accordingly ranges from -1 to 1, respectively connoting areas in which 100% of the population is in the most extreme group for deprivation or in the most extreme group for privilege.

We conceptualized and operationalized our three ICE measures in relation to economic and racial privilege as follows (13,40,48–53):

1. ICE for income: bottom 20th percentile vs top 80th percentile of US household income, with cut-points set at

Table 1. Distribution of total population and incident cases of invasive breast, cervical, and lung cancer*, Massachusetts, 2010–2014

		Site-specific cancer incidence cases		
	Total population	Breast (women only)	Cervical	Lung
Total, No. (%)	6 540 189	28 152 (100.0)	958 (100.0)	24 372 (100.0)
Age, y				
Continuous, mean (SD)	39.7 (22.7)	62.4 (13.9)	52.7 (15.7)	70.2 (11.3)
Categorical, No. (%), y				
<5	349 670 (5.3)	0 (0.0)	0 (0.0)	<5 (<0.1)
5–14	757 475 (11.6)	<5 (<0.1)	0 (0.0)	<5 (<0.1)
15–24	925 794 (14.2)	23 (0.1)	7 (0.7)	21 (0.1)
25–34	875 309 (13.4)	432 (1.5)	110 (11.5)	32 (0.1)
35–44	844 979 (12.9)	2336 (8.3)	217 (22.7)	284 (1.2)
45–54	991 625 (15.2)	5972 (21.2)	217 (22.7)	1907 (7.8)
55–64	843 510 (12.9)	6990 (24.8)	187 (19.5)	5086 (20.9)
65–74	505 744 (7.7)	6514 (23.1)	117 (12.2)	7791 (32.0)
75–84	296 445 (4.5)	4168 (14.8)	71 (7.4)	6835 (28.0)
85+	149 638 (2.3)	1716 (6.1)	32 (3.3)	2413 (9.9)
Unknown)†	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Gender, No. (%)				
Women	3 166 730 (48.4)	28 152 (100.0)	958 (100.0)	12 802 (52.5)
Men	3 373 459 (51.6)	N/A	N/A	11 569 (47.5)
Unknown†	0 (0.0)	0 (0.0)	0 (0.0)	<5 (<0.1)
Race/ethnicity, No. (%)				
White non-Hispanic	4 992 644 (76.3)	24 845 (88.7)	692 (73.0)	22 220 (91.4)
Black non-Hispanic	465 792 (7.1)	1290 (4.6)	91 (9.6)	973 (4.0)
Hispanic	681 824 (10.4)	1034 (3.7)	100 (10.6)	514 (2.1)
Asian and Pacific Islander non-Hispanic	386 287 (5.9)	810 (2.9)	64 (6.8)	573 (2.4)
American Indian/Alaska Native non-Hispanic	13 642 (0.2)	23 (0.1)	<5 (<0.1)	24 (0.1)
Unknown†	0 (0.0)	150 (0.5)	10 (0.1)	68 (0.3)
Urbanicity, No. (%)				
Large metro	4 688 217 (71.7)	19 479 (71.1)	667 (71.6)	16 703 (70.3)
Small and medium metro	1 755 449 (26.8)	7541 (27.5)	251 (26.9)	6706 (28.2)
Nonmetro	96 523 (1.5)	390 (1.4)	14 (1.5)	337 (1.4)
Unknown†	0 (0.0)	742 (2.6)	26 (2.7)	626 (2.6)
City/town characteristics				
City/town, No. (%)	313 (100)			
Unknown		742 (2.6)	26 (2.7)	626 (2.6)
City/town, mean (SD), ICE				
ICE: income	0.15 (0.18)	0.11 (0.19)	0.03 (0.18)	0.07 (0.18)
ICE: race/ethnicity	0.85 (0.15)	0.73 (0.24)	0.64 (0.28)	0.71 (0.25)
ICE: race/ethnicity + income	0.24 (0.13)	0.21 (0.13)	0.16 (0.12)	0.18 (0.12)
City/town, mean (SD), % below poverty	7.6 (5.2)	10.4 (7.2)	13.1 (8.0)	11.3 (7.3)
Census tract characteristics				
CT, No. (%)	1478 (100)			
Unknown		742 (2.6)	26 (2.7)	626 (2.6)
CT, mean (SD), ICE				
ICE: income	0.06 (0.25)	0.12 (0.23)	0.01 (0.24)	0.07 (0.22)
ICE: race/ethnicity	0.67 (0.34)	0.74 (0.29)	0.61 (0.37)	0.72 (0.30)
ICE: race/ethnicity + income	0.18 (0.17)	0.22 (0.16)	0.14 (0.16)	0.18 (0.15)
CT, mean (SD), % below poverty	12.9 (12.1)	9.7 (9.2)	14.2 (12.4)	11.0 (9.9)

*Includes invasive cancers only. CT = census tract; ICE = Index of Concentration at the Extremes; N/A = not applicable.
†Percent missing based on total; otherwise, distributions are based on observed cases only.

less than $20 0000 vs $125 000 or more (70), which we created using ACS Table B19001;

2. ICE for race/ethnicity: non-Hispanic black vs non-Hispanic white, created using ACS Table B03002; and

3. ICE for race/ethnicity + income (ie, racialized economic segregation): black population in the 20th percentile for US household income vs the non-Hispanic white population in the 80th income percentile, created using ACS Tables B19001H and B19001B.

The poverty measure pertained to the percentage of households below the US federal poverty line, which we created using ACS Table B17001. We computed quintiles for the ICE and poverty measures based on their Massachusetts distribution and set Q5 (best off) as the reference group.

Table 2. Invasive breast, cervical, and lung cancer incidence rates (IR) (age-standardized*, per 100 000 person-years), Massachusetts, 2010–2014

	Cancer incidence rates by primary site					
	Breast (women only): IR (95% CI)		Cervical: IR (95% CI)		Lung: IR (95% CI)	
Mass. state-wide rate	133.8	(132.2 to 135.4)	5.1	(4.7 to 5.4)	61.2	(60.4 to 62.0)
Age, y†						
<5	0.0	(0.0 to 0.0)	0.0	(0.0 to 0.0)	0.0	(0.0 to 0.0)
5–14	0.1	(0.0 to 0.3)	0.0	(0.0 to 0.0)	0.1	(0.0 to 0.2)
15–24	1.0	(0.6 to 1.5)	0.3	(0.1 to 0.6)	0.5	(0.3 to 0.7)
25–34	19.0	(17.2 to 20.9)	4.7	(3.9 to 5.7)	0.7	(0.5 to 1.0)
35–44	105.6	(101.3 to 110.0)	9.7	(8.4 to 11.1)	6.6	(5.9 to 7.5)
45–54	228.0	(222.2 to 234.0)	8.3	(7.3 to 9.5)	37.3	(35.6 to 39.0)
55–64	307.6	(300.3 to 315.0)	8.4	(7.2 to 9.7)	117.3	(114.1 to 120.6)
65–74	462.1	(450.8 to 473.7)	7.7	(6.3 to 9.3)	299.2	(292.5 to 306.1)
75–84	464.0	(449.8 to 478.6)	7.9	(6.2 to 10.1)	448.1	(437.4 to 459.0)
85+	323.1	(307.8 to 339.0)	6.2	(4.3 to 8.8)	313.0	(300.5 to 326.0)
Gender						
Women	133.8	(132.2 to 135.4)	5.1	(4.7 to 5.4)	57.9	(56.9 to 58.9)
Men	N/A		N/A		66.6	(65.3 to 67.8)
Race/ethnicity						
White non-Hispanic	140.8	(139.0 to 142.7)	2.4	(2.2 to 2.6)	63.8	(63.0 to 64.7)
Black non-Hispanic	113.6	(107.2 to 119.9)	4.4	(3.5 to 5.4)	53.1	(49.6 to 56.6)
Hispanic	86.9	(81.2 to 92.5)	4.6	(3.6 to 5.6)	30.7	(27.8 to 33.6)
Asian and Pacific Islander non-Hispanic	90.4	(84.0 to 96.9)	3.7	(2.7 to 4.6)	44.0	(40.2 to 47.7)
American Indian/Alaska Native non-Hispanic	64.1	(37.4 to 90.8)	1.5	(0.0 to 4.4)	41.0	(23.5 to 58.6)
Urbanicity‡						
Large metro	135.3	(133.4 to 137.2)	5.0	(4.6 to 5.4)	62.2	(61.2 to 63.1)
Small and medium metro	131.0	(127.9 to 134.0)	5.3	(4.6 to 6.0)	59.6	(58.1 to 61.0)
Non-metro	114.2	(102.3 to 126.2)	4.2	(1.8 to 6.6)	49.7	(44.2 to 55.1)
City/town§ characteristics						
Index of Concentration at the Extremes						
ICE: income (low vs high income)						
Q1 (worst off)	120.7	(118.1 to 123.3)	6.4	(5.8 to 7.0)	67.7	(66.2 to 69.1)
Q2	135.4	(131.7 to 139.1)	5.6	(4.8 to 6.5)	63.3	(61.5 to 65.0)
Q3	133.2	(129.0 to 137.5)	4.5	(3.6 to 5.3)	62.7	(60.6 to 64.8)
Q4	142.0	(137.9 to 146.1)	4.2	(3.5 to 5.0)	59.2	(57.2 to 61.1)
Q5 (best off)	153.4	(148.8 to 157.9)	2.9	(2.2 to 3.6)	45.6	(43.8 to 47.3)
ICE: race/ethnicity (black vs white)						
Q1 (worst off)	128.9	(126.6 to 131.2)	6.1	(5.6 to 6.7)	64.1	(62.9 to 65.3)
Q2	142.5	(138.8 to 146.1)	3.9	(3.3 to 4.6)	60.9	(59.2 to 62.5)
Q3	139.6	(135.3 to 144.0)	4.4	(3.5 to 5.3)	59.4	(57.3 to 61.4)
Q4	133.6	(128.3 to 138.9)	3.7	(2.7 to 4.7)	61.1	(58.5 to 63.6)
Q5 (best off)	131.7	(125.6 to 137.7)	4.1	(2.9 to 5.3)	50.0	(47.4 to 52.6)
ICE: race/ethnicity + income (low-income black vs high-income white)						
Q1 (worst off)	120.5	(117.9 to 123.1)	6.5	(5.9 to 7.1)	68.5	(67.1 to 70.0)
Q2	134.0	(130.3 to 137.7)	5.1	(4.3 to 5.9)	61.4	(59.7 to 63.2)
Q3	138.4	(134.0 to 142.7)	5.0	(4.0 to 5.9)	63.6	(61.5 to 65.7)
Q4	141.7	(137.5 to 145.9)	3.6	(2.9 to 4.4)	58.8	(56.8 to 60.8)
Q5 (best off)	152.9	(148.3 to 157.5)	3.2	(2.4 to 3.9)	44.6	(42.9 to 46.4)
% below poverty						
Q1 (worst off)	122.0	(119.6 to 124.5)	6.3	(5.7 to 6.9)	65.1	(63.8 to 66.4)
Q2	134.8	(131.0 to 138.7)	5.3	(4.5 to 6.2)	66.0	(64.2 to 67.9)
Q3	140.2	(135.8 to 144.6)	4.5	(3.6 to 5.4)	60.2	(58.1 to 62.2)
Q4	144.5	(140.2 to 148.8)	3.6	(2.9 to 4.3)	56.1	(54.1 to 58.0)
Q5 (best off)	148.0	(143.2 to 152.7)	3.2	(2.4 to 4.0)	51.0	(49.0 to 53.0)
Census tract characteristics						
Index of Concentration at the Extremes						
ICE: income (low vs high income)						
Q1 (worst off)	114.1	(110.2 to 118.0)	8.2	(7.1 to 9.3)	72.0	(69.7 to 74.3)
Q2	121.6	(118.1 to 125.1)	6.0	(5.1 to 6.8)	67.4	(65.5 to 69.3)
Q3	134.1	(130.6 to 137.7)	5.2	(4.4 to 6.0)	61.4	(59.8 to 63.1)
Q4	141.0	(137.4 to 144.5)	4.3	(3.7 to 5.0)	61.2	(59.5 to 62.8)
Q5 (best off)	149.2	(145.6 to 152.8)	2.9	(2.3 to 3.4)	50.0	(48.5 to 51.5)

(continued)

Table 2. (continued)

	Cancer incidence rates by primary site					
	Breast (women only): IR (95% CI)		Cervical: IR (95% CI)		Lung: IR (95% CI)	
ICE: race/ethnicity (black vs white)						
Q1 (worst off)	114.4	(110.6 to 118.2)	8.3	(7.3 to 9.3)	66.6	(64.4 to 68.8)
Q2	132.1	(128.3 to 136.0)	5.4	(4.6 to 6.2)	66.9	(64.9 to 68.9)
Q3	139.0	(135.4 to 142.6)	4.4	(3.7 to 5.1)	59.5	(57.8 to 61.2)
Q4	141.6	(138.1 to 145.0)	4.6	(3.9 to 5.3)	59.6	(58.0 to 61.2)
Q5 (best off)	136.2	(132.7 to 139.7)	3.6	(2.9 to 4.2)	57.1	(55.5 to 58.7)
ICE: race/ethnicity + income (low-income black vs high-income white)						
Q1 (worst off)	114.3	(110.4 to 118.2)	8.5	(7.4 to 9.6)	69.7	(67.4 to 72.0)
Q2	122.3	(118.7 to 125.9)	5.9	(5.0 to 6.7)	69.1	(67.2 to 71.0)
Q3	132.4	(128.9 to 136.0)	5.5	(4.8 to 6.3)	64.2	(62.5 to 66.0)
Q4	143.2	(139.7 to 146.7)	3.8	(3.2 to 4.4)	59.6	(58.0 to 61.3)
Q5 (best off)	147.9	(144.3 to 151.5)	3.0	(2.4 to 3.6)	48.8	(47.3 to 50.3)
% below poverty						
Q1 (worst off)	110.8	(106.7 to 114.8)	7.7	(6.6 to 8.7)	69.6	(67.2 to 72.0)
Q2	124.3	(120.6 to 127.9)	6.5	(5.6 to 7.4)	65.8	(63.9 to 67.6)
Q3	134.8	(131.3 to 138.3)	5.1	(4.3 to 5.8)	62.8	(61.1 to 64.5)
Q4	141.5	(138.0 to 145.0)	3.9	(3.3 to 4.5)	59.3	(57.7 to 60.9)
Q5 (best off)	146.1	(142.6 to 149.6)	3.5	(2.9 to 4.1)	54.2	(52.7 to 55.7)

*Adjusted to the year 2000 standard population. CT = census tract; ICE = Index of Concentration at the Extremes; N/A = not applicable.
†Age adjustment is not applied to the age-specific rates.
‡Using 2013 National Center for Health Statistics definitions, "large metro" was defined as counties in metropolitan statistical areas of 1 million or more people; "small and medium metro" was defined as counties in metropolitan statistical areas of a population of less than 1 million; "nonmetro" was defined as counties in micropolitan statistical areas and those that did not qualify as micropolitan.
§Using 2010 census boundaries, 59 of 351 Massachusetts towns were nested within census tracts containing two or more towns. To ensure that these towns conformed to the hierarchical structure of the rest of the data (ie, ≥1 census tract nested within a town), we aggregated these 59 towns into 21 "super-towns."

We focused on the black vs white contrasts for two reasons: 1) black vs white residential segregation is the most extreme and persistent form of US racial segregation (2,7,9); and 2) black low-income vs white high-income households, as observed by Massey, "continue to occupy opposite ends of the socioeconomic spectrum in the United States" (7) (p. 324). Related, US research on residential segregation and cancer has consistently observed effects for black vs white segregation, in contrast to mixed results for other measures of ethnic enclaves (eg, for Hispanics and Asian Americans) (42–44).

Statistical Analysis

We first generated descriptive data about the study base and then employed statistical models to test our a priori hypotheses. We thus first computed the age-standardized cancer incidence rates (using the year 2000 standard million to ensure comparability with Massachusetts and other cancer registry data) (63), overall and for each strata of the sociodemographic and place-based variables (50). We then tested our hypotheses using standard multilevel approaches for modeling small-area disease rates (71,72) using mixed-effects Poisson models that included random intercepts for the census tract and city/town levels. For all analyses, we used the observed data, given virtually no missing data (0% for age, <0.1 for gender, and <5% for race/ethnicity, urbanicity, and the census tract and city/town variables). We fit all models in STATA (version 14) using the mepoisson function with log(observed cases) as the dependent variable and log(expected count) as the offset. In all models, we included urbanicity as a covariate, and we included race/ethnicity as a covariate for the total population models and gender as a covariate for the lung cancer models; all models took into account the age structure of the Massachusetts population.

We employed three models to test our hypotheses about levels: Model 1a included only census tract measures for ICE or poverty, Model 1b included only city/town measures, and Model 2 included both levels. To assess whether patterns varied by race/ethnicity, we conducted stratified analyses. Small numbers within the racial/ethnic strata necessitated our comparing risk for the worst-off (Q1+Q2) vs best-off (Q3+Q4+Q5) quintiles for each measure for the black, Hispanic, and white non-Hispanic populations, and also precluded us from running models for the Asian and Pacific Islander and for American Indian and Alaska Native populations.

Results

Table 1 summarizes the distribution of sociodemographic characteristics and geographic contexts of the incident cancer cases and the Massachusetts population (2010–2014). Table 2 presents the age-adjusted cancer incidence rates stratified by these characteristics and contexts, with results showing expected gradients for breast, cervical, and lung cancer, and with gradients typically greater for the ICE compared with poverty measures, and also at the census tract level compared with the city/town level. Thus, as illustrated by the example of cervical cancer, the greatest span in age-standardized incidence rates (per 100 000), contrasting the best-off and worst-off quintiles, occurred for the ICE for racialized economic segregation: 3.0 (95% confidence interval [CI] = 2.4 to 3.6) to 8.5 (95% CI = 7.4 to 9.6) at the census tract level, and 3.2 (95% CI = 2.4 to 3.9) to 6.5 (95% CI = 5.9 to 7.1) at the city/town level. By contrast, for the poverty measure, this span was 3.5 (95% CI = 2.9 to

Table 3. Breast, cervical, and lung cancer* incidence rate ratios (IRR) (95% confidence interval): ICE and poverty, MA city/town and census tract, 2010-2014 for the total population

		ICE: income (low vs high income): IRR (95% CI)		ICE: race/ethnicity (black vs white non-Hispanic): IRR (95% CI)		ICE: race/ethnicity + income (low-income black vs high-income white non-Hispanic): IRR (95% CI)		Poverty (most vs least impoverished): IRR (95% CI)	
Outcome	Quintile comparisons	CT	City/town	CT	City/town	CT	City/town	CT	City/town
Breast cancer incidence (women only)	Model 1 (a, b): only 1 level	1a	1b	1a	1b	1a	1b	1a	1b
	Q1 (worst off)	0.86 (0.82 to 0.91)	0.86 (0.82 to 0.90)	1.01 (0.95 to 1.08)	1.09 (1.02 to 1.16)	0.89 (0.84 to 0.94)	0.86 (0.81 to 0.90)	0.88 (0.83 to 0.93)	0.90 (0.85 to 0.95)
	Q2	0.86 (0.82 to 0.91)	0.90 (0.85 to 0.94)	1.04 (0.99 to 1.09)	1.11 (1.04 to 1.18)	0.88 (0.84 to 0.93)	0.90 (0.85 to 0.95)	0.91 (0.86 to 0.95)	0.93 (0.88 to 0.99)
	Q3	0.92 (0.88 to 0.96)	0.87 (0.83 to 0.92)	1.05 (1.00 to 1.09)	1.09 (1.01 to 1.17)	0.91 (0.87 to 0.95)	0.90 (0.85 to 0.95)	0.95 (0.91 to 0.99)	0.94 (0.88 to 1.00)
	Q4	0.94 (0.90 to 0.98)	0.92 (0.88 to 0.97)	1.05 (1.01 to 1.10)	1.02 (0.95 to 1.10)	0.96 (0.92 to 1.01)	0.93 (0.88 to 0.99)	0.97 (0.93 to 1.01)	0.98 (0.93 to 1.04)
	Q5 (best off) (referent)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Model 2: both levels								
	Q1 (worst off)	0.89 (0.83 to 0.96)	0.93 (0.87 to 1.00)	0.95 (0.88 to 1.03)	1.11 (1.02 to 1.21)	0.94 (0.88 to 1.01)	0.91 (0.84 to 0.98)	0.91 (0.85 to 0.97)	0.95 (0.89 to 1.02)
	Q2	0.90 (0.84 to 0.95)	0.95 (0.89 to 1.02)	0.98 (0.91 to 1.04)	1.11 (1.03 to 1.21)	0.93 (0.87 to 0.99)	0.93 (0.87 to 1.00)	0.93 (0.88 to 0.98)	0.96 (0.90 to 1.03)
	Q3	0.95 (0.90 to 1.00)	0.90 (0.84 to 0.96)	0.98 (0.93 to 1.05)	1.09 (1.00 to 1.17)	0.95 (0.90 to 1.00)	0.92 (0.86 to 0.98)	0.97 (0.92 to 1.02)	0.95 (0.90 to 1.02)
	Q4	0.97 (0.93 to 1.02)	0.94 (0.89 to 0.99)	1.01 (0.96 to 1.06)	1.02 (0.94 to 1.10)	1.00 (0.95 to 1.05)	0.94 (0.88 to 0.99)	0.98 (0.94 to 1.02)	0.99 (0.93 to 1.05)
	Q5 (best off) (referent)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cervical cancer incidence	Model 1 (a, b): only 1 level	1a	1b	1a	1b	1a	1b	1a	1b
	Q1 (worst off)	2.82 (2.20 to 3.63)	2.31 (1.74 to 3.05)	2.44 (1.89 to 3.15)	1.42 (1.04 to 1.94)	2.87 (2.26 to 3.65)	2.14 (1.63 to 2.81)	2.14 (1.67 to 2.74)	1.96 (1.48 to 2.58)
	Q2	2.13 (1.68 to 2.71)	1.93 (1.44 to 2.58)	1.57 (1.24 to 1.99)	0.97 (0.69 to 1.36)	1.96 (1.55 to 2.48)	1.64 (1.23 to 2.19)	1.86 (1.49 to 2.32)	1.67 (1.24 to 2.25)
	Q3	1.78 (1.40 to 2.26)	1.63 (1.20 to 2.21)	1.32 (1.04 to 1.67)	1.08 (0.76 to 1.53)	1.88 (1.49 to 2.37)	1.61 (1.19 to 2.16)	1.48 (1.18 to 1.85)	1.41 (1.03 to 1.93)
	Q4	1.53 (1.21 to 1.95)	1.50 (1.11 to 2.03)	1.35 (1.08 to 1.70)	0.88 (0.60 to 1.30)	1.31 (1.03 to 1.66)	1.23 (0.90 to 1.67)	1.15 (0.91 to 1.45)	1.2 (0.88 to 1.65)
	Q5 (best off) (referent)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Model 2: both levels								
	Q1 (worst off)	2.61 (1.85 to 3.67)	1.19 (0.81 to 1.73)	2.54 (1.75 to 3.68)	0.84 (0.55 to 1.29)	3.02 (2.13 to 4.27)	0.96 (0.67 to 1.38)	1.88 (1.38 to 2.55)	1.29 (0.92 to 1.82)
	Q2	1.96 (1.41 to 2.72)	1.20 (0.84 to 1.74)	1.65 (1.16 to 2.36)	0.71 (0.47 to 1.07)	2.05 (1.47 to 2.86)	0.94 (0.66 to 1.34)	1.63 (1.23 to 2.16)	1.32 (0.94 to 1.85)
	Q3	1.64 (1.21 to 2.23)	1.15 (0.80 to 1.64)	1.46 (1.05 to 2.04)	0.84 (0.57 to 1.25)	1.91 (1.41 to 2.60)	1.11 (0.78 to 1.57)	1.32 (1.01 to 1.71)	1.25 (0.89 to 1.75)
	Q4	1.42 (1.08 to 1.87)	1.24 (0.89 to 1.71)	1.47 (1.11 to 1.95)	0.82 (0.55 to 1.21)	1.28 (0.97 to 1.71)	1.03 (0.74 to 1.43)	1.08 (0.85 to 1.38)	1.14 (0.82 to 1.58)
	Q5 (best off) (referent)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lung cancer incidence	Model 1 (a, b): only 1 level	1a	1b	1a	1b	1a	1b	1a	1b
	Q1 (worst off)	1.67 (1.55 to 1.79)	1.79 (1.64 to 1.96)	1.46 (1.34 to 1.58)	1.35 (1.20 to 1.51)	1.72 (1.60 to 1.85)	1.87 (1.72 to 2.03)	1.49 (1.39 to 1.60)	1.45 (1.31 to 1.60)
	Q2	1.43 (1.35 to 1.53)	1.49 (1.36 to 1.63)	1.27 (1.18 to 1.36)	1.22 (1.09 to 1.37)	1.49 (1.40 to 1.59)	1.52 (1.40 to 1.66)	1.25 (1.17 to 1.33)	1.34 (1.21 to 1.48)
	Q3	1.25 (1.18 to 1.33)	1.44 (1.31 to 1.57)	1.10 (1.04 to 1.18)	1.20 (1.07 to 1.35)	1.35 (1.27 to 1.43)	1.48 (1.36 to 1.61)	1.16 (1.10 to 1.23)	1.17 (1.06 to 1.30)
	Q4	1.20 (1.13 to 1.27)	1.32 (1.21 to 1.45)	1.05 (0.99 to 1.11)	1.21 (1.07 to 1.37)	1.21 (1.14 to 1.28)	1.37 (1.26 to 1.49)	1.08 (1.03 to 1.15)	1.12 (1.02 to 1.24)
	Q5 (best off) (referent)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Model 2: both levels								
	Q1 (worst off)	1.48 (1.36 to 1.61)	1.39 (1.25 to 1.55)	1.44 (1.31 to 1.59)	1.12 (0.99 to 1.28)	1.52 (1.40 to 1.66)	1.40 (1.26 to 1.55)	1.41 (1.30 to 1.53)	1.22 (1.10 to 1.36)
	Q2	1.27 (1.18 to 1.37)	1.28 (1.16 to 1.42)	1.25 (1.15 to 1.36)	1.15 (1.02 to 1.30)	1.32 (1.23 to 1.43)	1.26 (1.14 to 1.39)	1.18 (1.10 to 1.26)	1.23 (1.10 to 1.37)
	Q3	1.13 (1.06 to 1.22)	1.30 (1.18 to 1.44)	1.09 (1.01 to 1.17)	1.17 (1.04 to 1.33)	1.23 (1.14 to 1.32)	1.30 (1.18 to 1.43)	1.11 (1.04 to 1.18)	1.12 (1.00 to 1.24)
	Q4	1.11 (1.04 to 1.18)	1.25 (1.15 to 1.37)	1.03 (0.96 to 1.10)	1.21 (1.07 to 1.36)	1.11 (1.04 to 1.18)	1.29 (1.18 to 1.41)	1.06 (1.00 to 1.12)	1.09 (0.99 to 1.21)
	Q5 (best off) (referent)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

*Model 1a includes only the census tract measure, Model 1b includes only the city/town measure, and Model 2 includes measures from both levels. All models adjust for race/ethnicity and urbanicity. The lung cancer model also adjusts for gender. All models control for age. CT = census tract; ICE = Index of Concentration at the Extremes.

Table 4. Breast, cervical, and lung cancer incidence rate ratios (IRR) (95% CI): ICE and poverty, MA city/town, and census tract, 2010–2014, stratified by race/ethnicity

Outcome	Quintile comparisons: Q1+Q2 (worse off) vs Q3+Q4+Q5 (better off; ref)	ICE: income (low vs high income): IRR (95% CI)		ICE: race/ethnicity (black vs white non-Hispanic): IRR (95% CI)		ICE: race/ethnicity + income (low-income black vs high-income white non-Hispanic): IRR (95% CI)		Poverty: (most vs least impoverished): IRR (95% CI)	
		CT	City/town	CT	City/town	CT	City/town	CT	City/town
Breast cancer incidence (women only)	Model 1 (a, b): only 1 level	1a	1b	1a	1b	1a	1b	1a	1b
	White non-Hispanic	0.92 (0.89 to 0.95)	0.92 (0.89 to 0.95)	1.01 (0.98 to 1.05)	1.09 (1.04 to 1.13)	0.93 (0.90 to 0.96)	0.93 (0.90 to 0.96)	0.94 (0.91 to 0.97)	0.93 (0.90 to 0.97)
	Black non-Hispanic	0.82 (0.67 to 0.99)	0.87 (0.68 to 1.12)	0.82 (0.64 to 1.06)	0.93 (0.56 to 1.52)	0.82 (0.67 to 1.00)	0.91 (0.70 to 1.18)	0.99 (0.81 to 1.21)	0.90 (0.69 to 1.19)
	Hispanics	0.88 (0.74 to 1.05)	1.00 (0.80 to 1.24)	0.98 (0.80 to 1.20)	1.24 (0.80 to 1.92)	0.93 (0.77 to 1.11)	0.96 (0.77 to 1.20)	0.90 (0.75 to 1.07)	1.12 (0.88 to 1.43)
	Model 2: both levels								
	White non-Hispanic	0.95 (0.91 to 0.98)	0.95 (0.91 to 0.99)	0.99 (0.95 to 1.02)	1.09 (1.04 to 1.15)	0.95 (0.92 to 0.99)	0.95 (0.91 to 1.00)	0.95 (0.92 to 0.99)	0.96 (0.93 to 1.00)
	Black non-Hispanic	0.82 (0.65 to 1.03)	1.00 (0.74 to 1.35)	0.81 (0.61 to 1.06)	1.10 (0.64 to 1.88)	0.79 (0.62 to 1.01)	1.08 (0.79 to 1.49)	1.04 (0.82 to 1.32)	0.88 (0.64 to 1.21)
	Hispanics	0.82 (0.65 to 1.02)	1.17 (0.88 to 1.55)	0.92 (0.73 to 1.15)	1.34 (0.83 to 2.16)	0.91 (0.72 to 1.16)	1.03 (0.77 to 1.38)	0.78 (0.63 to 0.96)	1.36 (1.02 to 1.83)
Cervical cancer incidence	Model 1 (a, b): only 1 level	1a	1b	1a	1b	1a	1b	1a	1b
	White non-Hispanic	1.65 (1.40 to 1.95)	1.51 (1.24 to 1.82)	1.34 (1.13 to 1.57)	1.26 (1.01 to 1.56)	1.85 (1.57 to 2.17)	1.55 (1.28 to 1.87)	1.60 (1.36 to 1.89)	1.48 (1.22 to 1.79)
	Black non-Hispanic	1.16 (0.62 to 2.18)	2.16 (0.77 to 6.04)	1.04 (0.42 to 2.61)	N/E*	1.37 (0.67 to 2.79)	2.50 (0.77 to 8.09)	1.36 (0.69 to 2.69)	1.57 (0.56 to 4.37)
	Hispanics	2.22 (1.03 to 4.82)	2.49 (0.91 to 6.79)	1.84 (0.80 to 4.23)	2.72 (0.38 to 19.55)	2.43 (1.06 to 5.57)	2.24 (0.82 to 6.11)	2.12 (0.98 to 4.59)	4.04 (1.00 to 16.40)
	Model 2: both levels								
	White non-Hispanic	1.53 (1.25 to 1.88)	1.14 (0.91 to 1.44)	1.30 (1.08 to 1.57)	1.08 (0.84 to 1.38)	1.80 (1.46 to 2.22)	1.04 (0.83 to 1.32)	1.49 (1.23 to 1.81)	1.17 (0.93 to 1.46)
	Black non-Hispanic	0.82 (0.40 to 1.67)	2.51 (0.79 to 8.01)	0.84 (0.34 to 2.11)	N/E*	0.94 (0.42 to 2.11)	2.62 (0.69 to 9.93)	1.22 (0.56 to 2.68)	1.35 (0.41 to 4.42)
	Hispanics	1.76 (0.68 to 4.51)	1.61 (0.47 to 5.49)	1.64 (0.66 to 4.05)	1.74 (0.20 to 14.81)	2.19 (0.78 to 6.20)	1.22 (0.35 to 4.29)	1.45 (0.62 to 3.39)	3.02 (0.64 to 14.15)
Lung cancer incidence	Model 1 (a, b): only 1 level	1a	1b	1a	1b	1a	1b	1a	1b
	White non-Hispanic	1.23 (1.18 to 1.29)	1.34 (1.26 to 1.44)	1.17 (1.11 to 1.22)	1.14 (1.05 to 1.23)	1.29 (1.23 to 1.35)	1.35 (1.27 to 1.44)	1.18 (1.13 to 1.23)	1.24 (1.16 to 1.33)
	Black non-Hispanic	1.25 (0.97 to 1.62)	1.97 (1.35 to 2.88)	0.87 (0.65 to 1.17)	1.26 (0.64 to 2.47)	1.39 (1.06 to 1.82)	1.87 (1.27 to 2.75)	1.34 (1.02 to 1.75)	1.54 (1.04 to 2.28)
	Hispanics	1.18 (0.88 to 1.56)	1.37 (0.93 to 2.01)	1.28 (0.92 to 1.79)	1.55 (0.76 to 3.17)	1.31 (0.97 to 1.77)	1.48 (0.98 to 2.23)	1.21 (0.90 to 1.62)	1.71 (1.09 to 2.70)
	Model 2: both levels								
	White non-Hispanic	1.17 (1.11 to 1.23)	1.22 (1.13 to 1.31)	1.15 (1.10 to 1.21)	1.06 (0.98 to 1.15)	1.23 (1.17 to 1.29)	1.18 (1.10 to 1.27)	1.15 (1.09 to 1.20)	1.15 (1.07 to 1.24)
	Black non-Hispanic	0.98 (0.74 to 1.31)	2.00 (1.30 to 3.08)	0.82 (0.60 to 1.12)	1.46 (0.72 to 2.98)	1.13 (0.83 to 1.55)	1.70 (1.08 to 2.67)	1.20 (0.89 to 1.63)	1.36 (0.87 to 2.11)
	Hispanics	1.02 (0.72 to 1.45)	1.35 (0.84 to 2.16)	1.20 (0.83 to 1.74)	1.33 (0.60 to 2.91)	1.15 (0.80 to 1.66)	1.33 (0.81 to 2.19)	0.99 (0.71 to 1.38)	1.73 (1.03 to 2.91)

*Rate ratio not estimable because all 90 deaths due to cervical cancer among non-Hispanic black women were in quintiles 1 and 2 (the "worse off" category) of the ICE race/ethnicity measure at the city/town level. Model 1a includes only the census tract measure; Model 1b includes only the city/town measure; Model 2 includes measures from both levels. All models include gender (women; men; except for gender-specific outcomes) and urbanicity (large metro; medium and small metro; nonmetro), and control for age. CI = confidence interval; CT = census tract; ICE = Index of Concentration at the Extremes; IRR = incidence rate ratio.

4.1) to 7.7 (95% CI = 6.6 to 8.7) at the census tract level, vs 3.2 (95% CI = 2.4 to 4.0) to 6.3 (95% CI = 5.7 to 6.9) at the city/town level.

Table 3 presents the results, for the total population, of the analytic multilevel models designed to test our study hypotheses. Three patterns stand out for cervical cancer and lung cancer for the total population. First, the Model 1 Q1 (worst-off) vs Q5 (best off) rate ratio consistently equaled or exceeded 1.3 (with 95% CI excluding 1) for all the ICE measures and the poverty measure. Second, inclusion of both levels, in Model 2, led to greater attenuation of the city/town-level rate ratios compared with the census tract rate ratios, especially for cervical cancer (for which the city/town-level rate ratios were rendered null for all the ICE measures and the poverty measure). Third, in Model 2, the greatest point estimate for the Q1 vs Q5 rate ratio was consistently observed for the ICE for racialized economic segregation, and the lowest point estimate was observed for the poverty measure, as illustrated by cervical cancer, for which the Q1 vs Q5 rate ratio was greatest at the census tract level for the ICE for racialized economic segregation (3.0, 95% CI = 2.1 to 4.3) and least for the poverty measure (1.9, 95% CI = 1.4 to 2.6), with null associations at the city/town level.

By contrast, for breast cancer, the Q1 vs Q5 rate ratios were similar across the two ICE measures which included income, and also the poverty measure, and attenuation of estimates in Model 2 compared with Models 1a and 1b was both small and similar for the census tract– and city/town-level measures. In Model 2, the Q1 vs Q5 rate ratio for the ICE for income equaled 0.9 (95% CI = 0.8 to 1.0) at the census tract level and 0.9 (95% CI = 0.9 to 1.0) at the city/town level; for the poverty measure, these rate ratios, respectively, equaled 0.9 (95% CI = 0.9 to 1.0) and 1.0 (95% CI = 0.9 to 1.0).

Analyses stratified by race/ethnicity (Table 4) were less informative because of small numbers and thus large 95% confidence intervals, but they nevertheless suggested effect modification by race/ethnicity. Considering the site least affected by small numbers, that is, lung cancer, the multilevel analyses (Model 2) for the white non-Hispanic population yielded rate ratios for the worst-off (Q1+Q2) vs best-off (Q3+Q4+Q5) quintiles that hovered around 1.2 (95% CI excluding 1) at both the census tract and city/town levels, regardless of measure used. By contrast, the 95% confidence interval for these Model 2 rate ratios for the non-Hispanic black population excluded 1 solely at the city/town level, for both the ICE for racialized economic segregation (1.7, 95% CI = 1.2 to 2. 7) and the ICE for income (2.0, 95% CI = 1.3 to 3.1); among the Hispanic population, in Model 2 only, the poverty measure at the city/town level yielded a similar rate ratio (1.7, 95% CI = 1.0 to 2.9).

Discussion

Our results indicate that analysis and monitoring of inequities in cancer incidence may be improved by inclusion of measures of residential economic and racial segregation, both singly and combined, at both the census tract and city/town levels. The findings additionally support reporting of results stratified by race/ethnicity.

Our study has both limitations and strengths. One limitation is that we analyzed cancer incidence data for only one state, with findings potentially not generalizable to other US states. Second, we relied on cancer registry data for classification of cases' race/ethnicity, which are data obtained from medical records and thus typically not by self-report (73), whereas the denominator data relied on the self-report data in the US census (64). However, research indicates that bias introduced by racial/ethnic misclassification is low for the racial/ethnic groups for whom we conducted the stratified analyses (73).

The ICE and poverty measures likewise could be affected by instability in the ACS data, whose data are based on probability samples, for which sampling frames change annually (66). However, to mitigate against this problem, we 1) used the ACS five-year data and used quintiles for the ICE and poverty measures (50–53) and 2) employed models that used expected counts, thereby minimizing problems induced by potential numerator-denominator mismatch (71). Limiting etiologic interpretation, we lacked access to data on individuals' lifetime residential histories; nevertheless, our findings do quantify the population patterns of cancer at diagnosis. Moreover, high concordance exists in the United States between childhood and adult neighborhood economic conditions (9,10), and correction for area residential mobility bias in a French study increased the magnitude of economic disparities in cancer incidence (74). City/towns and census tracts, moreover, are geographical units employed to guide policy decisions and allocation of resources, whether or not individuals are aware of the census tract in which they reside (75,76). Our findings, which are in accordance with our a priori hypotheses, are thus likely not seriously compromised by bias.

We note four considerations supporting our recommendation for using multilevel measures of racialized economic segregation for monitoring cancer inequities. First, the ICE measure we employed can readily and comparably be employed, at multiple geographic levels, by cancer registries throughout the United States (40), and thus offers a means to avoid the contemporary nonstandardized use in US cancer research of diverse single-level segregation measures (42–44), which compromises the ability to compare results across time and place. Second, our new findings for cancer incidence are consistent with our past ICE findings regarding levels and choice of metric and effect modification by race/ethnicity for a range of other outcomes (13,40,48–53), and the gradients for each cancer site were in the expected direction (55–62). Third, other research has shown the ICE to be independently associated with health and social outcomes above and beyond individual- and household-level economic and sociodemographic characteristics (54,76,77). Fourth, this recommendation is in accordance with new calls for using multilevel measures of residential segregation, which to date remain uncommon in the population science literature (2–4,7–10). Future avenues of research meriting pursuit include 1) replicating this study in other cancer registries, including nationally; 2) exploring the use of additional ICE metrics to capture other dimensions of racial/ethnic segregation (eg, Hispanic vs non-Hispanic white) and additional social groups (eg, US-born vs foreign-born); and 3) designing etiologic studies to test hypotheses about specific pathways by which residential segregation structures population risk of cancer across the cancer continuum and across the life course (3,4,42–44).

In closing, both reproducibility of findings and consistent monitoring of the impact of residential segregation on the population burden of cancer across the cancer continuum require use of conceptually valid measures that can readily be generated and used by cancer registries at multiple levels in a consistent manner. Our study suggests that the ICE we have developed to quantify racialized economic segregation can help achieve this objective.

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