Area-Level Socioeconomic Disadvantage and Severe Pulmonary Tuberculosis: U.S., 2000–2008

Eyal Oren, PhD[a,b]
Masahiro Narita, MD[b,c]
Charles Nolan, MD[a]
Jonathan Mayer, PhD[a]

ABSTRACT

Objectives. Lower socioeconomic status (SES) is associated with increased risk of tuberculosis (TB) and diagnostic delays, but the extent to which this association reflects an underlying gradient in advanced status of pulmonary TB is unknown. We conducted a multilevel retrospective cohort analysis examining the relationship between socioeconomic characteristics and pulmonary TB disease status, as measured via sputum smears and chest radiography results.

Methods. We included 862 incident TB patients reported in King County, Washington, from 2000–2008. We abstracted patient-level measures from charts and surveillance data. We obtained socioeconomic characteristics of TB patients, as well as those of the areas where TB patients lived, from the 2000 U.S. Census. A socioeconomic position (SEP) index was derived to measure SES.

Results. Of those with known results, 814 of 849 patients (96%) displayed abnormal radiography findings. A total of 239 graded patients (39%) had positive smears, 136 (57%) of whom had grades of moderate (3+) or numerous (4+) acid-fast bacilli. In unadjusted analyses, patients living in lower SEP areas did not appear to have higher probabilities of more advanced disease. In multivariate models adjusting for individual demographic and socioeconomic measures, as well as area-based demographic variables, block-group SEP was not significantly associated with more advanced pulmonary disease.

Conclusions. Lower SEP was not significantly associated with greater pulmonary disease severity after controlling for individual age, race, sex, and origin, and block-group race, ethnicity, and origin. These findings suggest that the severity of pulmonary TB at diagnosis is not synonymous with delayed diagnosis.

[a]University of Washington, Department of Epidemiology, Seattle, WA

[b]Public Health—Seattle & King County, Tuberculosis Control Program, Seattle, WA

[c]University of Washington, Division of Pulmonary and Critical Care Medicine, Seattle, WA

Address correspondence to: Eyal Oren, PhD, Public Health—Seattle & King County, Tuberculosis Control Program, HMC-PH-0100, 325 Ninth Ave., Seattle, WA 98104; tel. 206-744-2196; e-mail <eoren@uw.edu>.

Although tuberculosis (TB) incidence continues to decline in the United States, the proportion of advanced pulmonary TB, defined as smear-positive or cavitary disease, has been increasing.[1,2] Advanced clinical presentation may result from delayed diagnosis and treatment and may lead to greater infectivity and likelihood of transmission within a community.[3,4]

Lower socioeconomic status (SES) has been linked to more severe disease status for a variety of diseases including cystic fibrosis,[5] sarcoidosis,[6] subclinical coronary heart disease,[7] cancers,[8,9] and pulmonary fibrosis.[10] While the presence of other comorbidities, poor access to care, substance abuse, low income, education level, and lack of insurance[11–16] constitute risk factors for delays in TB diagnosis, little work has been done to characterize the association between SES and advanced pulmonary TB disease, as more advanced disease is often seen as characteristic of diagnostic delay. Furthermore, much of the work examining diagnostic delay has been examined outside the U.S. Areas in which people live are likely to have differential access to care, including proximity, cost, and presence of public clinics and transportation.[17,18] Disease status is likely to be impacted by such variations in area-level factors and, in particular, by variations in area-level SES across neighborhoods.

Using TB case registry data on incident TB patients combined with chart reviews, we explored the relationship between individual patient demographic and SES attributes, in combination with area-level social characteristics, and two TB severity outcomes at diagnosis—lung cavitation and smear-positive acid-fast bacilli (AFB) in sputum smears. These measures have been linked to impaired pulmonary function, TB treatment failure, or death[19,20] and represent later disease stages.[21,22]

Specifically, this study was designed to assess whether severity of pulmonary TB disease was positively associated with area-based socioeconomic disadvantage within King County, Washington. By examining socioeconomic and demographic characteristics of block groups, our hope was to identify those factors that might play an important role in predicting disease severity at diagnosis. Such findings could provide insight into pathways by which area-level SES independently affects pulmonary disease severity.

METHODS

Study population and setting

A total of 862 incident pulmonary TB patients were reported in King County from January 1, 2000, to December 31, 2008. Criteria for diagnosis of pulmonary TB patients met either Centers for Disease Control and Prevention (CDC) laboratory criteria for a sputum culture positive diagnosis or the clinical case definition, which includes either an abnormal chest radiograph or other signs and symptoms compatible with TB.[23] Individuals had either exclusively pulmonary disease or pulmonary involvement. Due to considerations regarding age of research consent, all models excluded minors (<18 years of age). Included patients represented 380 block groups within King County. A census block group was defined as a cluster of census blocks having the same first digit of their four-digit identifying numbers within a census tract.[24] Block groups have previously been validated as an informative spatial scale at which to report socioeconomic data.[25]

Study design

The analysis used a retrospective cohort design, merging reporting and chart data for TB patients and U.S. block-group-level census data for residents of King County.

Data sources

Measurement of socioeconomic position. A socioeconomic position (SEP) index was constructed combining data on six singular SES measures: percentage of the population who were working class, were unemployed, were living in poverty, had less than a high school education, and owned expensive homes, as well as median household income. To construct the score, we gave each variable a standardized z-score, which was the sum of all block-group values with SEP data (n=1,576), minus the mean sum, divided by the standard deviation, and then summed the individual z-scores. Variables included for each block group were taken from the 2000 U.S. Census Summary Tape File-3 and were consistent with a previously validated composite measure used in the Public Health Disparities Geocoding Project. The Geocoding Project developed this measure based on a factor analysis of 11 individual SES factors using rank values of the Census data.[25] The SEP index was modeled as a four-level categorical variable, using quartiles in the block-group distribution as cutoffs, with the highest quartiles representing the wealthiest block groups.

Measurement of disease severity. We chose two available characteristics of advanced pulmonary TB at diagnosis from 2000–2008: grade of sputum smear and chest radiographic abnormalities. Sputum smears were quantified using fluorochrome stains and categorized using sputum smear grades in an ordinal fashion as negative (no AFB seen), 1+ (rare), 2+ (few), 3+ (moderate), and 4+ (numerous), depending on AFB load. Smears were also dichotomized as positive or negative. Standard posterior-anterior chest radiographs were categorized ordinally as normal, abnormal non-cavitary, or cavitary in the patient medical chart by the Public Health–Seattle & King County TB Control Program medical director, with patients with normal radiographs serving as the referent category. Radiographs were also separately categorized as to whether there was unilateral or bilateral pulmonary involvement. Both radiography and smear results were obtained from the Tuberculosis Information Management System (TIMS)[26] and supplemented with available data from patient medical charts with quantitative smear grade. Smear grade was obtained for the 76% of patients with complete medical records.

Anthropometric and psychosocial individual measures. The following individual measures from the National Tuberculosis Surveillance System[23] were used: race, sex, age, ethnicity, foreign birth, homelessness, human immunodeficiency virus (HIV) status, and provider type. In addition, an experienced nurse measured height and weight to compute body mass index (BMI). Participants reported on standardized clinic forms whether or not they were in paid employment at diagnosis, as well as their occupation, insurance, smoking status, and alcohol intake history. Patient-level variables were subsequently aggregated by block group.

Other area-level measures. We derived area-based covariates from the U.S. Population Census 2000, SF1 and SF3.[27,28] We modeled the proportion of each block group that was black, Asian, Hispanic, and foreign-born using quartiles of each population in each block group, with the quartile directly below serving as the referent group.

Statistical analysis and modeling

We excluded observations from univariate analyses when the percentage unknown or missing was <2%. We examined unadjusted proportions of individuals in each SEP index quartile and stratified them by both quantitative smear grade and radiography results, with percentages adding up to 100 across SEP index quartiles. We also examined the relationship between TB sputum smear grade and radiology results using Pearson's Chi-square test.

To examine area-level influences in addition to individual attributes as they relate to variation in severity of disease, we used multilevel logistic regression models.[29] These classes of models allowed for analysis of the ordered outcomes and accommodated the hierarchical data structure.

After building multilevel models of significant fixed effects, other parameters were added, allowing for baseline variation in disease severity across block groups. For ordinal models, the forms used were similar, but used an ordered logit model allowing for three responses for radiography outcomes (normal, abnormal non-cavitary, and abnormal cavitary) and five responses for smear grade (negative, 1+, 2+, 3+, and 4+).

For each outcome, we tested four nested models. Model 1 tested area-based socioeconomic quartiles and the association with dependent variables. Model 2 included individual demographic factors (mean-centered age modeled continuously and as a quadratic term, race modeled using dummy variables, sex modeled as a binary term, and foreign birth as a binary term) as covariates. Individual-level SES factors were additionally included (homelessness as a binary term and provider type as a dummy variable) in Model 3. Area-level factors (ethnicity, foreign birth, and race) were added in Model 4 to assess the contextual effects of Asian and black race, Hispanic ethnicity, and foreign birth while controlling for individual confounders and area-level SEP. We used complete case analysis such that the number of patients with missing covariates excluded from each model was the same. We performed multilevel model building and estimation using the Generalized Linear Latent and Mixed Models extension of Stata® version 10.0.[30]

RESULTS

Description of TB patients

Table 1 portrays overall and analysis-specific patient population characteristics. A total of 862 TB patients were included in the initial analysis, with 65% being male and a median age at diagnosis of 44 years. TB patients were primarily Asian (40%), black (24%), or white (26%). More than 70% of the patient population was foreign-born. TB risk factors included homelessness (20%), unemployment prior to diagnosis (36%), HIV infection (9% of known results), and smoking (28% of known results). Patients were included in subsequent analyses if a sputum specimen (n=806) and/or chest radiograph result (n=849) was available. A total of 616 patients were included in a subgroup for quantitative smear-grade analysis, excluding patients for whom smear grades were unknown (n=246). The flow chart shows the patient inclusion process for each severity measure (Figure 1).

Table 1. Characteristics of TB patients reported in King County, Washington: 2000–2008

		Smear status		*Chest radiography degree*		
Characteristic	*Population* N *(percent)*[a]	*Positive* N *(percent)*[a]	*Negative* N *(percent)*[a]	*Normal* N *(percent)*[a]	*Abnormal* N *(percent)*[a]	*Cavitary* N *(percent)*[a]
Total (*N*)	862	416	390	35	579	235
Sex: male	556 (64.5)	289 (69.5)	237 (60.8)	19 (54.3)	363 (62.7)	168 (71.5)
Age (in years): mean (SD)	44.2 (20.5)	43.4 (19.0)	45.5 (20.3)	39.7 (14.9)	45.8 (21.6)	40.7 (17.8)
Age categories (in years)						
0–4	18 (2.1)	0 (0.0)	3 (0.8)	1 (2.9)	16 (2.8)	1 (0.4)
5–14	14 (1.6)	3 (0.7)	8 (2.1)	0 (0.0)	12 (2.1)	2 (0.9)
15–24	132 (15.3)	76 (18.3)	55 (14.1)	4 (11.4)	78 (13.5)	49 (20.9)
25–44	297 (34.5)	153 (36.8)	137 (35.1)	20 (57.1)	183 (31.6)	90 (38.3)
45–64	236 (27.4)	119 (28.6)	106 (27.2)	9 (25.7)	157 (27.1)	68 (28.9)
≥65	161 (18.7)	65 (15.6)	81 (20.8)	1 (2.9)	133 (23.0)	25 (10.6)
Race						
American Indian	49 (5.7)	31 (7.5)	18 (4.6)	4 (11.4)	36 (6.2)	8 (3.4)
Asian	353 (40.1)	151 (36.3)	175 (44.9)	8 (22.9)	247 (42.7)	95 (40.4)
Black	205 (23.8)	104 (25.0)	94 (24.1)	12 (34.3)	130 (22.5)	59 (25.1)
Native Hawaiian	19 (2.2)	9 (2.2)	9 (2.3)	1 (2.9)	13 (2.3)	5 (2.1)
White	224 (26.0)	115 (27.6)	92 (23.6)	20 (28.6)	148 (25.6)	65 (27.7)
Multiple races	2 (0.2)	1 (0.2)	1 (0.3)	0 (0.0)	2 (0.4)	0 (0.0)
Ethnicity						
Hispanic[b]	96 (11.1)	60 (14.4)	31 (8.0)	6 (17.1)	53 (9.2)	36 (15.3)
Country of origin						
U.S.-born	250 (29.0)	118 (28.4)	102 (26.2)	15 (42.9)	165 (28.5)	63 (26.8)
Foreign-born[c]	610 (70.8)	297 (71.4)	287 (73.6)	20 (57.1)	413 (71.3)	171 (72.8)
Time from U.S. arrival to TB diagnosis (in years)[d]						
0–4	235 (38.5)	110 (37.0)	121 (42.2)	8 (40.0)	165 (39.7)	60 (35.1)
5–9	91 (14.9)	54 (18.2)	36 (12.5)	2 (10.0)	54 (13.1)	35 (20.5)
10–19	135 (22.1)	62 (20.9)	65 (22.7)	3 (15.0)	96 (23.2)	35 (20.5)
≥20	101 (16.6)	53 (17.9)	42 (14.6)	5 (25.0)	66 (16.0)	30 (17.5)
Missing	48 (7.9)	18 (3.1)	23 (8.0)	2 (10.0)	33 (8.0)	11 (6.4)
HIV status						
Negative	634 (73.9)	319 (76.7)	293 (75.1)	23 (65.7)	405 (70.0)	201 (85.5)
Positive	62 (7.2)	34 (8.2)	26 (6.7)	9 (25.7)	44 (7.6)	7 (3.0)
Unknown/missing[e]	162 (18.9)	62 (15.1)	71 (18.2)	3 (8.6)	130 (22.4)	27 (11.5)
Homeless within past year						
No	688 (79.8)	310 (74.5)	327 (83.9)	19 (54.3)	479 (82.7)	182 (77.5)
Yes	169 (19.6)	106 (25.5)	62 (15.9)	15 (45.7)	99 (17.2)	53 (22.6)
Insurance						
No	277 (32.1)	144 (34.4)	198 (33.5)	13 (37.1)	195 (33.7)	65 (27.7)
Yes	144 (16.7)	77 (18.4)	105 (17.7)	2 (5.7)	90 (15.5)	51 (21.7)
Missing	441 (51.2)	198 (47.3)	289 (48.8)	20 (57.1)	294 (50.8)	119 (50.6)
Unemployed within past 24 months						
Yes	314 (36.4)	145 (34.9)	144 (36.9)	15 (42.9)	227 (39.2)	70 (29.8)
No	548 (63.6)	271 (65.1)	246 (63.1)	20 (57.1)	352 (60.8)	165 (70.2)
Injecting drug use within past year						
No	806 (93.5)	384 (92.3)	374 (95.9)	30 (85.7)	547 (94.5)	220 (93.6)
Yes	26 (3.0)	17 (4.1)	8 (2.1)	3 (8.6)	17 (2.9)	6 (2.6)
Missing	30 (3.5)	15 (3.6)	8 (1.0)	2 (5.7)	2 (2.6)	9 (3.8)
Non-injecting drug use within past year						
No	757 (93.5)	353 (84.9)	357 (91.5)	26 (74.3)	524 (90.5)	199 (84.7)
Yes	70 (8.1)	45 (10.8)	23 (5.9)	7 (20.0)	38 (6.6)	24 (10.2)
Missing	35 (4.1)	18 (4.3)	10 (2.6)	2 (5.7)	17 (2.9)	12 (5.1)
Excess alcohol use within past year[f]						
No	704 (81.7)	314 (75.5)	343 (88.0)	25 (71.4)	490 (84.6)	181 (77.0)
Yes	131 (15.2)	87 (20.9)	43 (11.0)	7 (20.0)	79 (13.6)	45 (19.2)
Missing	27 (3.2)	15 (3.6)	4 (1.0)	3 (8.6)	10 (1.7)	9 (3.8)

continued on p. 103

Table 1 (continued). Characteristics of TB patients reported in King County, Washington: 2000–2008

		Smear status		Chest radiography degree		
Characteristic	*Population* N *(percent)*[a]	*Positive* N *(percent)*[a]	*Negative* N *(percent)*[a]	*Normal* N *(percent)*[a]	*Abnormal* N *(percent)*[a]	*Cavitary* N *(percent)*[a]
Smoking history						
No	348 (40.4)	177 (42.2)	273 (46.1)	12 (34.3)	245 (42.3)	86 (36.6)
Yes	135 (15.7)	75 (17.9)	74 (12.5)	5 (14.3)	84 (14.5)	46 (19.6)
Missing	379 (44.0)	167 (39.9)	245 (41.4)	18 (51.4)	250 (43.2)	103 (43.8)
Chest radiographic result						
Normal	35 (4.1)	7 (1.7)	22 (5.6)	NA	NA	NA
Abnormal, non-cavitary	579 (66.0)	211 (50.7)	330 (84.6)	NA	NA	NA
Abnormal, cavitary	235 (27.3)	193 (46.4)	36 (9.2)	NA	NA	NA
Not done	3 (0.4)	1 (0.2)	1 (0.3)	NA	NA	NA
Bilateral lung involvement						
No	288 (33.4)	134 (32.0)	254 (42.9)	16 (45.7)	209 (36.1)	60 (25.5)
Yes	183 (21.2)	114 (27.2)	85 (14.4)	1 (2.9)	108 (18.7)	72 (30.6)
Unknown	391 (45.4)	171 (40.8)	253 (42.7)	18 (51.4)	262 (45.3)	103 (43.8)
Sputum smear result[g]						
Positive	416 (48.2)	NA	NA	7 (20.0)	211 (36.4)	193 (82.1)
Negative	390 (45.2)	NA	NA	22 (62.9)	330 (57.0)	36 (15.3)
Not done	48 (5.6)	NA	NA	4 (11.4)	37 (6.4)	5 (2.1)
Provider type						
Health department	686 (79.6)	338 (81.3)	313 (80.3)	27 (77.1)	454 (78.8)	198 (80.6)
Private provider	65 (7.5)	26 (6.3)	29 (7.4)	2 (5.7)	52 (4.7)	11 (7.7)
Both	101 (11.7)	49 (11.8)	45 (11.5)	6 (17.1)	70 (9.2)	23 (11.7)

[a]Percentages may not total 100 due to rounding and exclusion of unknown when <2%.

[b]People of Hispanic ethnicity may be of any race or multiple races.

[c]Foreign-born includes people born outside the U.S., American Samoa, the Federated States of Micronesia, Guam, the Republic of the Marshall Islands, Midway Island, the Commonwealth of the Northern Mariana Islands, Puerto Rico, the Republic of Palau, the U.S. Virgin Islands, and U.S. minor and outlying Pacific islands.

[d]Among foreign-born patients

[e]Unknown or missing includes indeterminate, refused, not offered, test done but unknown, and unknown.

[f]Excess alcohol use is ≥5 drinks on same occasion on each of ≥5 days in past 30 days.

[g]From the National Tuberculosis Surveillance System; smears not done/unknown account for 56 (6%) of total smear results.

TB = tuberculosis

SD = standard deviation

HIV = human immunodeficiency virus

NA = not available

Block-group characteristics

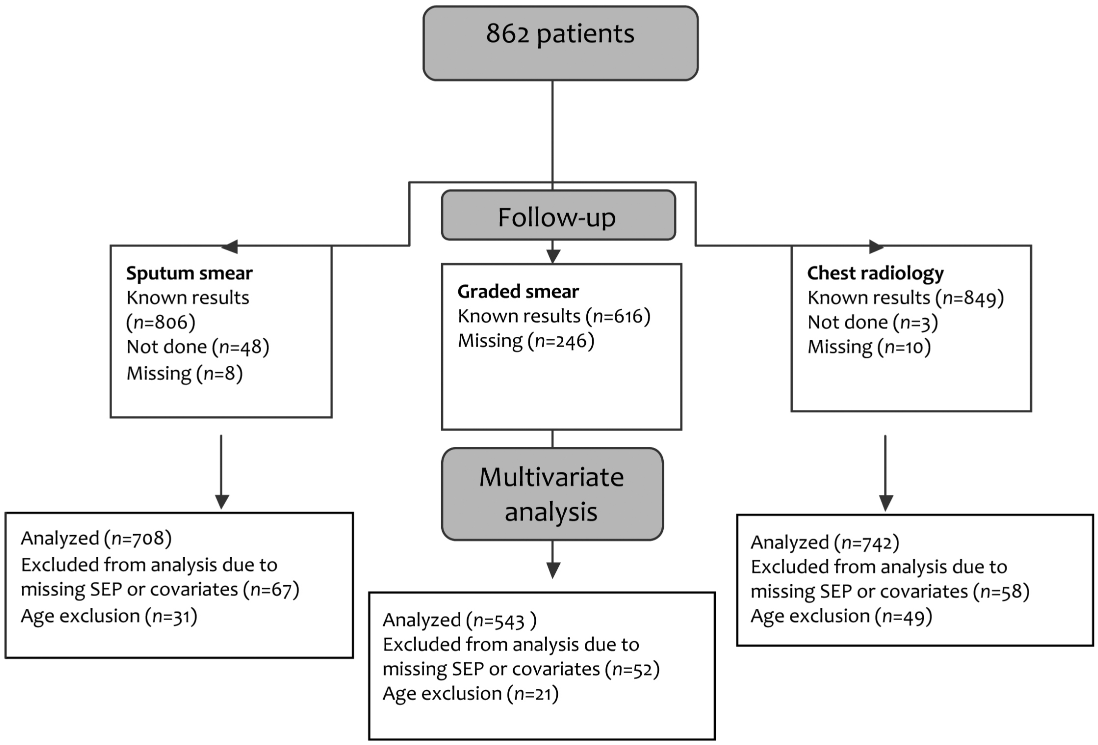
The 380 block groups included in the analysis were more likely to contain individuals reporting black or Asian descent as well as Hispanic ethnicity compared with median values in King County. Additionally, the median proportion of foreign-born individuals in these block groups was more than 1.5 times as high as the King County median (Table 2).

Disease severity findings

Of those with known results, 96% (814/849) of patients displayed abnormal radiography findings, with approximately one-third (33%) exhibiting extensive bilateral lung involvement. For the quantitative smear-grade outcome analysis, 39% (239/616) of graded patients had positive smears, of whom 57% had grades of moderate (3+) or numerous (4+) AFB. Higher grades of smear and cavitary radiographs were positively correlated, where greater proportions of cavitary x-rays were observed with progressively higher smear grade ($p<0.001$). Bilateral lung disease was significantly associated with both higher sputum smear grade ($p<0.001$) and cavitary disease ($p<0.001$) (data not shown).

Eighty-one percent of TB patients resided in block groups in the lowest two SEP index quartiles. In unadjusted analyses, patients living in areas with higher levels of deprivation did not have statistically higher probabilities of severe radiographs or higher smear grade (Figures 2 and 3).

Figure 1. Flow diagram detailing inclusion criteria in an analysis of socioeconomic disadvantage and pulmonary tuberculosis severity: King County, Washington, 2000–2008



SEP = socioeconomic position

Table 2. Characteristics of 380 block groups included in an analysis of socioeconomic disadvantage and pulmonary tuberculosis severity in King County, Washington, based on 2000 U.S. Census data

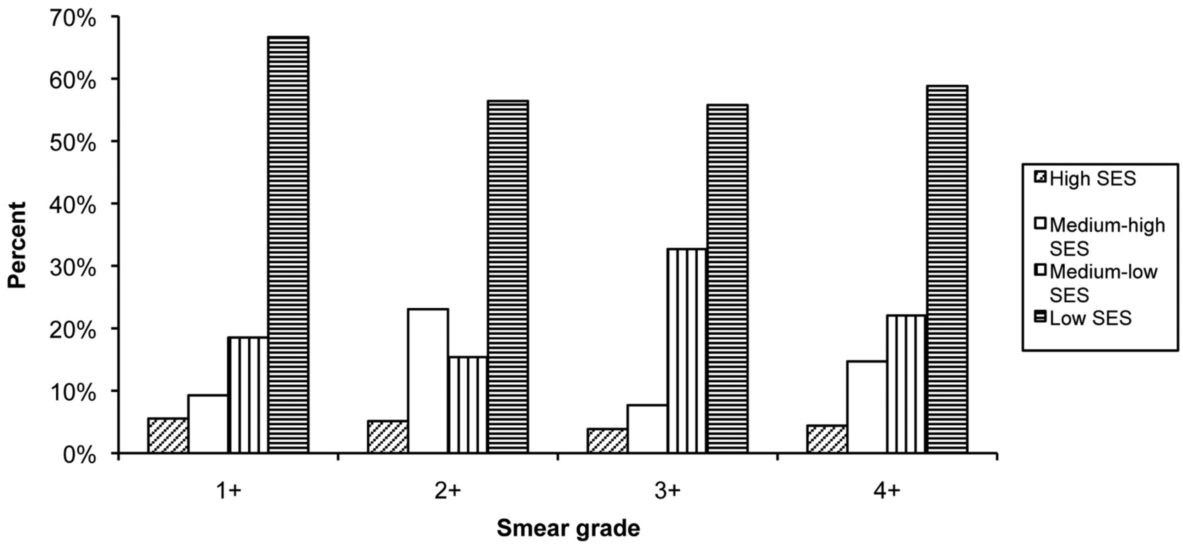
Variable	*Median*	*Mean*	*SD*	*Range*	*King County median*[a]
Demographics					
Population size (*N*)	1,130	1,211	545	246–4,721	1,011
Race					
Non-Hispanic white (percent)	69.1	63.3	22.7	3.1–97.5	79.7
Non-Hispanic Asian (percent)	11.3	14.9	14.0	0.0–73.2	7.1
Non-Hispanic black (percent)	4.7	8.5	10.6	0.0–56.3	1.8
Hispanic ethnicity (percent)	4.9	7.2	7.1	0.0–44.4	3.5
Foreign-born (percent)[b]	17.4	20.2	12.8	0.0–62.4	11.7
Socioeconomics					
<High school education (percent)	8.7	12.2	10.7	0.0–59.7	6.9
Unemployment (percent)	2.9	3.5	3.1	0.0–26.4	2.6
Median household income (in U.S. dollars)	$50,357	$52,741	$21,545	$7,382–$146,129	$56,691
Poverty (percent)	7.5	10.5	10.2	0.0–62.7	5.5
Working class (percent)	56.1	55.5	13.8	14.0–85.4	51.1
Home ownership (percent)	65.1	61.2	27.0	0.0–100.0	73.5
Tuberculosis measures					
Mean patients per block group (per year)	0.1	0.2	0.3	0.1–3.9	0.0
Incidence rate per block group (per 100,000 person-years)	14.4	22.1	29.8	3.5–334.4	0.0

[a]King County median reflects all block groups with socioeconomic status variables available (*n*=1,576).

[b]Excluding U.S. territories and those born abroad to U.S. parents

SD = standard deviation

Figure 2. Proportion of tuberculosis patients in quartiles of block-group SES, by sputum smear grade: King County, Washington, 2000–2008[a]



[a]Excludes smear grades that were not done or unknown, as well as missing SES

SES = socioeconomic status

Multivariate analyses

Chest radiograph model. In unadjusted analyses, the baseline model indicated that individuals living in lower SEP index neighborhoods did not have more severe x-ray presentation, with the odds ratio (OR) of more severe disease not significantly increased in the lowest as compared with the highest quartile (OR=0.95, 95% confidence interval [CI] 0.53, 1.70; p=0.935) (Table 3, Model 1). In addition, in individual-level multivariate models (Table 3, Models 2 and 3), inclusion of demographic and SES covariates did not significantly alter the association between SEP index quartile and disease severity, although foreign birth decreased and white race increased the odds for more severe presentation. Inclusion of individual insurance status and behavioral risk factors (i.e., drug and alcohol use, smoking, and BMI) on smaller available samples did not change the observed association (data not shown). In multivariate analyses restricted to non-HIV-infected individuals, no significant changes were observed in SEP effect estimates on severity.

Comparison of coefficients from Models 3 and 4 did not show substantial change in the SEP-TB association when other area-level influences were added (Table 3, Model 4). There was modest change in the strength of the effect, but direction and magnitude of the associations were consistent across the two models. Of four area-level variables examined at the block-group level in addition to SEP index, none remained statistically significant in the multilevel model (Table 3, Model 4). Area-level variables explained little between-block group variance, such that only 9% of variance in severity was attributable to the block group.

Sputum smear models. As with the radiograph findings, lower SES quartiles were not associated with higher smear grade with any of the models run. In models examining binary positive/negative smear outcomes, a positive smear was not significantly associated with SEP quartile, and this lack of a relationship remained after controlling for demographic, individual SES, and area-based demographic factors. Homelessness was linked to higher odds of positive sputum smears but did not change the observed SEP-smear estimates. The relative contribution of each of the individual-level main effects was similar in both sputum smear models, suggesting that area-level factors did not diminish the effect of individual-level influences. None of the between-block group variance in the probability of having a positive smear result was accounted for by block-group SEP. However, when individual-level age, race, sex, and origin were added in Model 2, the variance increased fivefold, indicating that heterogeneity in disease severity across block groups was partially accounted for by underlying demographic characteristics.

DISCUSSION

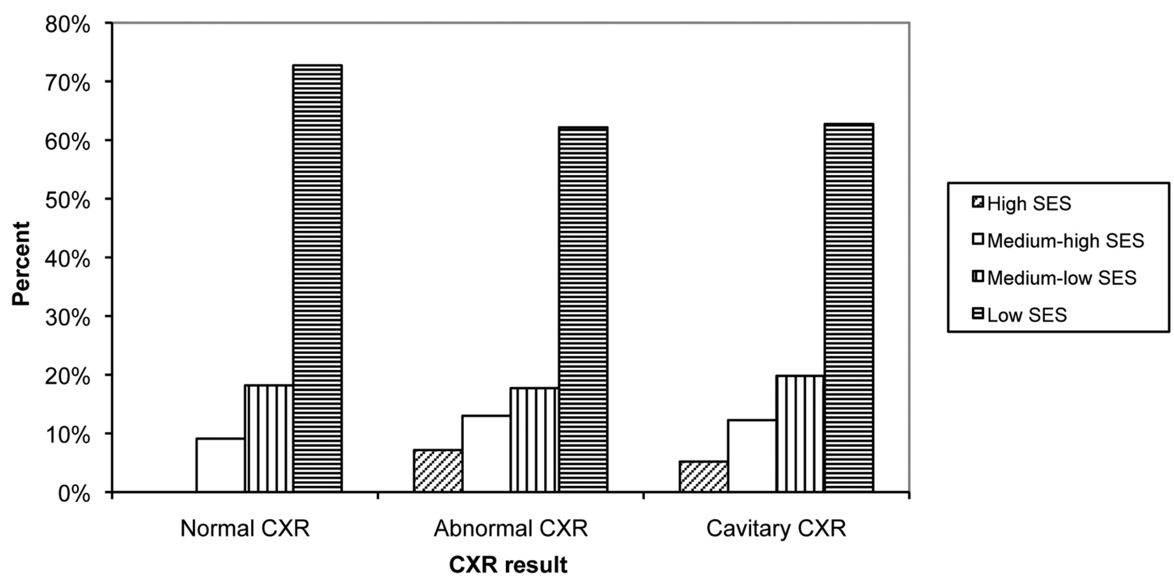
The results of this research, indicating that residing in areas with high levels of poverty is not significantly associated with more severe pulmonary disease at diagnosis, are noteworthy and not consistent with previous studies examining other diseases.[9,31] These findings remained after attempting to control for important individual-level risk factors and area-level measures and were consistent across three measures of severity.

Previous studies of SES and delayed TB diagnoses found that low income and poverty constitute risk factors for delays.[12–14,32] Low education level has previously been described as a risk factor for delays,[15] as have large family size,[33] unemployment,[34] and lack of health insurance.[18] However, no studies have previously documented the direct association between area-based SES and TB disease severity in a multilevel model, perhaps because severity is often seen as representative of diagnostic delays, with longer time to diagnosis thought to lead to increased infectiousness as patients progress to higher bacillary load on sputum smears and cavitary disease.[3,35]

Previous reports have hypothesized that individuals living in poorer SES areas present with later-stage disease because of decreased access to medical care and screening awareness.[10,36] Yet, possible explanatory pathways for these effects are complex. A previous study found that lack of employment and knowledge about where to obtain care were closely associated with clinically significant delay, raising concerns about the equity of access to care among TB patients.[34] More equitable access to care may occur when the need for care or severity of illness predicts utilization better than potential access barriers (e.g., appointment waiting time).[37] If access to care were distributed evenly, we would expect that TB patients with more severe illness would be more likely to promptly seek medical care. But others note that perceived access barriers appeared to explain more of the delay than did illness severity, suggesting that subgroups of the TB population were facing inequitable barriers to care.[34] As such, we might expect that more severe disease would be impacted by area-level access factors influencing delays.

However, while "where you live" may play an important role in disease incidence and transmission, it may be a less important factor in defining the risk of presenting with more severe disease. This finding may be because individual SES factors are often thought to be more closely linked to access or usage of health care, including longer wait times and fewer referrals.[38–40] Effects of individual SES may be more pronounced, such that more comprehensive health insurance, greater health knowledge, and motivation

Figure 3. Proportion of tuberculosis patients in quartiles of block-group SES, by chest radiography result: King County, Washington, 2000–2008[a]



[a]Excludes chest radiographs that were not done or unknown, as well as missing SES

SES = socioeconomic status

CXR = chest radiography

Table 3. Relative odds of being diagnosed with more advanced tuberculosis according to individual and area-level characteristics: King County, Washington, 2000–2008

Variable	Model 1 OR (95% CI)	Model 2 AOR[a] (95% CI)	Model 3 AOR[b] (95% CI)	Model 4 AOR[c] (95% CI)
Chest radiography				
Highest SEP	Ref.	Ref.	Ref.	Ref.
Medium-high SEP	0.80 (0.40, 1.59)	0.83 (0.41, 1.67)	0.85 (0.42, 1.71)	0.84 (0.40, 1.73)
Medium-low SEP	1.21 (0.63, 2.30)	1.18 (0.62, 2.25)	1.22 (0.64, 2.34)	1.18 (0.59, 2.36)
Lowest SEP	0.95 (0.53, 1.70)	0.88 (0.49, 1.58)	0.91 (0.50, 1.65)	0.88 (0.43, 1.80)
P-value	0.935	0.680	0.764	0.863
Sputum smear grade				
Highest SEP	Ref.	Ref.	Ref.	Ref.
Medium-high SEP	1.19 (0.69, 2.06)	1.18 (0.68, 2.06)	1.19 (0.68, 2.07)	1.16 (0.66, 2.06)
Medium-low SEP	1.09 (0.62, 1.89)	1.03 (0.59, 1.81)	1.04 (0.59, 1.82)	1.01 (0.54, 1.89)
Lowest SEP	1.06 (0.65, 1.73)	0.99 (0.60, 1.64)	0.95 (0.57, 1.59)	0.93 (0.49, 1.79)
P-value	0.986	0.733	0.611	0.672
Binary sputum smear				
Highest SEP	Ref.	Ref.	Ref.	Ref.
Medium-high SEP	1.45 (0.80, 2.64)	1.42 (0.78, 2.59)	1.49 (0.82, 2.70)	1.48 (0.80, 2.73)
Medium-low SEP	1.44 (0.82, 2.50)	1.40 (0.80, 2.45)	1.41 (0.81, 2.46)	1.33 (0.73, 2.43)
Lowest SEP	1.54 (0.92, 2.63)	1.47 (0.85, 2.53)	1.38 (0.81, 2.37)	1.25 (0.65, 2.43)
P-value	0.246	0.413	0.474	0.880

[a]Model 2 adjusted for age, sex, race, and foreign birth.

[b]Model 3 adjusted for age, sex, race, foreign birth, homelessness, and provider type.

[c]Model 4 adjusted for age, sex, race, foreign birth, homelessness, provider type, area-level race, and ethnicity.

OR = odds ratio

AOR = adjusted odds ratio

SEP = socioeconomic position

Ref. = reference group

to seek care play important roles in predicting severity. Indeed, greater proportions of uninsured and unemployed people were observed in lower SEP quartile block groups in our study, and these variables were significantly associated with more severe radiography results. These data are consistent with observed correlations between unmet medical need and lower income and lack of insurance in King County.[40]

In unadjusted analyses, the association found between more severe disease and various SES surrogates has precedence in the literature. Substance abusers are more likely to have sputum smear-positive TB disease and cavitary disease.[41,42] Homelessness is associated with smear-positive TB disease and cavitary disease,[43] and smoking is associated with cavitary lesions.[44] After two months, sputum smear microscopic examination is more often positive in diabetic patients, but we did not examine diabetes comorbidity in our study population.[45]

The effect of HIV on TB severity is of particular concern. HIV infection may alter the radiographic appearance of pulmonary TB due to altered immunity.[46] HIV infection also promotes rapid progression to active TB disease,[47] though its effect on infectiousness remains disputed.[48] Indeed, our results demonstrated that HIV-infected individuals were more likely to have abnormal non-cavitary disease. However, in multivariate analyses restricted to non-infected individuals, no significant changes were observed in SES effect estimates on severity, likely due to small numbers of HIV-positive people in the analysis.

A recent publication found that increases in proportions of advanced (smear-positive or cavitary disease) pulmonary TB were greatest among groups with lower rates of TB, including white, U.S.-born, employed, HIV non-infected, and non-homeless people.[1] It was hypothesized that greater increases in the proportion of advanced disease among lower-risk groups were due to a lower index of suspicion for TB disease among patients and providers, leading to delays in accessing treatment and diagnosing disease. Our study results demonstrate the importance of examining not only these individual risk factors, but also area-level risk factors for disease.

Strengths and limitations

This study had several strengths, including the careful assessment of block-group boundaries, validation of the geocode with the county, incorporation of multilevel models, and inclusion of area-based socioeconomic measures to examine SES at both the individual and area level. Because no relationship was observed when either smear grade or presence or absence of a positive smear result was analyzed, lower block-group SEP did not seem more important in distinguishing bacterial load in the lungs any more than it did presence or absence.

This study was also subject to several limitations. One limitation was the scope of area- and individual-level variables studied. There are likely many area-based variables that could have potentially confounded observed associations between area-based SES and disease severity, as well as relevant measures of individual SES that were unavailable to us. The latter precluded our ability to assess relative impact of area and individual SES in the prediction of TB severity. While the geographic availability and accessibility of health-care services, which may result in differential diagnostic delay, were not included, given King County's predominantly urban composition, geography was less likely to have been a strong confounding factor. Additionally, these results may not be generalizable to other regions, given that we adjusted only for certain relevant patient- and area-level demographic factors. And because residence was only measured at TB diagnosis, we also do not know whether residence at previous times could have been relevant to the development of disease. Furthermore, unmeasured variations among block-group risk factor norms (e.g., average alcohol intake) could be residually responsible for community contextual effects, but because controlling for individual-level risk factors did not attenuate the block-group SEP effect on disease severity, it seems unlikely that these factors would have an impact on the neighborhood-level SES-severity association.

CONCLUSIONS

In this study, area-level social resources were not associated with pulmonary TB disease severity at diagnosis. These findings are important because they suggest that factors other than area-level SES may predict severity. At-risk groups should be targeted for TB interventions regardless of area-level SES, with an emphasis on examining those characteristics related to access to and utilization of TB services. This study raises other actionable next steps including understanding what factors are tied in to disease severity, both individually and at the community level, whether the SES-severity association is further modified by other factors such as race, and the potential impact of SES on delays leading to more severe diagnoses.

Approval was granted for this study in May 2009 from the University of Washington and Washington State Institutional Review Boards.

The authors thank the Public Health—Seattle & King County Tuberculosis Control Program for access to data, and the staff for their support of this project.

REFERENCES

1. Wallace RM, Kammerer JS, Iademarco MF, Althomsons SP, Winston CA, Navin TR. Increasing proportions of advanced pulmonary tuberculosis reported in the United States: are delays in diagnosis on the rise? Am J Respir Crit Care Med 2009;180:1016-22.
2. Decrease in reported tuberculosis cases—United States, 2009. MMWR Morb Mortal Wkly Rep 2010;59(10):289-94.
3. National Tuberculosis Controllers Association, Centers for Disease Control and Prevention (US). Guidelines for the investigation of contacts of persons with infectious tuberculosis. Recommendations from the National Tuberculosis Controllers Association and CDC. MMWR Recomm Rep 2005;54(RR-15):1-47.
4. Loudon RG, Spohn SK. Cough frequency and infectivity in patients with pulmonary tuberculosis. Am Rev Respir Dis 1969;99:109-11.
5. Schechter MS, Margolis PA. Relationship between socioeconomic status and disease severity in cystic fibrosis. J Pediatr 1998;132:260-4.
6. Rabin DL, Richardson MS, Stein SR, Yeager H Jr. Sarcoidosis severity and socioeconomic status. Eur Respir J 2001;18:499-506.
7. Steptoe A, Hamer M, O'Donnell K, Venuraju S, Marmot MG, Lahiri A. Socioeconomic status and subclinical coronary disease in the Whitehall II epidemiological study. PLoS One 2010;5:e8874.
8. Klassen AC, Curriero FC, Hong JH, Williams C, Kulldorff M, Meissner HI, et al. The role of area-level influences on prostate cancer grade and stage at diagnosis. Prev Med 2004;39:441-8.
9. MacKinnon JA, Duncan RC, Huang Y, Lee DJ, Fleming LE, Voti L, et al. Detecting an association between socioeconomic status and late stage breast cancer using spatial analysis and area-based measures. Cancer Epidemiol Biomarkers Prev 2007;16:756-62.
10. Giunta A, Arcasoy SM, Patel N, Wilt J, Lederer DJ. Low socioeconomic status is associated with greater disease severity in idiopathic pulmonary fibrosis. Abstract presented at the 2010 International Conference of the American Thoracic Society; 2010 May 14–19; New Orleans.
11. Storla DG, Yimer S, Bjune GA. A systematic review of delay in the diagnosis and treatment of tuberculosis. BMC Public Health 2008;8:15.
12. Farah MG, Rygh JH, Steen TW, Selmer R, Heldal E, Bjune G, et al. Patient and health care system delays in the start of tuberculosis treatment in Norway. BMC Infect Dis 2006;6:33.
13. Kiwuwa MS, Charles K, Harriet MK. Patient and health service delay in pulmonary tuberculosis patients attending a referral hospital: a cross-sectional study. BMC Public Health 2005;5:122.
14. Sherman LF, Fujiwara PI, Cook SV, Bazerman LB, Frieden TR. Patient and health care system delays in the diagnosis and treatment of tuberculosis. Int J Tuberc Lung Dis 1999;3:1088-95.
15. Mesfin MM, Newell JN, Walley JD, Gessessew A, Madeley RJ. Delayed consultation among pulmonary tuberculosis patients: a cross sectional study of 10 DOTS districts of Ethiopia. BMC Public Health 2009;9:53.
16. Ngamvithayapong J, Yanai H, Winkvist A, Diwan V. Health seeking behaviour and diagnosis for pulmonary tuberculosis in an HIV-epidemic mountainous area of Thailand. Int J Tuberc Lung Dis 2001;5:1013-20.
17. Benjamins MR, Kirby JB, Bond Huie SA. County characteristics and racial and ethnic disparities in the use of preventive services. Prev Med 2004;39:704-12.
18. Phoa LL, Teleman MD, Wang YT, Chee CB. Characteristics of patients with delayed diagnosis of infectious pulmonary tuberculosis. Respirology 2005;10:196-200.

19. Radhakrishna S, Frieden TR, Subramani R, Santha T, Narayanan PR; Indian Council of Medical Research. Additional risk of developing TB for household members with a TB case at home at intake: a 15-year study. Int J Tuberc Lung Dis 2007;11:282-8.
20. Pasipanodya JG, Miller TL, Vecino M, Munguia G, Garmon R, Bae S, et al. Pulmonary impairment after tuberculosis. Chest 2007;131:1817-24.
21. Golub JE, Bur S, Cronin WA, Gange S, Baruch N, Comstock GW, et al. Delayed tuberculosis diagnosis and tuberculosis transmission. Int J Tuberc Lung Dis 2006;10:24-30.
22. Helke KL, Mankowski JL, Manabe YC. Animal models of cavitation in pulmonary tuberculosis. Tuberculosis (Edinb) 2006;86:337-48.
23. Centers for Disease Control and Prevention (US). CDC tuberculosis surveillance data training: report of verified case of tuberculosis (RVCT): instruction manual. Atlanta: CDC; 2009.
24. Census Bureau (US). Census block groups cartographic boundary files descriptions and metadata: 2005 [cited 2012 Oct 22]. Available from: URL: http://www.census.gov/geo/www/cob/bg_metadata.html
25. Krieger N, Chen JT, Waterman PD, Soobader MJ, Subramanian SV, Carson R. Geocoding and monitoring of US socioeconomic inequalities in mortality and cancer incidence: does the choice of area-based measure and geographic level matter?: the Public Health Disparities Geocoding Project. Am J Epidemiol 2002;156:471-82.
26. Centers for Disease Control and Prevention (US). Tuberculosis Information Management System [cited 2012 Nov 27]. Available from: URL: http://www.cdc.gov/tb/programs/tims/tims.htm
27. Census Bureau (US). Summary file 3: 2000 census of population and housing. Washington: Census Bureau; 2007.
28. Census Bureau (US). Summary file 1: 2000 census of population and housing. Washington: Census Bureau; 2007.
29. Luke DA. Multilevel modeling. Thousand Oaks (CA): Sage Publications Inc.; 2004.
30. Rabe-Hesketh S, Skrondal A, Pickles A. Generalized multilevel structural equation modeling. Psychometrika 2004;69:167-90.
31. Klassen AC, Kulldorff M, Curriero F. Geographical clustering of prostate cancer grade and stage at diagnosis, before and after adjustment for risk factors. Int J Health Geogr 2005;4:1.
32. World Health Organization. Addressing poverty in TB control. Options for national TB control programmes. Geneva: WHO; 2005.
33. Long NH, Johansson E, Diwan VK, Winkvist A. Different tuberculosis in men and women: beliefs from focus groups in Vietnam. Soc Sci Med 1999;49:815-22.
34. Asch S, Leake B, Anderson R, Gelberg L. Why do symptomatic patients delay obtaining care for tuberculosis? Am J Respir Crit Care Med 1998;157:1244-8.
35. Madebo T, Lindtjorn B. Delay in treatment of pulmonary tuberculosis: an analysis of symptom duration among Ethiopian patients. Med Gen Med 1999:E6.
36. Centers for Disease Control and Prevention (US). Health, United States, 2011, with special feature on socioeconomic status and health [cited 2012 Oct 22]. Available from: URL: http://www.cdc.gov/nchs/hus/special.htm
37. Aday LA, Andersen RM. Equity of access to medical care: a conceptual and empirical overview. Med Care 1981;19:4-27.
38. Dunlop S, Coyte PC, McIsaac W. Socio-economic status and the utilisation of physicians' services: results from the Canadian National Population Health Survey. Soc Sci Med 2000;51:123-33.
39. Alter DA, Naylor CD, Austin P, Tu JV. Effects of socioeconomic status on access to invasive cardiac procedures and on mortality after acute myocardial infarction. N Engl J Med 1999;341:1359-67.
40. Public Health—Seattle & King County. King County community health indicators [cited 2012 Oct 18]. Available from: URL: http://www.kingcounty.gov/healthservices/health/data/chi.aspx
41. Oeltmann JE, Kammerer JS, Pevzner EE, Moonan PK. Tuberculosis and substance abuse in the United States, 1997–2006. Arch Intern Med 2009;169:189-97.
42. Oeltmann JE, Oren E, Haddad MB, Lake LK, Harrington TA, Ijaz K, et al. Tuberculosis outbreak in marijuana users, Seattle, Washington, 2004. Emerg Infect Dis 2006;12:1156-9.
43. Asch S, Leake B, Knowles L, Gelberg L. Tuberculosis in homeless patients: potential for case finding in public emergency departments. Ann Emerg Med 1998;32:144-7.
44. Altet-Gômez MN, Alcaide J, Godoy P, Romero MA, Hernandez del Rey I. Clinical and epidemiological aspects of smoking and tuberculosis: a study of 13,038 cases. Int J Tuberc Lung Dis 2005;9:430-6.
45. Alisjahbana B, Sahiratmadja E, Nelwan E, Purwa AM, Ahmad Y, Ottenhoff TH, et al. The effect of type 2 diabetes mellitus on the presentation and treatment response of pulmonary tuberculosis. Clin Infect Dis 2007;45:428-35.
46. Geng EH, Kreiswirth BN, Burzynski J, Schluger NW. Transmission trends for human immunodeficiency virus associated tuberculosis in New York City. Int J Tuberc Lung Dis 2005;9:661-6.
47. Daley CL, Small PM, Schecter GF, Schoolnik GK, McAdam RA, Jacobs WR Jr, et al. An outbreak of tuberculosis with accelerated progression among persons infected with the human immunodeficiency virus. An analysis using restriction-fragment-length polymorphisms. N Engl J Med 1992;326:231-5.
48. Cruciani M, Malena M, Bosco O, Gatti G, Serpelloni G. The impact of human immunodeficiency virus type 1 on infectiousness of tuberculosis: a meta-analysis. Clin Infect Dis 2001;33:1922-30.