Neighborhood-Level Socioeconomic Disadvantage and Adherence to Guidelines for the Evaluation of Patients With Incidentally Detected Pulmonary Nodules

Jacob M. Abrahams, BS; Beth Creekmur, MA; Janet Shin Lee, MS; In-Lu Amy Liu, MS; Mayra Macias, MS; and Michael K. Gould, MD

BACKGROUND: The management of incidental pulmonary nodules is guided by recommendations set forth by the Fleischner Society. Although most pulmonary nodules are benign, timely and evidence-based follow-up can reduce morbidity and mortality. There are known socioeconomic disparities for engagement with recommended cancer screenings; however, it is unclear whether disparities exist for follow-up of incidentally detected pulmonary lesions.

RESEARCH QUESTION: Do patients residing in more socioeconomically deprived neighborhoods have reduced likelihood of adherence to guideline-recommended follow-up of incidentally detected pulmonary nodules?

STUDY DESIGN AND METHODS: We assembled a retrospective cohort of 32,965 patients within a large, regional integrated health care system with a defined membership who had a pulmonary nodule $\leq$ 30 mm identified on diagnostic CT scan between 2012 and 2016. Patients with prior history of malignancy were excluded. Participants were subsequently divided into quartiles using the Neighborhood Deprivation Index as a metric for socioeconomic status. Adherence was ascertained using International Classification of Diseases, Ninth Revision-coded or Current Prodecural Terminology-coded imaging or biopsy to determine if follow-up was performed within an interval specified by 2005 Fleischner Society guidelines (with a $\pm$ 33% margin of error) based on each patient's nodule characteristics. Negative binomial regression was performed to determine the association between neighborhood-level deprivation and adherence to guideline-concordant care, with and without adjustment for plausible confounders.

RESULTS: Only 49.6% of patients had follow-up imaging or other diagnostic procedure performed within the guideline-recommended time frame. There was a 3% reduction in adherence to follow-up for patients residing in the most socioeconomically deprived neighborhood quartile (relative risk [RR], 0.97; 95% CI, 0.94-1.0) compared with the least deprived quartile. Smoking status was also associated with worse adherence (previous tobacco use vs does not smoke: RR, 0.67; 95% CI, 0.65-0.69; active tobacco use vs does not smoke: RR, 0.73; 95% CI, 0.70-0.76). Multimorbidity, and congestive heart failure in particular, was associated with decreased adherence to guideline-recommended care (Charlson Comorbidity Index 3 vs 0: RR, 0.93; 95% CI, 0.89-0.97; history of congestive heart failure: RR, 0.93; 95% CI, 0.90-0.97).

INTERPRETATION: In the context of poor adherence overall, patients residing in the most socioeconomically deprived neighborhoods were shown to be less likely to receive care in concordance with Fleischner Society recommendations for management of incidental pulmonary nodules.

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KEY WORDS: adherence; guidelines; pulmonary nodule; socioeconomic status

Take-Home Points

Study Question: Do patients residing in more socioeconomically deprived neighborhoods as measured by the Neighborhood Deprivation Index have decreased rates of guideline-concordant follow-up of incidentally found pulmonary nodules?

Results: Patients residing in the most socioeconomically deprived quartile as measured by the Neighborhood Deprivation Index are 3% to 7% less likely to receive guideline-concordant care, consistent with the Fleischner Society recommendations.

Interpretation: Upstream social factors may result in decreased rates of follow-up of potentially malignant pulmonary findings.

Annually, nearly 1.6 million individuals are found to have a pulmonary nodule in the United States, with nearly 1 in 3 diagnostic chest CT scans revealing a pulmonary nodule as an incidental finding.[1] Although most of these nodules are benign, the probability of malignancy has been found to vary with nodule size, history of tobacco use, edge characteristics, and presence of calcification on CT scan.[2] Depending on the likelihood of malignancy derived from these characteristics, guidelines suggest surgical referral for the most worrisome nodules, nonsurgical biopsy or functional imaging with PET scan for medium risk nodules, or surveillance imaging with chest CT scan for low probability nodules.[3]

At the neighborhood level, income is strongly associated with a greater burden of malignancy and poorer outcomes after a cancer diagnosis.[4] Although income is one metric of socioeconomic status, many studies have used validated metrics of neighborhood-level socioeconomic deprivation, which include multiple weighted determinates of relative deprivation (eg, educational attainment, income, employment, demographic characteristics by census tract). Composite metrics of neighborhood socioeconomic deprivation, including the Area Deprivation Index, Social Vulnerability Index, and Neighborhood Deprivation Index (NDI), have been previously leveraged to identify both a higher prevalence and mortality of lung cancer among individuals residing in areas with higher relative socioeconomic deprivation.[5]

Although previous research has identified disparate lung cancer mortality and morbidity associated with area level deprivation, the association between these metrics and cancer diagnostic practices is unclear. Previous studies have identified the Area Deprivation Index as a factor associated with adherence to recommended screening and follow-up of chronic conditions.[6,7] Furthermore, studies have demonstrated that neighborhood deprivation is independently associated with worse adherence to US Preventive Services Task Force (USPSTF) recommended screening for breast, colorectal, and cervical malignancies.[8,9] Given that localized non-small cell lung cancer is amenable to resection, early detection is essential to reduce morbidity and mortality.[10] Early detection through screening has been recommended by the USPSTF for populations deemed at risk; however, adherence to these guidelines varies depending on individual clinical and sociodemographic characteristics.[11] For individuals undergoing recommended screening due to longstanding tobacco use, better adherence has been associated with more worrisome findings in previous studies.[12] Racial disparities in the initiation of screening have also been noted in previous studies.[13] Although these studies have examined and evaluated potential patient factors associated with decreased adherence among a population deemed eligible for screening according to USPSTF guidelines, few studies have investigated factors associated with adherence to follow-up of pulmonary nodules detected incidentally on chest CT scan.

The evaluation of incidental pulmonary nodules is guided by published recommendations from the Fleischner Society and the American College of Chest Physicians (CHEST).[3,14-16] Studies evaluating resource

ABBREVIATIONS: KPSC = Kaiser Permanente Southern California; NDI = Neighborhood Deprivation Index; NLP = natural language processing; RR = relative risk; USPSTF = United States Preventive Services Task Force

AFFILIATIONS: From the Kaiser Permanente Bernard J. Tyson School of Medicine (J. M. A.); the Department of Research and Evaluation (B. C., J. S. L., I.-L. A. L., and M. M.), Kaiser Permanente Southern California; and the Department of Health Systems Science (M. K. G.), Kaiser Permanente Bernard J. Tyson School of Medicine, Pasadena, CA.

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CORRESPONDENCE TO: Jacob M. Abrahams, BS; email: jacob.m.abrahams@kp.org

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utilization for pulmonary nodule evaluation have found guideline-discordant underutilization rates of at least 30% to 40%.[17-22] Although a low rate of guideline-concordant care for incidental pulmonary nodule management has been established, few studies have evaluated clinical and demographic factors associated with adherence. One such study found a modest increase in adherence for patients seen by a pulmonologist, patients with larger pulmonary nodules, and those with a history of COPD, and a lower rate of adherence for patients of Hispanic descent.[20] Another study of 419 patients with incidental nodules found adherence was associated with communication of results to the patient and referring physician, without any clear association with demographic variables.[19] One study demonstrated low socioeconomic status, as measured by the Social Vulnerability Index, and residential segregation as predictors of poor adherence to guideline-concordant care.[23] To date, there has not been a study primarily evaluating the role of socioeconomic status as measured by the NDI in patient adherence with recommendations for nodule evaluation, and no study evaluating possible disparities has been conducted within an integrated care system. Although overall adherence is poor, and disparities exist in adherence to routine screening, it is unclear if there are associations between sociodemographic characteristics and adherence with the recommended evaluation of incidentally found nodules, and which, if any, disparities exist in this population.

Study Design and Methods

We conducted a retrospective cohort study of participants aged > 35 years with pulmonary nodules detected on diagnostic chest CT scans between 2012 and 2016. This cohort was assembled using dictated radiology reports from the Kaiser Permanente Southern California (KPSC) Radiology Information System. We applied a validated natural language processing (NLP) algorithm to all chest CT scan reports from this time period to identify members with incidentally detected nodules measuring 2 to 30 mm in widest diameter. NLP was also used to extract information about nodule size and other characteristics from dictated radiology reports.[24] Based on extracted nodule characteristics and participant smoking history, we determined the recommended timing and type of follow-up testing using the 2005 Fleischner Society guidelines, which were operational during the study time period. Adherence was then quantified by determination of presence or absence of subsequent chest CT scanning or biopsy within the recommended time frame. Participant NDI was determined as subsequently described, and the cohort was divided into quartiles. Adjusted and unadjusted regression analyses were performed to determine the relationship between NDI and adherence to guideline-recommended care. The study received expedited approval from the KPSC institutional review board (approval #5804).

Study Setting

KPSC is an integrated health care system that provides care to > 4.7 million members. The membership of KPSC is largely representative of the Southern California population.[25] Previous analysis of the demographics of the membership pool of KPSC showed that neighborhood-level income, racial and ethnic background, age, and education were largely aligned with US Census Data, with only a marginal decrease in the proportion of members living in extreme poverty or in neighborhoods with high education attainment.[25] During the study period, most patients with pulmonary nodules were managed by primary care or pulmonary medicine physicians in 1 of 15 medical center service areas in the Southern California region. Most chest CT scans were interpreted by general radiologists. Radiologists were provided with standardized templates that summarized the Fleischner Society recommendations for nodule evaluation, but the use of templates was not mandatory, and a minority of radiologists developed and used their own templates (or no template) instead of the standardized one. During the interval of this study, a system for monitoring pulmonary nodules was not in place; however, such a system has subsequently been implemented.

Data Sources

Patient clinical and demographic data were drawn from the KPSC Radiology Information System and Service Files, the local cancer registry, and the KPSC Research Data Warehouse, which contains curated, structured data from longitudinal electronic health records, fully implemented in our health system since 2007. Data from these sources link member sociodemographic information, including geocoded NDI, with comprehensive data from outpatient, inpatient, laboratory, pharmacy, imaging, and emergency department encounters, as documented in the electronic health record. Due to the defined membership and fully integrated model, outside claims

are infrequent and largely limited to emergency care. Thus, receipt of routine surveillance imaging outside the system would be extremely uncommon.

Study Population

The population of interest included all adults aged > 35 years with a pulmonary nodule detected on diagnostic chest CT scan between January 1, 2012, and December 31, 2016. Presence of a pulmonary nodule was determined by extracting data from the Radiology Information System and Service Files using a validated NLP algorithm, previously found to have a sensitivity of 98.6% and a specificity of 100%.[24] The study population was subsequently limited to patients without a prior history of lung cancer or extrathoracic cancer (with the exception of non-melanoma skin cancer) within five years of the index scan, using International Classification of Diseases codes from at least 2 clinical encounters and cancer registry data. We excluded patients with nodules noted to be part solid or nonsolid, because such nodules were not covered by the 2005 Fleischner Society guidelines. When nodule attenuation was not specified in the radiology report, we assumed that the nodule was solid.

Exposures

Neighborhood-level deprivation was quantified using a validated index derived from census tract data from the American Community Survey, centered on domains of poverty, education, employment, housing, and occupation.[26] Principal component analysis was used to create this index based on variables shown in Table 1.

The KPSC Geographically Enriched Member Sociodemographic data mart maintains NDI information for the service area in which the KPSC population resides. NDI is evaluated as a z score centered at 0, indicating the mean level of deprivation within the region, with most scores ranging from −3 to 3. Participants were then stratified into cohorts based on NDI quartile, resulting in 4 comparison groups.

Outcomes

Based on extracted nodule characteristics and smoking history, participants were assigned to an interval of follow-up based on Fleischner Society guidelines from 2005. Adherence to follow-up was dichotomously coded based on the presence of Current Prodecural Terminology codes for chest CT scanning and/or biopsy within the recommended time frame, allowing for deviations of ± 33% in the timing of actual follow-up testing. For example, chest CT scans performed within 121 to 240 days of the index CT scan were considered adherent with the recommendation to perform CT surveillance at 180 days (approximately 6 months). For the primary analysis, we adopted a liberal definition of adherence to include follow-up that was at least as intensive as guideline-recommended care. As an example, 2 patients who underwent follow-up chest CT scanning, 1 at 6 months and another at 3 months, were both considered to be adherent with a guideline recommendation of CT follow-up scan in 6 months. In a secondary analysis, we adopted a more stringent definition of exact adherence, in which the type and timing of follow-up was neither more nor less intensive than recommended.

Statistical Analysis

We reported demographic and nodule characteristics in the full sample, and by NDI quartile, using means and SDs for continuous variables and counts and percentages for categorical variables.

Because adherence outcomes were not uncommon, multivariable analysis was performed by using negative binomial regression with robust error, with quartile 1 (the least deprived quartile) serving as the reference group for the main association of interest. Unadjusted and adjusted risk ratios of adherence were calculated, with

TABLE 1] Variables Included in Neighborhood Deprivation Index

Variable
Percent of adult population with less than a high school diploma
Percent of households earning < $30,000 per year
Percent of households with below poverty level income
Proportion of civilian noninstitutionalized population between 18 and 64 y of age who are unemployed
Proportion of households on public assistance
Percent in crowded housing
Proportion of households headed by female individuals (no male individuals present) with dependent children
Percent of male individuals in management or professional occupations

adjustment for prespecified, clinically plausible confounders, including age, sex, insurance plan type, smoking history, BMI, comorbidity burden, nodule size, and nodule edge characteristics. In a sensitivity analysis, we excluded patients with nodules for which the guidelines recommended no or optional follow-up. Results were considered significant with $P < .05$. All analyses were performed using SAS version 9.4 (SAS Institute).

Results

Among 203,351 patients aged > 35 years who underwent chest CT scanning during the study period, 57,412 were KPSC members with a nodule identified by NLP. We excluded patients with prior cancer; those with nodules that had semisolid, fat, or water density; and those without a known NDI. The final analytical cohort included 32,925 patients (Fig 1). The mean age of the population was 65.7 ± 12.65 years; 55.8% were female, and 46.4% were non-White or Hispanic. Forty-nine percent of the sample had no smoking history. Multimorbidity was common, with an overall mean Charlson Comorbidity Index score of 1.6. The median NDI for this sample was 0.1 (interquartile range, −0.6 to 0.7), indicating a level of deprivation that was only slightly higher than the deprivation of the surrounding region at large.

Compared with less deprived quartiles, patients in the most deprived quartile were more racially and ethnically diverse, and were more likely to have active tobacco use, be obese, and have a higher comorbidity burden (Table 2). The mean age was younger with increasing levels of deprivation. Patients in more socioeconomically deprived quartiles were more likely to be female. Furthermore, patients in the most deprived quartile were more likely to have commercial insurance compared with the least deprived quartile, which had a higher proportion of Medicare patients.

The mean nodule size in this population was 8.0 mm, and 10% of nodules had irregular or spiculated edges noted on chest CT scan (Table 3). Nodule features including location, size, and edge characteristics were similar across NDI quartiles.

Using our primary, more liberal definition, we found that adherence was notably poor overall, with only 49.6% of the population receiving follow-up at a level at least as intensive as recommended guidelines. According to the more stringent definition of adherence, only 33.0% of patients received follow-up in concordance with Fleischner Society recommendations, and 16.6% of patients received more intensive care than guidelines currently recommend. In a sensitivity analysis that excluded low-risk patients with nodules measuring ≤ 4 mm in size, only 39.3% of patients met our liberal definition of adherence, 26.5% of patients met our

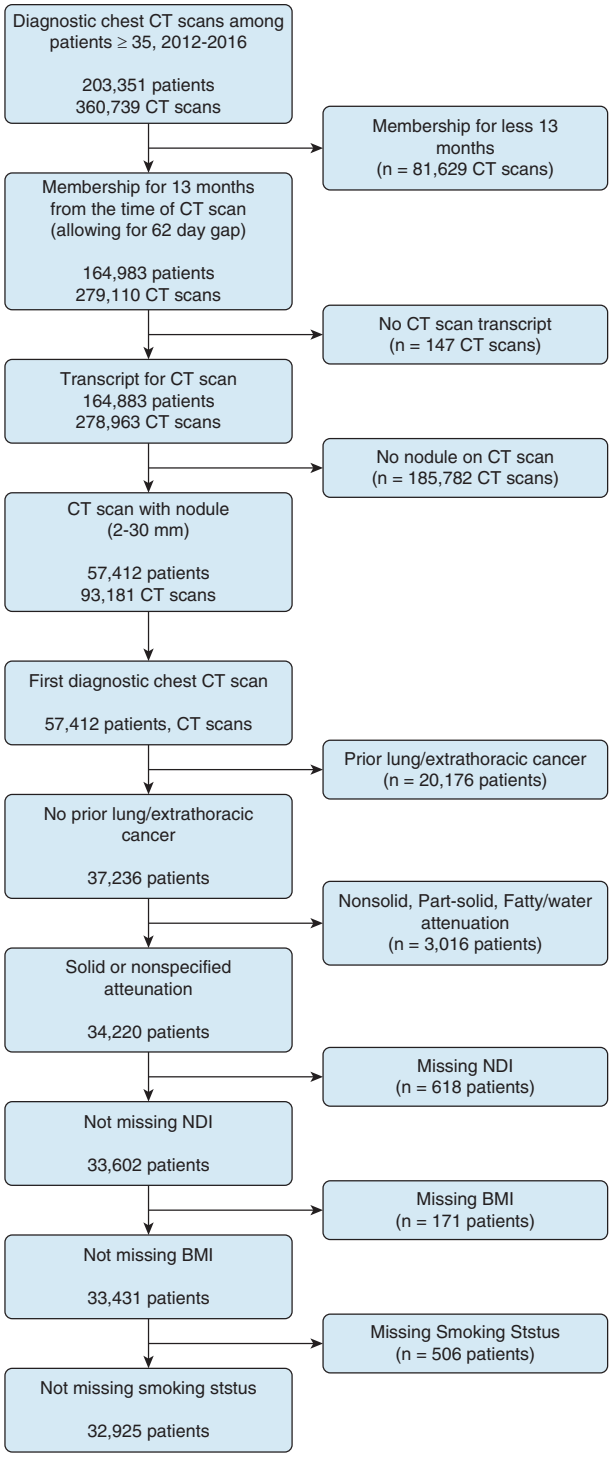

Figure 1 – *Consolidated Standards of Reporting Trials diagram of final cohort. NDI = Neighborhood Deprivation Index.*

TABLE 2] Final Cohort Clinical and Socioeconomic Demographics

Variable	NDI Q1 (n = 8,265)	NDI Q2 (n = 8,223)	NDI Q3 (n = 8,227)	NDI Q4 (n = 8,210)	Total (N = 32,925)
Age, y					
Mean [SD]	67.1 [12.56]	66.2 [12.39]	65.2 [12.72]	64.4 [12.75]	65.7 [12.65]
Sex					
Male	3,891 (47)	3,696 (45)	3,581 (44)	3,396 (41)	14,564 (44)
Female	4,374 (53)	4,527 (55)	4,646 (56)	4,814 (59)	18,361 (56)
Race/ethnicity					
Asian	879 (11)	807 (10)	749 (9)	527 (6)	2,962 (9%)
Black	287 (3)	555 (7)	1,040 (13)	1,689 (21)	3,571 (11)
Hispanic	875 (11)	1,376 (17)	2,326 (28)	3,475 (42)	8,052 (24)
Multiple	17 (0)	18 (0)	12 (0)	7 (0)	54 (0)
Native American Alaskan	21 (0)	18 (0)	14 (0)	26 (0)	79 (0)
Other race/ethnicity	61 (1)	54 (1)	46 (1)	22 (0)	183 (1)
Pacific Islander	31 (0)	58 (1)	71 (1)	55 (1)	215 (1)
Unknown	37 (0)	46 (1)	40 (0)	24 (0)	147 (0)
White	6,057 (73)	5,291 (64)	3,929 (48)	2,385 (29)	17,662 (54)
Insurance type					
Commercial/private pay	3,441 (42)	3,605 (44)	3,822 (46)	3,843 (47)	14,711 (45)
Dual	66 (1)	101 (1)	176 (2)	304 (4)	647 (2)
Medicaid	113 (1)	141 (2)	193 (2)	293 (4)	740 (2)
Medicare	4,645 (56)	4,376 (53)	4,036 (49)	3,770 (46)	16,827 (51)
Education					
Less than college	4,351 (53)	5,398 (66)	6,291 (77)	7,025 (86)	23,065 (70)
Income					
Income < $50,000	2,154 (26)	2,761 (34)	3,393 (41)	4,449 (54)	12,757 (39)
NDI					
Mean [SD]	−0.9 [0.20]	−0.4 [0.15]	0.3 [0.23]	1.5 [0.62]	0.1 [0.94]
Median	−0.9	−0.4	0.2	1.3	−0.1
Range	−1.7 to −0.6	−0.6 to −0.1	−0.1 to 0.7	0.7 to 5.7	−1.7 to 5.7
Smoking status					
Active tobacco use	677 (8)	850 (10)	942 (11)	1,042 (13)	3,511 (11)
Previous tobacco use	3,349 (41)	3,412 (41)	3,274 (40)	3,147 (38)	13,182 (40)
Passive tobacco use	30 (0)	35 (0)	48 (1)	45 (1)	158 (0)
Does not smoke	4,209 (51)	3,926 (48)	3,963 (48)	3,976 (48)	16,074 (49)
BMI					
Normal	2,876 (35)	2,392 (29)	2,231 (27)	2,020 (25)	9,519 (29)
Underweight	277 (3)	269 (3)	246 (3)	222 (3)	1,014 (3)
Overweight	2,841 (34)	2,779 (34)	2,673 (32)	2,609 (32)	10,902 (33)
Obese	2,271 (27)	2,783 (34)	3,077 (37)	3,359 (41)	11,490 (35)
Charlson Comorbidity Index score					
Mean [SD]	1.5 [1.43]	1.6 [1.47]	1.6 [1.49]	1.7 [1.51]	1.6 [1.48]

Values are presented as No. (%) or as otherwise indicated. NDI = Neighborhood Deprivation Index; Q = quartile.

stringent definition of adherence, and 12.8% of patients received more intensive follow-up than recommended (Fig 2).

We found that neighborhood-level socioeconomic deprivation was associated with worse adherence to guideline-recommended nodule follow-up (Table 4).

TABLE 3] Final Cohort Nodule Characteristics

Characteristic	NDI Q1 (n = 8,265)	NDI Q2 (n = 8,223)	NDI Q3 (n = 8,227)	NDI Q4 (n = 8,210)	Total (N = 32,925)
Laterality					
Right	4,376 (53)	4,420 (54)	4,548 (55)	4,503 (55)	17,847 (54)
Left	2,283 (28)	2,196 (27)	2,166 (26)	2,218 (27)	8,863 (27)
Both	1,114 (13)	1,113 (14)	1,063 (13)	1,067 (13)	4,357 (13)
Not specified	492 (6)	494 (6)	450 (5)	422 (5)	1,858 (6)
Lobe					
Upper (including lingula)	2,728 (33)	2,703 (33)	2,796 (34)	2,863 (35)	11,090 (34)
Middle	942 (11)	986 (12)	1,000 (12)	1,001 (12)	3,929 (12)
Lower	3,058 (37)	3,015 (37)	2,988 (36)	2,965 (36)	12,026 (37)
> 1 lobe	571 (7)	547 (7)	577 (7)	547 (7)	2,242 (7)
Not specified	966 (12)	972 (12)	866 (11)	834 (10)	3,638 (11)
Nodule size					
Mean [SD]	7.9 [6.06]	8.0 [6.09]	8.0 [6.06]	8.0 [6.15]	8.0 [6.09]
Nodule size, mm					
≤ 4	2,653 (32)	2,531 (31)	2,671 (32)	2,674 (33)	10,529 (32)
4 to < 6	1,348 (16)	1,365 (17)	1,296 (16)	1,306 (16)	5,315 (16)
6 to < 8	1,489 (18)	1,465 (18)	1,425 (17)	1,424 (17)	5,803 (18)
8 to < 15	1,654 (20)	1,718 (21)	1,727 (21)	1,665 (20)	6,764 (21)
≥ 15	1,121 (14)	1,144 (14)	1,108 (13)	1,141 (14)	4,514 (14)
Edge characteristics					
Smooth	253 (3)	220 (3)	213 (3)	191 (2)	877 (3)
Lobulated	98 (1)	114 (1)	103 (1)	109 (1)	424 (1)
Irregular	580 (7)	579 (7)	547 (7)	566 (7)	2272 (7)
Spiculated	228 (3)	239 (3)	268 (3)	210 (3)	945 (3)
Not specified	7,106 (86)	7,071 (86)	7,096 (86)	7,134 (87)	28,407 (86)

Values are presented as No. (%) or as otherwise indicated. NDI = Neighborhood Deprivation Index; Q = quartile.

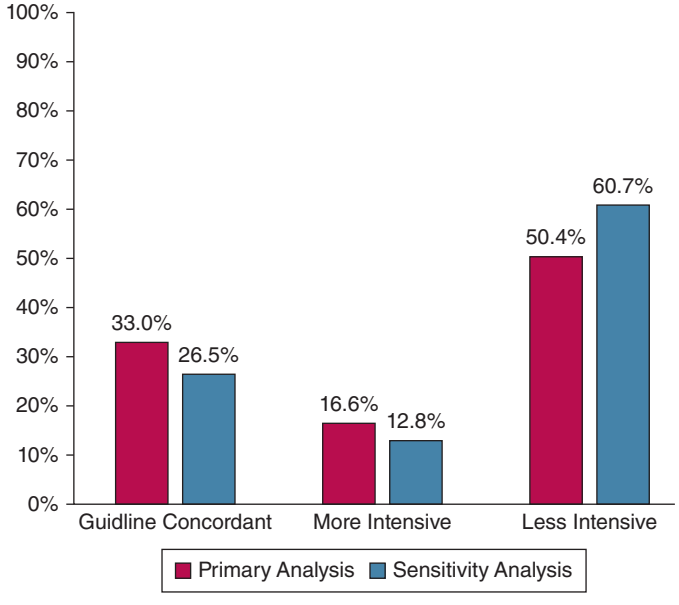

Figure 2 – *Total cohort adherence to guideline-recommended nodule follow-up.*

TABLE 4] Adjusted and Unadjusted RR for Adherence to Nodule Follow-Up by NDI

Adherence Measure	Quartile 4[a] (n = 8,210)	Quartile 1[a] (referent) (n = 8,265)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Primary analysis				
Liberal definition	3,954 (48.1)	4,183 (50.6)	0.95 (0.91-0.99)	0.97 (0.94-1.00)
Strict definition	2,620 (31.9)	2,785 (33.7)	0.95 (0.90-1.00)	0.95 (0.90-0.99)
Adherence Measure	Quartile 4[a] (n = 6,815)	Quartile 1[a] (referent) (n = 6,829)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Sensitivity analysis				
Liberal definition	2,559 (37.5)	2,747 (40.2)	0.93 (0.88-0.99)	0.95 (0.91-0.99)
Strict definition	1,732 (25.4)	1,861 (27.3)	0.93 (0.87-1.00)	0.93 (0.88-0.99)

NDI = Neighborhood Deprivation Index; RR = relative risk.
[a]Data presented as raw number of patients defined as adherent to guideline-recommended follow-up within that quartile (percentage of the cohort that is adherent compared to the full quartile).

Unadjusted analysis using the more liberal definition of adherence revealed a 5% reduction in adherence between the most deprived quartile compared with the least deprived quartile (relative risk [RR], 0.95; 95% CI, 0.91-0.99). After adjustment, there was a 3% reduction in guideline-concordant care between the most and least deprived quartiles (RR, 0.97; 95% CI, 0.94-1.0).

When using a more stringent definition of adherence, a similar effect was noted (Table 4). Before adjustment, there was a 5% reduction in guideline-concordant care between the most and least deprived quartile (RR, 0.95; 95% CI, 0.90-1.0), and multivariate analysis demonstrated a 5% reduction in adherence after adjustment for plausible confounders (RR, 0.95; 95% CI, 0.90-0.99).

We did not find statistically significant differences in adherence using either the liberal or stringent definition when comparing the least deprived quartile with the second and third quartiles of the NDI. In a sensitivity analysis that excluded patients with recommendations for no or optional follow-up, we found that associations between the NDI and adherence to follow-up were slightly greater in magnitude than those found in the primary analysis using either definition of adherence (Table 4).

Multivariate analysis demonstrated that other clinical variables were also associated with poor adherence when using the liberal definition of adherence. Patients with ≥ 3 comorbid conditions were 7% less likely to complete follow-up within the recommended time frame than patients with no comorbidities (RR, 0.93; 95% CI, 0.89-0.97); in particular, patients with a history of congestive heart failure were 7% less likely to be adherent (RR, 0.93; 95% CI, 0.90-0.97). Compared with patients who do not smoke, patients who smoked were 27% less likely to be guideline adherent (RR, 0.73; 95% CI, 0.70-0.76), and patients who smoked were 33% less likely to be adherent (RR, 0.67; 95% CI, 0.65-0.69).

Subsequent effect-modification analysis between smoking status, NDI, and adherence was performed. Analysis demonstrated a nonsignificant interaction between smoking status and NDI rank using both definitions of adherence ($\chi^2 = 3.6$, $P = .72$; $\chi^2 = 5.0$, $P = .54$). Subgroup analysis demonstrated that among patients in the second quartile of deprivation, current smoking status was associated with slightly increased levels of adherence compared with patients without a tobacco use history, only when using the strict definition of adherence (RR, 1.24; 95% CI, 1.08-1.44).

Of note, there were also associations between nodule characteristics and adherence. Using the strict definition of adherence, patients with nodules measuring > 8 to 15 mm (RR, 1.20; 95% CI, 1.13-1.27) and those measuring > 15 mm (RR, 1.55; 95% CI, 1.46-1.65) were more likely to receive guideline-concordant care than patients with nodules measuring 6 to 8 mm. Patients found to have nodules with irregular or spiculated edges were more likely to be adherent when using either the liberal (RR, 1.24; 95% CI, 1.19-1.29) or strict definition (RR, 1.24; 95% CI, 1.18-1.30) of adherence.

Given the findings of an association between larger nodule size and adherence to follow-up, effect-modification analysis was performed to elicit the relationship between nodule size, NDI, and adherence. In this analysis, there was a nonsignificant interaction between nodule size and NDI rank when using either definition of adherence ($\chi^2 = 4.6$, $P = .87$; $\chi^2 = 8.2$, $P =$

.51). However, a subgroup analysis found that adherence was significantly worse in the least deprived compared with the most deprived quartile for participants with nodules < 6 mm in size (RR, 0.90; 95% CI, 0.83-0.90).

Discussion

In this large, population-based sample, we found an independent association between more severe neighborhood level deprivation and worse adherence to follow-up for patients with pulmonary nodules, consistent with studies demonstrating socioeconomic disparities in engagement with other preventive care measures.[6-9] Consistent with previous theoretical frameworks, our study describes the possible impact of neighborhood as a determinant of engagement with the health care system.[27] In addition, we observed poor overall guideline-concordant follow-up of patients with incidental nodules, confirming the findings of several smaller studies.[17,19-23]

These findings build on the work done by Thakore et al,[23] demonstrating higher levels of social vulnerability and in particular racialized economic segregation within neighborhoods as independent predictors of guideline-disconcordant care. However, in contrast to Thakore et al,[23] our study finds that within a large integrated health care system, the effects of socioeconomic status may be mitigated, given the relatively small discrepancy in this cohort between the most deprived and least deprived cohort. Furthermore, a study of 1,610 patients found that having a Medicaid insurance plan was independently associated with poorer adherence.[28]

The way in which socioeconomic status and neighborhood-level deprivation impact receiving guideline-concordant care is complex and multifactorial. Given the composite nature of the NDI, it is difficult to ascertain which aspect of this index is the primary driver of poor adherence. Patients residing in these areas may have decreased access to transportation to reach medical centers for follow-up of abnormal findings or overlying distrust of the health care system itself. One study suggests that poorer health literacy in areas with decreased educational attainment or lack of investment in the public school system may contribute to this disparity.[29]

Of note, our study describes a threshold effect of neighborhood-level deprivation, with significant disparities only existing between the most deprived and least deprived groups. It is reasonable to infer that the underlying mechanism of this disparity may be exacerbated by living in the most deprived neighborhoods, where historic factors including redlining have led to significant divestment in infrastructure and community investment.[30]

Nevertheless, it remains unclear whether this decreased adherence to follow-up results in higher morbidity, due to the benign nature of most incidental pulmonary nodules.[18,31] Furthermore, given the combination of poor overall adherence across the population, and the relatively small reduction in adherence in the most deprived quartile, it is unclear whether a targeted or universal intervention to increase guideline-concordant care would be more effective in reducing sociodemographic disparities in adherence. Hedstrom et al[32] demonstrated that radiologist-recommended follow-up is often concordant with Fleischer Society recommendations. However, actual patient adherence to radiologist-recommended care is substantially lower, indicating that in this patient pool, improved communication downstream of initial radiologist recommendations may improve quality of care.[32] These findings have recently been redemonstrated by Slatore et al,[22] indicating that systems-level factors beyond radiologist-recommended follow-up may drive low population-level adherence. Systems-level interventions to improve communication of abnormal findings and to encourage follow-up with vulnerable patients would help to address this disparity and reduce guideline-disconcordant care overall.

Our study also demonstrated several clinical features associated with adherence in this population. Most notably, there was a significant decrease in adherence to guideline-concordant care among both patients with active and previous tobacco use compared with patients without tobacco use history. Previous studies have identified current smoking behavior as a potential risk factor for lack of engagement with recommended cancer screening, including USPSTF recommended lung cancer screening.[33-35] This phenomenon has been described as multifactorial, with one hypothesis being that people with active tobacco use tend to engage in avoidant behaviors surrounding cancer detection.[35,36] Furthermore, some studies have suggested that patients who use tobacco may underestimate their own risk toward adverse health outcomes secondary to tobacco use.[37] In this sense, patients with an incidentally found pulmonary nodule may not engage with follow-up due

to lack of perceived importance of these findings. In a population being evaluated for known pulmonary nodules, avoidance of a possible cancer diagnosis may contribute to worse adherence.

We also found that a higher comorbidity burden resulted in worse adherence to guideline concordant care. For patients with these burdens, it is likely that long-term follow-up of these findings may not be advised given limited life expectancy. In particular, a history of congestive heart failure was independently associated with worse adherence recommended follow-up. Although we did not find a statistically significant effect, patients with COPD were slightly more likely to be adherent, consistent with previous studies that have found ongoing engagement with a pulmonologist to be predictive of improved guideline-concordant nodule care.[20] In contrast to findings published by Iaccarino et al,[20] we did not find an independent association between racial identity and adherence. Because patients in neighborhoods with higher levels of socioeconomic deprivation were also more racially diverse, underlying socioeconomic status may be more predictive of adherence rather than racial identity itself.

Nodule features more suggestive of malignant processes were also found to be associated with increased adherence to guideline-concordant care. It is likely that within this integrated system, providers were more likely to use consensus recommendations for management of patients with features suggestive of malignancy, including irregular or spiculated edges on CT scan. The positive association between nodule size and adherence to guideline-recommended management of incidental nodules has been previously demonstrated by Iaccarino et al.[20]

A limitation of the study is the necessity to use 2005 Fleischner Society guidelines given the time period in which this retrospective cohort was assembled. Nevertheless, the 2005 guidelines in which nodules $<$ 4 mm did not require follow-up are more stringent than the current guidelines, which recommend optional follow-up for nodules $<$ 6 mm. Although our sensitivity analysis does exclude participants with pulmonary nodules $<$ 4 mm, it can be inferred that under current guidelines, participants with nodules $<$ 4 mm would still be adherent without undergoing interval imaging.

As a retrospective study, we cannot infer causation from our findings. In addition, because neighborhood deprivation functions at the census tract level, we cannot determine individual socioeconomic risk factors from this study. Our study was also limited to patients enrolled in KPSC, limiting the generalizability of our findings to an insured population. In addition, the NDI, as a composite variable, functions as a marker of other geographic and socioeconomic variables. We are unable to isolate which, if any, factor most contributes to lapses in adherence. Given the complex care pathway from nodule detection to subsequent follow-up, we cannot deduce where in the care pathway patients may be lost, or whether nonadherence was driven by a radiologist, ordering provider, or patient-level factors. Poor adherence may be a result of poor physician-patient communication, lack of access to transportation, limited time for imaging procedures, or a combination of several factors. Given the low rates of guideline concordant care across the population, more research is needed to identify specific interventions to ensure patients with pulmonary nodules receive appropriate follow-up to ensure timely diagnosis of lung cancer.

Interpretation

Our findings show that socioeconomic deprivation at the neighborhood level is independently associated with worse adherence to Fleischner Society recommendations for follow-up of incidentally found pulmonary nodules. Although this effect was small, there was significant guideline-discordant underutilization for management of these nodules within the total population, indicating the need for upstream measures to ensure timely acquisition of evidence-based care.

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