Geographically Derived Socioeconomic Factors to Improve Risk Prediction in Patients Having Aortic Valve Replacement

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Socioeconomic status (SES) has been associated with adverse outcomes after cardiac surgery, but is not included in commonly applied risk adjustment models. This study evaluates whether inclusion of SES improves aortic valve replacement (AVR) risk prediction models, as this is the most common elective operation performed at our institution during the study period. All patients who underwent AVR at a single institution from 2005 to 2015 were evaluated. SES measures included unemployment, poverty, household income, home value, educational attainment, housing density, and a validated SES index score. The risk scores for mortality, complications, and increased length of stay were generated using models published by the Society for Thoracic Surgeons. Univariate models were fitted for each SES covariate and multivariable models for mortality, any complication, and prolonged length of stay (PLOS). A total of 1,386 patients underwent AVR with a 2.7% mortality, 15.1% complication rate, and 9.7% PLOS. In univariate models, higher education was associated with decreased mortality (odds ratio [OR] 0.96, p = 0.04) and complications (OR 0.97, p < 0.01). Poverty was associated with increased length of stay (OR 1.02, p = 0.02). In the multivariable models, the inclusion of SES covariates increased the area under the curve for mortality (0.735 to 0.750, p = 0.14), for any complications (0.663 to 0.680, p < 0.01), and for PLOS (0.749 to 0.751, p = 0.12). The inclusion of census-tract-level socioeconomic factors into the the Society of Thoracic Surgeons risk predication models is new and shows potential to improve risk prediction for outcomes after cardiac surgery. With the possibility of reimbursement and institutional ranking based on these outcomes, this study represents an improvement in risk prediction model. **(Am J Cardiol 2019;123:116−122)**

Low socioeconomic status (SES) has been associated with increased early and long-term mortality after cardiac surgery, even in subgroups divided by age, gender, educational level, marital status, type of procedure, and year of surgery.[1−4] Despite these findings, the current risk prediction models from the Society of Thoracic Surgeons (STS) for morbidity and mortality after cardiac surgery do not include SES.[5−7] This was in part because individual patient SES information has not routinely available. Recently, robust research methods for geographically derived SES information routinely extractable from census data has been validated.[8,9] SES data for geographic areas ranging from zip code down to a block group (a group of about 600 to 3,000 subjects) can be used to "geolocate" an address into an area with defined SES data. This technique then could be feasibly applied to the whole of the STS database with perhaps further impact on the risk predication models being incorporated into quality metrics, public reporting, and institutional comparisons such as the "star" rating system.[10] This study evaluates whether geographically derived SES variables were associated with worse outcomes after aortic valve replacement (AVR), and if these variables could improve the STS AVR morbidity and mortality risk prediction models.

Methods

The Institutional Review Board at the University of Pennsylvania approved the study and waived the need for patient consent. All patients who underwent isolated AVR at a single institution from 2005 to 2015 were evaluated. We estimated patients' SES using census-tract-level data, which are more precise than ZIP-code-level data.[8] We excluded patients (~5%) with addresses that could not be geolocated to census tracts. SES covariates were available for 95% of the study population. The SES covariates considered for the study were previously validated and included (1) Unemployment: Percentage of persons aged 16 years or older in the labor force

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See page 121 for disclosure information.

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https://doi.org/10.1016/j.amjcard.2018.09.019

Table 1
Univariate analysis of socioeconomic status variables

Univariate	OR	2.50%	97.50%	p	AUC	OR_score*	p_score†
Mortality							
Unemployment	1.012	0.927	1.097	0.779	0.737	3.468	0.000
Poverty	1.008	0.977	1.035	0.583	0.738	3.482	0.000
Low education	1.024	0.990	1.056	0.149	0.744	3.690	0.000
High education	0.966	0.934	0.997	0.039	0.749	2.670	0.000
Crowded house	1.039	0.865	1.199	0.641	0.736	3.446	0.000
Income	0.824	0.625	1.068	0.154	0.743	2.893	0.000
Home Owner	0.868	0.664	1.121	0.287	0.735	3.014	0.000
Complication							
Unemployment	0.988	0.954	1.024	0.526	0.661	3.845	0.000
Poverty	1.011	0.998	1.024	0.083	0.671	4.347	0.000
Low education	1.001	0.985	1.018	0.874	0.664	4.058	0.000
High education	0.974	0.962	0.985	0.000	0.668	2.708	0.000
Crowded house	1.000	0.925	1.076	0.993	0.663	4.025	0.000
Income	0.784	0.708	0.866	0.000	0.677	2.662	0.000
Homeowner[5]	0.827	0.749	0.913	0.000	0.667	2.903	0.000
PLOS							
Unemployment	1.049	1.000	1.099	0.050	0.754	3.086	0.000
Poverty	1.018	1.002	1.033	0.024	0.749	2.962	0.000
Low education	1.011	0.989	1.031	0.324	0.748	2.863	0.000
High education	0.999	0.982	1.016	0.887	0.749	2.716	0.000
Crowded house	1.080	0.989	1.171	0.073	0.748	2.869	0.000
Income	0.968	0.840	1.116	0.657	0.750	2.656	0.000
Homeowner	0.960	0.833	1.105	0.569	0.751	2.632	0.000

*,† p value of likelihood ratio test for the 2 models: outcome ~ risk score + **Socioeconomic Status** covariate outcome ~ risk score.

who are unemployed (and actively seeking work); (2) Poverty: Percentage of persons below the federally defined poverty line; (3) Income: Median household income; (4) Homeowner: Median value of owner-occupied homes; (5) Low education level (Low education): Percentage of persons aged >25 years with less than a twelfth-grade education; (6) High education level (High education): Percentage of persons aged >25 years with at least 4 years of college; (7) Crowded house: Percentage of households containing 1 or more person per room. Because of possible collinearity of SES variables, we performed a correlation matrix and also used an SES index score. SES index score = 50 + (−0.07 × crowded) + (0.08 × prop100) + (−0.10 × pct_poverty) + (0.11 × hhinc100) + (0.10 × high_educ) + (−0.11 × low_educ) + (−0.08 × pct_unemp) (Creation of New Race-Ethnicity Codes and Socioeconomic Status [SES] Indicators for Medicare Beneficiaries).[11]

The risk scores for mortality, complications, and increased length of stay were generated using models published by the STS.[12] Univariate models were fitted for each SES covariate with outcome ~ risk score + 1 SES covariate and a cut-off of $p < 0.2$ for inclusion in the multivariable models. Multivariable model was then fitted with all significant (p value < 0.2) SES covariates included outcome ~ risk score + all significant SES covariates. Different multivariable models were used for (1) mortality, (2) any complication, and (3) prolonged length of stay (PLOS) in addition to the expected risk. The multivariable model was then compared versus the null model (outcome ~ risk score) using likelihood ratio test. Another multivariable model was fitted with the SES index score included instead of all "significant" SES covariates: outcome ~ risk score + SES index score. We evaluated the incremental value of SES covariates using the area under the curve (AUC).

Observed versus Expected outcomes were calculated for each patient using STS formulas for mortality, complication, PLOS. Patients stratified based on SES index score into 6 groups. Observed outcomes for each patient in each group placed in numerator over expected outcomes for that SES group of patients. Confidence intervals at the 95% level calculated for each outcome. P values < 0.05 were considered significant for all analyses.

Results

From 2005 to 2015, 1,386 patients who underwent isolated AVR were included in the study. The in-hospital mortality for the entire cohort was 2.7%, any complication rate was 15.1% and PLOS was 9.7%. The univariate analyses of each SES variable are shown in Table 1. Higher education quartile was associated with decreased mortality (OR 0.96, $p = 0.04$) and complications (OR 0.97, $p < 0.01$). Poverty was associated with increased length of stay (LOS) (OR 1.02, $p = 0.02$), and crowded home trended toward PLOS (OR 1.08 $p = 0.07$).

Multivariable models showed the inclusion of SES covariates increased the AUC for all models but the trend was not always statistically significant (Table 2). A correlation matrix showed a high degree of collinearity between the variables (Table 3). To adjust for this, we also evaluated the effect of an SES index score (Table 4). The multivariable model with SES index score increased AUC for mortality and complication as well but to a lesser degree than the models of individual SES covariates.

Table 2
Multivariate model with STS predicted risk and predictive socioeconomic status variables

	OR	2.50%	97.50%	p	AUC*	AUC†	Improve%	p_LR‡
Mortality								
Risk score	2.942	2.162	4.051	0.000	0.750	0.735	2.04	0.145
Low education	1.015	0.980	1.049	0.371				
High education	0.963	0.910	1.014	0.168				
Income	1.084	0.701	1.679	0.718				
Complication								
Risk score	2.831	2.263	3.566	0.000	0.680	0.663	2.56	0.000
Poverty	1.010	0.997	1.022	0.121				
High education	0.982	0.956	1.009	0.204				
Income	0.808	0.654	0.999	0.048				
Homeowner	1.126	0.899	1.409	0.301				
Prolonged length of Stay								
Risk score	3.078	2.664	3.585	0.000	0.751	0.749	0.27	0.121
Unemployment	1.020	0.960	1.084	0.525				
Poverty	1.011	0.989	1.032	0.306				
Crowded house	1.034	0.931	1.139	0.511				

* AUC of model: outcome ~ risk score + Socioeconomic Status covariates.
† AUC of model: outcome ~ risk score.
‡ p value of the likelihood ratio test comparing the 2 models.

Table 3
SES variable correlation matrix

Variable	Unemployment	Poverty	Lower education	Higher education	Crowded house	Income	Home owner
Unemployment	1.00	0.50	0.52	−0.53	0.37	−0.45	−0.49
Poverty	0.50	1.00	0.69	−0.52	0.48	−0.61	−0.49
Lower Education	0.52	0.69	1.00	−0.71	0.59	−0.64	−0.60
Higher Education	−0.53	−0.52	−0.71	1.00	−0.38	0.73	0.77
Crowded House	0.37	0.48	0.59	−0.38	1.00	−0.38	−0.32
Income	−0.45	−0.61	−0.65	0.73	−0.38	1.00	0.73
Home Owner	−0.49	−0.49	−0.60	0.77	−0.32	0.73	1.00

Observed-expected ratios for mortality, any complications and by SES score of patients are shown in Figure 1 with each group containing 231 patients. Most O/E confidence intervals overlapped 1.0 and were not significant. For mortality, there was no clear trend or significant association with SES. There was a trend toward fewer complications with higher SES starting with SES group 5 and SES group 6 significantly lower. For PLOS, there was no clear trend, but SES group 6 had a nearly significant 0/E 0.55 (0.26 to 1.01).

In order to graphically evaluate the incidence of aortic valve operations on the individual census-tract levels with a specific SES index score for each census tract, Figure 2 shows the number of patients per census tract who underwent AVR at the institution in this study. Figure 3 maps the spectrum of SES scores by census tract, which is indepen-

Table 4
Multivariable model with SES index score for VAR

	OR	2.5%	97.5%	p	AUC*	AUC†	Improve%
Mortality							
Risk score	2.511	1.727	3.649	0.000	0.740	0.735	0.69
SES score	0.984	0.965	1.003	0.107			
Complication							
Risk score	2.621	2.067	3.341	0.000	0.668	0.663	0.79
SES score	0.989	0.984	0.994	0.000			
Prolonged Length of Stay							
Risk score	2.883	2.288	3.661	0.000	0.748	0.749	−0.09
SES score	1.002	0.993	1.011	0.660			

* AUC of model: outcome ~ risk score + Socioeconomic Status score.
† AUC of model: outcome ~ risk score.

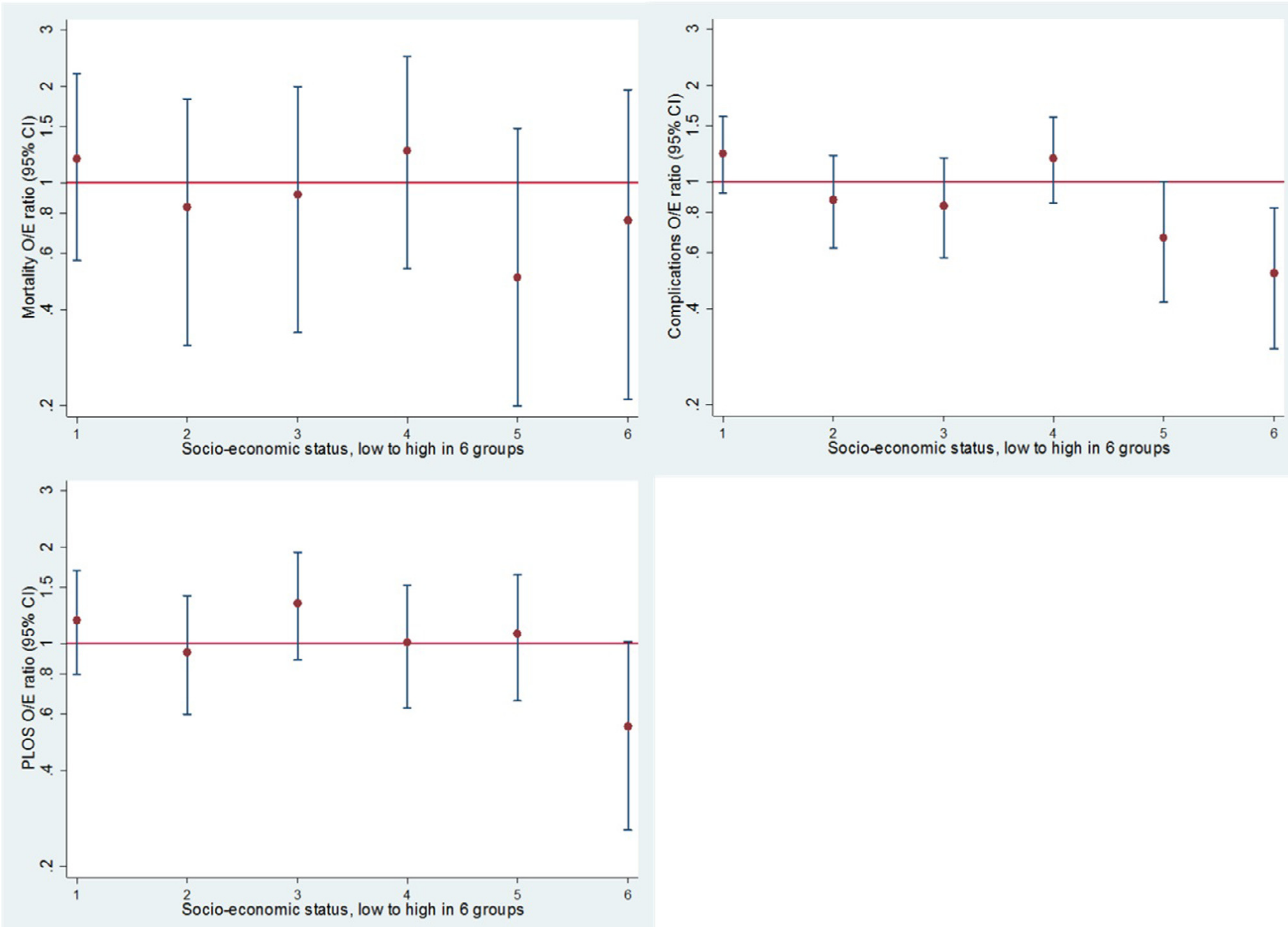


Figure 1. Observed-expected ratios for mortality (top left), complications (top right), and PLOS (bottom), by socioeconomic status score of patients' residential locations.

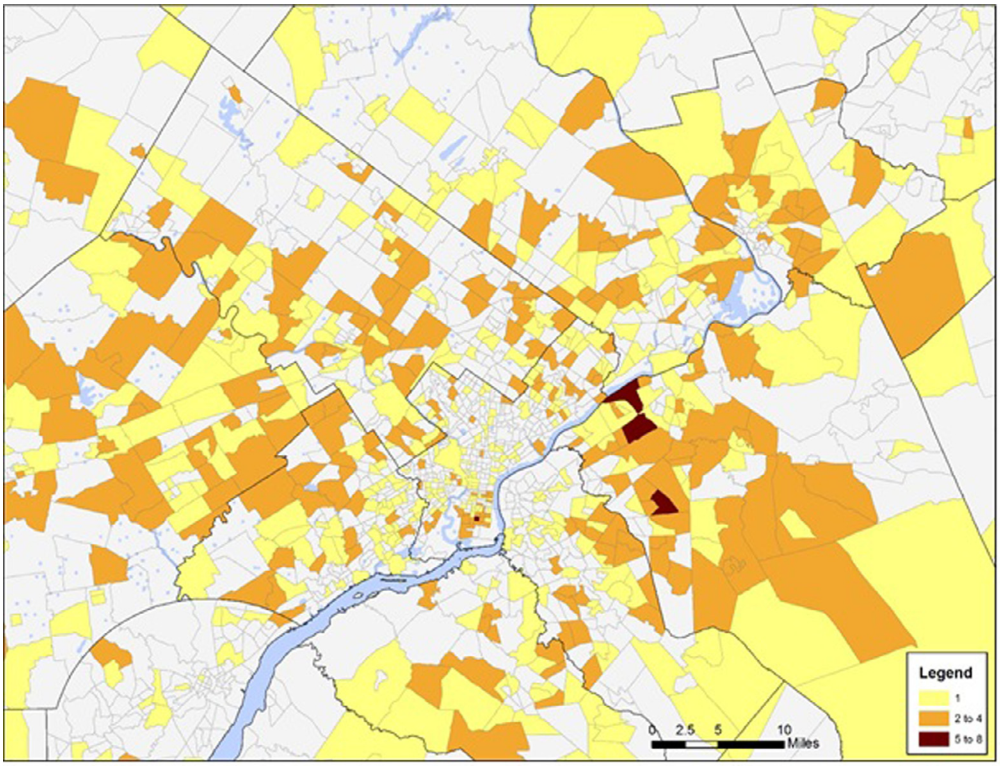
dent of institution where patients receive cardiac surgery. There is a broad range of SES scores from 38 to 70, with a recognizable pattern of lower SES scores in the smaller, more densely populated, and centrally located/urban tracts and high SES scores in the larger, suburban tracts. There does not appear to be an overlapping pattern between Figures 2 and 3 suggesting no clear correlation between AVR incidences with low or high SES.

Discussion

In this study, we evaluated the inclusion of SES factors in STS risk prediction models for AVR mortality and morbidity in patients from a large, urban academic medical center. We used AVR for this study, because AVR is the most common elective cardiac surgery procedure performed in our health system. There are 3 main findings from this study. First and most importantly, the use of census-tract-level socioeconomic factors in STS risk prediction models is new and shows potential to improve risk prediction for outcomes after AVR, particularly for predictions of any complications after AVR. Secondly, there are different ways to measure SES and this study found that using individual SES variables led to the greatest improvement in STS risk prediction models but due to high collinearity a composite SES variables may be more appropriate. Last, this study demonstrates the possible value of utilizing the national level database in order to fully capture outcomes of AVR or other index cardiac surgeries.

A number of previous studies have evaluated the association with SES and health outcomes. Low SES has been associated with increased disease burden in a number of different countries but specifically with increased cardiovascular disease in the United States, deceased access to coronary artery bypass grafting (CABG) operations or increased likelihood to have CABG at a low volume center.[1,2,13−17] The lack of access and likely clustering of other risk factors have been linked to worse outcomes and notably, adverse outcomes after the most common types of cardiac surgery including AVR, mitral valve replacement (MVR), and CABG.[1,3,18−26] Although the exact mechanism of SES and worse outcomes either in the short- or long term is debatable, there exists a significant body of evidence to suggest SES may offer independent value in risk prediction in cardiac surgery.

In our study, SES was correlated to worse outcomes, but the apparent effect was modest. We were surprised that SES indicators did not have a stronger relation to outcomes. There are several plausible explanations for this result. It is



Number of Patients in Tract	Count
1	413
2	154
3	63
4	29
5	2
6	1
8	1

Figure 2. Number of patients per census tract.

possible that SES does not have as large an impact as we supposed. The current STS risk model for AVR does include race, and much of the "effect" of low SES may be captured in this variable, particularly as more African-Americans live in low SES areas. A recent publication that examined outcomes after acute myocardial infarction found that 26% of black patients lived in low SES areas as opposed to 5.7% of white patients.[27] Sorting of races into lower or higher SES areas may be more pronounced in Philadelphia and the surrounding areas, thus blunting any outcome differences between low and high SES areas in our single institution study.

This study provides novel information in that it evaluates the association of SES and outcomes after AVR as well as the incremental value in adding SES variables to the existing, robust STS risk prediction models for morbidity and mortality after AVR. The SES variables of unemployment, poverty, income, home ownership, lower education, higher education, and crowded house were evaluated in unadjusted and adjusted analysis for mortality and the morbidities of any complication and specifically PLOS. Despite including patients from only 1 health system, the results showed the models for mortality and morbidity improved with the inclusion of SES as judged by the increased AUC. The magnitude of the effect was statistically significant for any complication and trended toward significance for mortality and PLOS, which is notable given the use of only a single center experience in a competitive Northeastern area of the United States.

The use of a single center's experience and the other cardiac surgery programs in the same region are important considerations for how SES variables are captured and potentially included into a risk prediction model. SES variables for each individual patient are not captured by any large clinical database due to concerns of practicality and privacy. Instead, SES variables are geographically derived and regularly captured by the US census bureau. SES variables must then be deidentified, pooled, and linked to health outcomes. The pooling of SES variables can vary in scale in descending size rank from continents to countries, states, counties, cities, zip codes, census tracts, block groups, and finally individual blocks. There has been an ongoing debate regarding the most appropriate and accurate pooling size with census-tract-level data equating to approximately 4,000 residencies being sufficient to capture SES. These area-based measures can be conceptualized as meaningful indicators of socioeconomic context in their own right and not merely "proxies" for individual level data, providing information on not only the area's residents (its composition) but also area-level characteristics not reducible to the individual level (e.g., concentration of poverty, absence of a nearby clinic, or adjacency to a toxic waste site) although also representing certain health hazards in the community.[9]

A larger study using a comprehensive database such as the national STS database could potentially enhance the findings of these studies in 3 important areas. First, this study was limited to a degree by sample size but more importantly as only 1 health system in a competitive market, there are likely a number of other patients within these census tracts that underwent AVR. In order to fully power the incremental value of adding SES variables to STS risk prediction model, capturing all patients with available

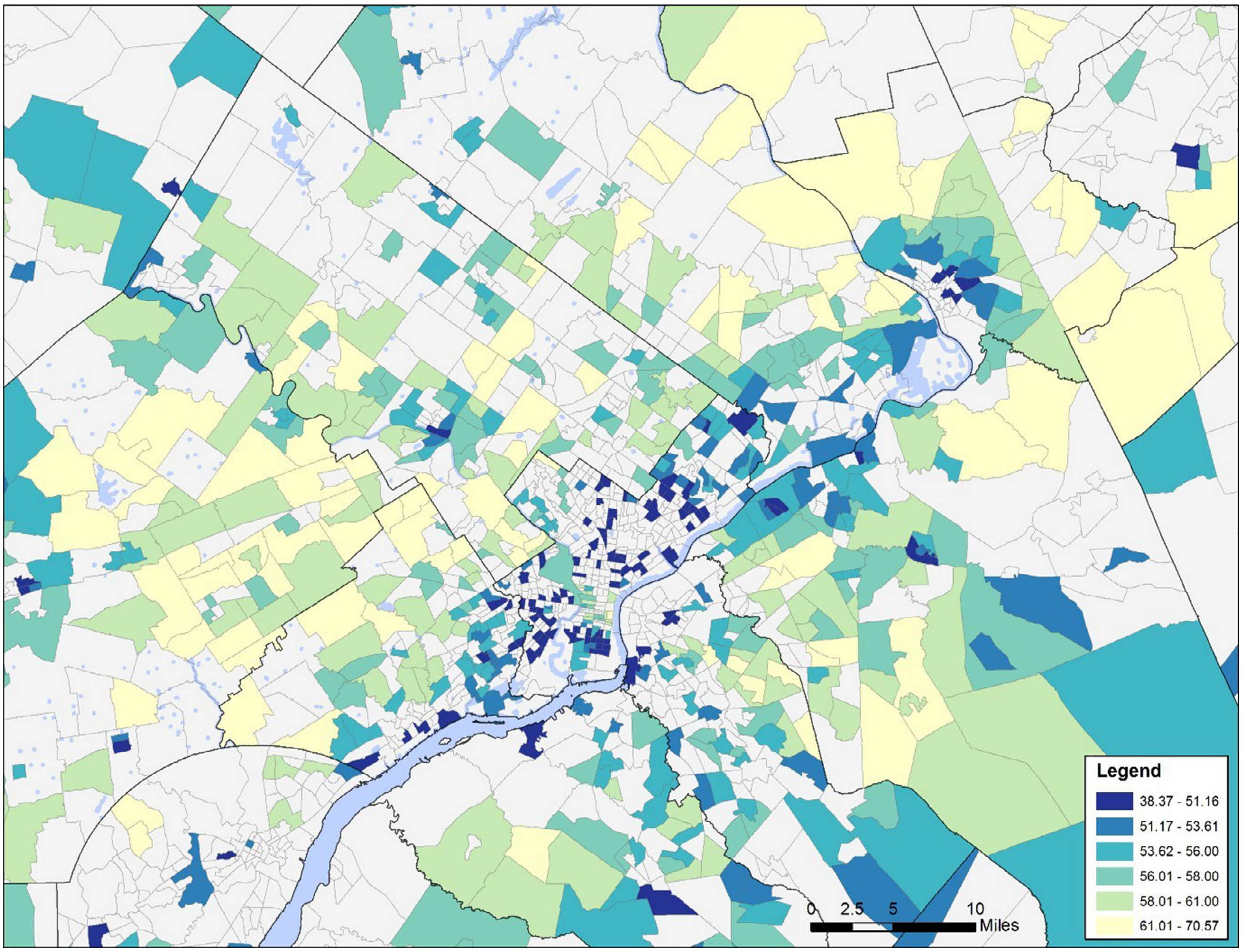


Figure 3. Range of SES scores by census tract.

census-level SES data would allow the models to further discriminate between SES variables and incorporate those associated with improved risk prediction above and beyond current models. The second important analysis potentially made possible by a national study would be to inform the current imperatives for public reporting and interhospitals comparisons. By not including SES variables associated with worse outcomes in the current risk models and outcomes comparison adjustments, hospitals, and providers that care for low SES patients are potentially disadvantaged in comparisons and possibly discouraged from taking on riskier patients that lack any adjustment in currently used models. Last, the identification of these variables such as home ownership, crowded home or education level offer opportunities to better understand preoperative risk, and potential areas for improvement or focus efforts for new policies or public health initiatives.

This study was limited by SES variables that had to be extrapolated from census-tract data and linked to a single institutional database, which means SES variables are geographically derived rather than representing the SES of each individual patient. Additionally, patients within the census-tracts could have potentially undergone AVR at another institution and would not be captured by this study. Despite these power limitations, inclusion of SES variables from the census-tracts of the patients in the study improved the risk prediction models for morbidity and mortality. The study was also limited by evaluating only 1 cardiac surgery operation. All 3 of these limitations could potentially be addressed by a national study of the major index cardiac surgery operations with already established risk prediction models.

The inclusion of census-tract-level socioeconomic factors into the STS risk predication models is new and shows potential to improve risk prediction for outcomes after cardiac surgery. With the possibility of reimbursement and institutional ranking based on these outcomes, this study represents an improvement in risk prediction even when limited to census tracts and a single institution's experience.

Disclosures

None of the authors have any conflicts of interest.

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