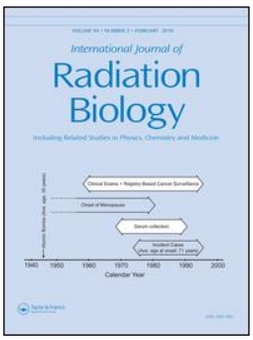

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ORIGINAL ARTICLE

Validating the use of census data on education as a measure of socioeconomic status in an occupational cohort

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ABSTRACT

Purpose: Adjusting for smoking status or a reliable surrogate [such as socioeconomic status (SES)] is critically important in occupational epidemiology studies when any smoking-related cancer or cardiovascular disease is an outcome of interest. Sometimes, however, data on smoking patterns or individual-level smoking surrogates such as job title, education, pay scale or other measures of SES are not readily available in occupational cohorts.

Methods and materials: To obtain a surrogate measure for missing smoking or individual-level SES data, we demonstrate a method used to obtain and geocode residential address histories which were then linked to area-level SES measures from the United States Census in three test samples and then in a full cohort of workers from the Mound nuclear weapons facility in Dayton, Ohio, USA. The mean educational attainment of the Census Block Group was used to derive a categorical estimate of educational attainment which was compared to self-reported (SR) education available from Mound worker histories using Kappa statistics. Lung cancer mortality patterns between area-derived (AD) and SR education were investigated using Standardized Mortality Ratios (SMR) and Cox Proportional Hazards models with stratification or adjustment by either SR or AD education.

Results: Home address histories were obtained from linkages of individual worker data to online resources. In the test cohorts, mean educational attainment was the Census Block Group measure found to have the largest magnitude association with individual-level SES measures. Among 7251 Mound workers, 5685 (78.4%) had at least one residential address match (mean 4.9 addresses) identified. The SR and AD educational attainment measures were highly correlated (weighted Kappa coefficient 0.10, $p < .0001$). SMR patterns by SR and AD educational attainment were similar, with steadily decreasing mortality with increased educational attainment by either measure. Cox models for lung cancer using AD education produced similar results as those using SR education as an adjustment factor.

Conclusion: When individual-level SES indicators are not available for statistical adjustment, area-level SES measures can serve as a reliable surrogate when investigating outcomes that are affected by lifestyle factors such as smoking.

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Epidemiology; database; lung neoplasms; modeling

Introduction

Adjustment for individual-level socioeconomic status (SES) is frequently employed in occupational studies to control for possible confounding factors such as tobacco use and other lifestyle factors that are not available but may influence mortality and morbidity. Often, indicators of SES such as educational attainment, job title, income, or pay-type (hourly versus salaried) are used as surrogates for smoking status, as individuals with lower SES tend to smoke at higher rates than those with higher SES (National Academies 2015). There is a growing body of literature supporting the idea that a person's environment is strongly associated with lifestyle factors, such as smoking and drinking patterns, obesity, risk of accidents and others (e.g. Cohen et al. 2011), and thus while individual-level SES variables are preferred over area-level variables for confounder adjustment, in the absence of individual measures, area-level variables have been shown to be adequate correlates of SES in occupational and other studies of cancer, heart disease and overall (Anderson et al. 1997; Waitzman and Smith 1998; Yen and Kaplan 1999; Diez Roux et al. 2001; Steenland et al. 2004). Thus, an innovative and resourceful approach to determining SES for occupational workers when individual-level measures are not available is to use area-level measures of education obtained from residential histories. In this study, we first demonstrate results from samples from three Million Person Study (MPS) cohorts that evaluated area-level measures derived from census data as surrogates for individual-level measures. Next, using one

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MPS cohort, we compare various measures of SES [none, individual-level, and area-derived (AD)] as an adjustment factor in models examining the association between radiation dose to the lung and lung cancer mortality.

Methods

Approval for Human Subjects research was received from the Oak Ridge Site-wide Institutional Review Board and the Vanderbilt University Institutional Review Boards.

Test samples

Three MPS cohorts were selected for testing of methodology to establish the best area-level measure from census data to use as a surrogate for individual SES measures. The test samples evaluated include workers from the Mound nuclear weapons facility (hereafter referred to as the Mound cohort), workers at the Mallinckrodt Chemical Works (MCW), and radiation workers at Rocketdyne (Atomics International) facilities in California. Details of each of these MPS cohorts have been published (Boice et al. 2011, 2014, 2018; Ellis et al. 2018; Golden et al. 2019). For the Mound population, a stratified random sample of 100 workers was selected within four categories of individual-level education obtained from work histories. For the Rocketdyne sample, the surrogate measure for SES was hourly or salaried worker status as available from occupational records; a simple random sample of 100 Rocketdyne workers was selected. For MCW workers, hourly or salaried status was the available SES surrogate from the work histories; for this population, the entire cohort of 2514 workers was included in the test sample.

Rosters for each of the three samples were matched via LexisNexis® to all available residential histories (Mumma et al. 2019). All matching residential addresses were geocoded and linked to Census Block Group measures including mean home value, mean educational attainment, and mean income. A Census Block Group contains about 600–3000 persons, or 250–1000 households, and due to this small size, residents are generally similar with regard to education, income, and home value. Within each test sample, a series of AD SES measures using census variables (including the lowest ever, highest ever, and most recent measures) were examined individually in relation to the available individual-level SES measures using ANOVA.

Mound cohort

After using the three test samples to identify the census measure most highly correlated with individual-level SES, we conducted an analysis using the full population of workers from the Mound nuclear weapons facility located near Dayton, Ohio, to compare adjustment with individual-level versus AD SES measures in models examining the association between radiation dose to the lung and lung cancer mortality. Among the Mound workers, vital status as of 31 December 2009, and the underlying cause of death were determined as previously described (Boice et al. 2014; Mumma et al. 2019). Vital status was obtained for 98.7% of the population and 50.7% had died by 2009. Self-reported (SR) education was extracted from employment records as Grade School or less, Some High School, High School Graduate, and Associates degree or higher, and was available for 6859 (94%) of all Mound workers and 4811 (97%) of radiation workers.

Demographic information for all Mound workers was used to conduct residential address history searches, including dates when the address was active. Addresses were then geocoded using SAS Proc Geocode. Addresses not successfully geocoded at the street-level and addresses containing a PO Box or rural delivery route were attempted to be geocoded to the ZIP plus 4 level. Addresses that did not geocode to the ZIP plus 4 were not used to derive educational attainment, as the ZIP code would likely be too large to reflect neighborhood characteristics. Geocoded address locations were then placed into 2000 (addresses active prior to 2005) or 2010 (addresses active after 2004) Census Block Groups. Based on the work done in the test samples described in the Methods above and Results below, the mean educational attainment from the Census Block Group was selected to be the AD measure of SES and was thus merged by Block Group to each address. The highest mean educational attainment for a worker's address history was a continuous measure that was then grouped such that the AD education cut-points were similar to the SR education distribution; cut-points were made at 13.3, 15.1, and 16 years to create a four-level categorical measure.

Standardized mortality ratio (SMR) analyses, using an approach similar to Marsh et al. (1998), compared the numbers of deaths observed among Mound workers with the numbers expected based on general population rates in the United States for persons of the same age, race, and sex over the same time periods using the underlying cause of death. SMR analyses for multiple outcomes were performed on the subset of workers for whom both an SR and AD education measure was available, and SMRs were calculated within categories of each education measure (SR and AD). Person-time began at the date of first hire at Mound and ended either at the date of death; 31 December 2009; age 95, or date of loss to follow-up, whichever came first.

Analyses within cohort were conducted using Cox proportional hazards models to compute risks of lung cancer (Cox 1972). Lung cancer mortality was determined from the underlying cause of death. Radiation doses specifically to the lung from external (photon and neutron) as well as internal intakes of radionuclides (tritium, polonium, and plutonium) were obtained as described previously (Boice et al. 2014; NCRP 2018); for these analyses, the radiation weighting factor is taken to be 1 for internal intakes. Radiation doses were lagged by 10 years and treated as a time-dependent covariate in the model. Age was used as the timescale for the hazard function and all models included adjustment for year of birth (six categories) and sex (male/female). Hazard ratios (HR) and 95% confidence intervals (CI) for lung cancer mortality were produced for categories of radiation exposure in the subset of radiation workers with non-missing values for

both SR and AD education. Models were constructed in this subgroup first without any adjustment for SES, then using the SR measure, and finally using the AD measure. Additionally, a model using SR education when available and imputed with AD education when the SR measure was missing was fitted in order to utilize the maximum available number of workers and serve as a demonstration of a hybrid approach that might be used in future studies. All analyses were conducted with SAS/STAT software (SAS/STAT software, Version 9.4 of the SAS System for Windows, SAS Institute Inc., Cary, NC, USA).

Results

Test samples

Address histories were linked to the three test sample rosters using available demographic information. For the Mound sample, 73% of the sample had at least one match to a residence and the average number of linked addresses was 3.7 (range 1–13). For the Rocketdyne sample, 89% of workers had at least one match with an average of 6.3 linked addresses (range 1–14). Among the MCW workers, 1777 (71%) had at least one linked address with an average of 3.9 linked addresses (range 1–16). Addresses for workers who died prior to 1995 were more difficult to obtain. Workers with no matching addresses were disproportionately in the lowest education group in the Mound sample (chi-square $p < .0001$) or were hourly workers as opposed to salaried workers in the Rocketdyne (chi-square $p = .025$) and Mallinckrodt samples (chi-square $p < .0001$).

Census variables including mean home value, mean income, and mean education were generally significantly positively associated with individual-level SES measures across the three test samples (Tables 1–3). Highest mean level of education at any address had the largest magnitude of association with individual-level education in the Mound cohort ($p = .0001$), and was also significantly associated with hourly/salary status in the MCW workers ($p < .0001$) as well as in the Rocketdyne cohort ($p = .007$).

Table 1. Evaluation of individual-level SES (measured as pay type: hourly versus salary) with area-level SES measures associated with home addresses in the Mallinckrodt Chemical Workers cohort ($N = 2514$).

	Individual-level SES Measure: Pay type			
Area-derived SES measure	Hourly Mean	Salary Mean	Missing Mean	*p*-Value*
Median home value ($)				
Lowest at any address	91,838	125,184	114,655	<.0001
Highest at any address	212,396	312,721	316,637	<.0001
Most recent	173,891	254,856	258,678	<.0001
Mean education (years)				
Lowest at any address	12.4	13.0	12.9	<.0001
Highest at any address	13.9	14.9	14.8	<.0001
Most recent	13.4	14.3	14.3	<.0001
Median household income ($)				
Lowest at any address	37,169	43,263	40,122	<.0001
Highest at any address	69,137	88,053	91,566	<.0001
Most recent	59,020	72,140	73,666	<.0001

*p-value from ANOVA. ANOVA model does not include the missing hourly/salary column (i.e. comparison is only hourly/salary).

Mound cohort

After establishing that highest mean level of education at any address was the best census measure to use as a surrogate for individual-level SES, we conducted an analysis to compare effects of adjustment with this AD measure compared to the individual-level measure of education in the full population of Mound workers. The Mound cohort has been previously described (Wiggs et al. 1991; Boice et al. 2014). In brief, 7270 employees first hired between 1944 and 1979 were identified including 4954 who were monitored for any type of radiation exposure. Most of the workers were male (75.2%), white (80.3%), born before 1930 (56.0%), hired before 1960 (51.4%), and followed for more than 30 years (82.3%).

In the Mound workers, the SR measure of education obtained from occupational work histories (four categories) and AD measure of education taken as the Census Block Group highest mean educational attainment in four categories were correlated, with a Kappa coefficient of 0.10 ($p < .0001$). Figure 1 shows the positive linear association between the mean Census Block Group educational attainment and the four SR education categories.

Figure 2 shows that the SMRs in the Mound workers for smoking-related cancers, lung cancer, and heart disease within categories of either SR or AD education were similar with a steady decrease in the SMRs as educational attainment increases. Similar inverse associations were seen over

Table 2. Evaluation of individual-level SES (measured as four levels of education) with area-level SES measures associated with home addresses in the Mound worker test sample ($N = 100$).

	Individual-level SES measure: Education				
Area-derived SES measure	Grade school ($n = 16$) Mean	Some high school ($n = 12$) Mean	High school graduate ($n = 32$) Mean	Associate's degree or more ($n = 13$) Mean	*p*-Value*
Mean home value ($)					
Lowest at any address	110,227	112,531	179,483	188,902	.072
Highest at any address	198,548	161,435	440,524	362,397	.0003
Mean education (years)					
Lowest at any address	12.00	12.08	12.84	13.38	.0055
Highest at any address	13.38	13.58	15.06	15.00	.0001
Mean income ($)					
Lowest at any address	42,277	45,831	45,773	56,209	.42
Highest at any address	64,908	72,191	104,615	99,367	.0023

*p-value from ANOVA.

Table 3. Evaluation of individual-level SES (measured as pay type: hourly versus salary) with area-level SES measures associated with home addresses in the Rocketdyne test sample ($N = 100$).

	Individual-level SES measure: Pay type		
Area-derived SES measure	Hourly workers Mean	Salary workers Mean	*p*-Value*
Mean home value			
Lowest at any address	231,060	262,843	.40
Highest at any address	626,256	692,691	.19
Mean education			
Lowest at any address	11.51	12.44	.0005
Highest at any address	14.58	15.38	.007
Mean income			
Lowest at any address	45,617	51,846	.19
Highest at any address	105,689	127,436	.002

*p-value from ANOVA.

categories of both SR and AD measures of education for other disease outcomes known to be associated with lifestyle measures such as smoking and alcohol consumption including cirrhosis of the liver, nephritis and nephrosis, and external causes of death (data not shown).

The results of the internal cohort analyses for the Mound workers are shown in Table 4 with separate models being fitted including no adjustment for SES, adjustment for the SR education measure, and adjustment for the AD education measure. The model without adjustment for SES had a lower HR in the dose category ≥500 milligray (mGy) than models with either SR or AD education adjustment. The models including SR and AD adjustment had very similar HRs in all categories of lung dose. The final model was fitted to the full Mound radiation cohort of 4954 workers using SR education when available ($N = 4811$ workers) and imputed with AD

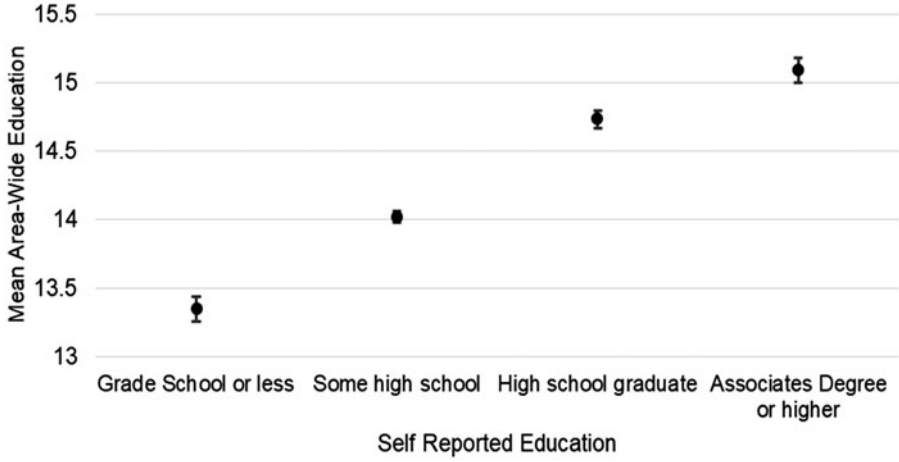

Figure 1. Mean educational attainment at the Census Block Group level by individual-level self-reported educational attainment from worker records among Mound workers. Note: Error bars show two standard errors from the mean

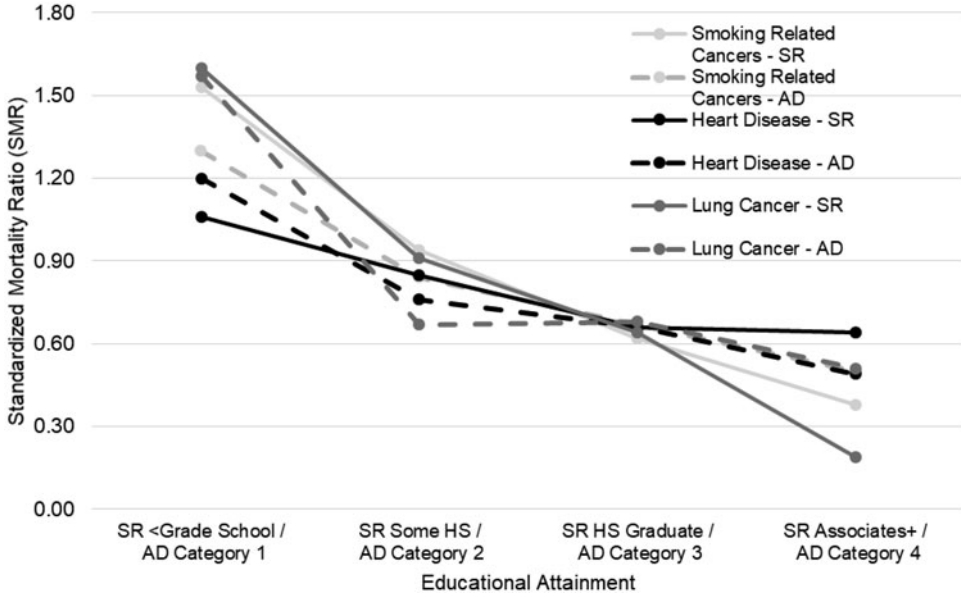

Figure 2. Standardized Mortality Ratio (SMR) for smoking-related cancers, lung cancer, and heart disease by categories of SR and AD education among Mound workers. SR = Self-reported; AD = Area-derived; HS = High school; AD categories of education are based on Census Block Group mean educational attainment using cut-points at 13.3, 15.1, and 16 years.

Table 4. Internal cohort dose-response analysesa and HR for lung cancer mortality over categories of organ-specific radiation dose among 3994 Mound workers with non-missing self-reported and area-derived education measures.

Dose to lung (mGy)	Number of workers	Number of cases	Adjusted for self-reported education		Adjusted for area-derived education		No adjustment for SES	
			HR	95% CI	HR	95% CI	HR	95% CI
<10	2104	52	1.0	REF	1.0	REF	1.0	REF
10–	1201	50	1.12	0.76–1.67	1.13	0.76–1.67	1.14	0.77–1.69
100–	540	23	1.13	0.68–1.86	1.10	0.67–1.81	1.06	0.64–1.74
≥500–	149	12	1.68	0.87–3.27	1.61	0.83–3.11	1.41	0.73–2.72
p for trend	3994	137		*0.81 (+)*		*0.94 (+)*		*0.77 (−)*

All models were adjusted for gender and year of birth. *p*-value for test for linear trend in the HR computed for continuous lung dose. *p*-values are two-sided and '+' denotes a positive trend and '−' a negative trend. REF denotes reference category. Self-reported and area-derived education were included as categorical covariates with four levels. Lung cancer deaths determined from underlying cause of death. HR: Hazard ratios.
[a]Radiation doses were lagged by 10 years and treated as a time-dependent covariate in the model.

education when SR was missing ($N = 143$ workers); the HRs (95% CI) for lung doses of <10, 10–99, 100–499, and 500+ mGy were 1.0 (reference), 1.24 (0.90–1.70), 0.86 (0.56–1.33), and 1.36 (0.79–2.36), respectively compared to HRs (95% CIs) of 1.24 (0.90–1.70), 0.84 (0.54–1.30), and 1.21 (0.70–2.09), respectively, when the model included no SES adjustment.

Discussion

We found that individual-level measures of SES such as SR education or pay type were highly correlated with area-level Census Block Group measures linked to individual home addresses including mean or median home value, mean or median income, and mean educational attainment. Prior work has indicated that area-level measures are adequate correlates of individual-level measures (Anderson et al. 1997; Waitzman and Smith 1998; Yen and Kaplan 1999; Diez Roux et al. 2001; Steenland et al. 2004), and this study supports those findings.

For most of the cohorts in the MPS, SES variables are available in the source files that can be used for statistical adjustment such as job title, education level, military rank, or pay scale. However, three important MPS cohorts do not have consistent measures of individual-level SES that could be used as adjustment factors: nuclear power plant workers, industrial radiographers, and medical radiation workers. The current study was conducted in large part to establish whether the use of area-level measures from census blocks could reasonably serve as surrogates for individual-level SES in these cohorts. The reason why measures of SES are not readily available relates in large part to the data sources used to identify these populations for study which include the Nuclear Regulatory Commission (NRC) Radiation Exposure Information and Reporting System (REIRS) and the Landauer, Inc. dosimetry database (Muirhead et al. 1996; NRC 1994, 2018; Anzenberg et al. 2010; NCRP 2018).

This study has several strengths as well as limitations. The MPS cohorts utilized in both the test samples and the full cohort analysis are occupational cohorts with long follow-up (up to 60 years), high quality capture of occupational radiation doses, a low percentage of workers who were lost to follow-up, and a low percentage of deaths for which a specific cause was not available. For the Mound study, we were able to utilize the entire cohort to compare the statistical effects of adjustment using an individual-level measure of education captured in the work histories to compare with an area-level measure derived from address histories. Limitations include the relatively small number of workers in the Mound population and the lack of individual-level smoking history which precludes a full assessment regarding the ability of AD measures of SES to serve as appropriate surrogates for smoking. Nonetheless, it was informative that the area-level measures of SES correlated so closely with the frequently used individual-level measures derived from occupational histories including job title, salary information, and/or education level.

In conclusion, this study demonstrates that individual-level measures of SES are highly correlated with area-level measures linked to individual home addresses, and that in the absence of individual-level measures, area-level measures can serve as a reliable surrogate for SES when investigating lifestyle-related morbidity and mortality. These findings are directly applicable to work on-going within the MPS, particularly for the cohorts of individuals where the available source data do not contain sufficient information to group individual workers according to SES.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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