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Residential Proximity to High Traffic Roadways and Post-Stroke Mortality

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Abstract

Background—Living in areas with higher levels of ambient air pollution has been associated with a higher incidence of ischemic stroke and all-cause mortality, but less is known about the relationship between traffic related pollution and long term survival following stroke.

Methods—We identified consecutive patients admitted to Beth Israel Deaconess Medical Center with ischemic stroke between 1999 and 2008 and determined distance to the nearest roadway with an average daily traffic count >10,000 vehicles/day. Categories of residential proximity were defined as ≤100 meters (m), 100 to 200, 200 to ≤400 or > 400m from a busy roadway. We identified deaths through June 2012 using the Social Security Death Index and used Cox proportional hazards models adjusted for medical history, and socioeconomic factors to calculate hazard ratios for the association between residential proximity to a high traffic roadway and all-cause mortality.

Results—Among 1683 stroke patients with complete data, there were 950 deaths [median follow-up = 4.6 years]. We observed higher post-stroke mortality among people living closer to high traffic roadways. Patients living ≤100m from high traffic roadways had a 20% (95% CI: 1%, 43%) higher rate of post-stroke mortality than patients living >400m away (p-trend=0.02).

Conclusions—In this study, living close to a high traffic roadway was associated with an elevated mortality rate. This relationship remained statistically significant after adjustment for

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Disclosures

None.

individual and neighborhood- level factors, providing evidence that traffic-related pollution is associated with a higher mortality rate among stroke survivors.

Introduction

Stroke is a major source of morbidity and mortality worldwide and an estimated 795,000 people in the United States experience a new or recurrent stroke each year [1]. Stroke is now the leading cause of long-term disability, and this burden is expected to continue to increase as the population ages [2]. Efforts to prevent stroke have primarily focused on traditional cardiovascular disease risk factors [3] but less is known about the role of potentially modifiable environmental risk factors and long-term prognosis [4].

Elevated exposure to air pollution over the course of hours to days has previously been identified as a trigger of stroke in population-based studies[5–8] and long term exposure to air pollution over years to decades has also been associated with higher mortality rates and greater atherosclerotic burden [9–11], but whether long-term exposure is also associated with post-stroke mortality remains unclear. One study previously examined this association and observed higher post stroke mortality in areas with higher levels of estimated particulate matter (PM_{10}) and nitrogen dioxide (NO_2) in the United Kingdom [12], but these findings have not been replicated elsewhere. We hypothesized that residential proximity to high traffic roadways would be associated with elevated mortality in the greater Boston area and that the strongest associations would also be observed among individuals living in the closest proximity (≤100 meters) to a high traffic road.

Materials and Methods

Participants

We identified 1763 consecutive patients ≥21 years of age admitted to the Beth Israel Deaconess Medical Center (BIDMC) between April 1, 1999 and October 31, 2008, with neurologist-confirmed ischemic stroke. The BIDMC is a 650-bed teaching hospital of Harvard Medical School designated as a primary stroke service hospital. Patients with in-hospital strokes or transient ischemic attacks were excluded. We restricted our analyses to patients living in the greater Boston metropolitan area (within 40 kilometers of the hospital) to reduce confounding by factors related to residential proximity to a high traffic road and stroke severity. This study was approved by the committee on clinical investigations at BIDMC.

Information on demographics, presenting symptoms, medical history and imaging results were abstracted from medical records at the time of hospitalization for stroke onset. Stroke pathophysiology was characterized as: as (1) large-artery atherosclerosis, (2) small-vessel occlusion, (3) cardioembolism, (4) other determined cause or (5) undetermined cause, using the approach developed for the Trial of ORG 10172 in Acute Stroke Treatment (TOAST).[13] The time of stroke symptom onset or time last seen normal was documented by the attending stroke neurologist at the time of hospital presentation. We excluded 58 participants for whom the precision of onset symptoms was unclear and 22 patients for whom complete address data was not available. Final models included data from 1683 participants.

Exposure Assessment

Addresses were geocoded using ArcGIS 9.2 (ESRI, Redlands, CA). Distance to the nearest high traffic roadway, defined as a roadway with >10,000 vehicles/day, was computed in ArcGIS based on average daily traffic counts provided by the Massachusetts Department of Transportation. Each geocoded address was linked to the appropriate 2000 US census block group and assigned block group level median household income and percentage of adults aged ≥25 years without high school diplomas. Our primary analysis was to examine the association between residential proximity to a road with >10,000 vehicles/day and survival time following stroke. Evidence suggests that exposure to traffic-related pollutants is highest within 100–300 meters from major road [14] and several studies have observed associations between living within this proximity of a major road and increased risk of cardiovascular disease and mortality[15–18]. Therefore, we evaluated associations for the following categories of residential proximity to a high traffic road: ≤100 meters (m), 100 to ≤200m, 200 to ≤400m or >400m.

Outcome Assessment

Deaths were determined using the Social Security Death Index (SSDI). Participants were censored at the time of death or at the date June 26, 2012. Follow up was determined by date of symptom onset to censor date.

Statistical Methods

Cox proportional hazard models were used to calculate hazard ratios (HR) and 95% confidence intervals (CI) for the association between residential proximity to a high traffic road and all-cause mortality. Proportionality of hazards was evaluated by testing interactions with time. All models were adjusted for age (continuous), gender, race (white vs. other or unknown), Hispanic ethnicity (yes or no), smoking status (current, former, or never), history of stroke, coronary artery disease, atrial fibrillation, heart failure, diabetes, dyslipidemia, and hypertension, tertiles of percent of adults age ≥25 without a high school diploma and quartiles of median income at the block group level. The primary analysis was to examine residential proximity to a road with over 10,000 vehicles/day and survival following stroke using categories of residential proximity to a high traffic road as described above.

We conducted trend tests for the association across the four categories by testing the statistical significance of a linear term using the log of the median distance to a high traffic road for each category. We hypothesized that the association between residential proximity to a high traffic road and mortality would be approximately log-linear and examined the association between the log of proximity to a high traffic road (continuous) and the rate of all-cause mortality. In secondary analyses, we evaluated the shape of the exposure-response relationship using penalized splines with 3 degrees of freedom. We tested for effect modification by age (age ≥75), gender, race (white versus other), smoking status, median household income (<$39,340 per year), history of diabetes, coronary artery disease, previous stroke, and stroke subtype by examining interactions with living ≤100m of a major road compared to living >100m away.

We conducted several sensitivity analyses to evaluate the robustness of our findings. Instead of using continuous variables, we modeled median household income and percent of adults without a high school diploma using natural splines with three degrees of freedom and models for age using two degrees of freedom to consider nonlinear associations with socioeconomic factors. In separate models, we allowed the baseline mortality rate to vary by age and because people who survive to a particularly old age may reflect a different subgroup of the population, we conducted an analysis excluding participants over 100 years of age (n=3). Since stroke severity may be related to distance from a high traffic roadway and to mortality rates, we further adjusted for length of hospital stay (continuous and then as ≥4 days) as an indicator of stroke severity. All p-values are 2-sided, and we considered values <0.05 to be statistically significant. Analyses were performed using the R (v2.14) survival package (v.2.36-14) and survival curves were plotted using STATA v12.

Results

Characteristics of the 1683 study participants are described in Table 1. There were 499 participants living ≤100m of a high traffic road, 329 participants living 100 to ≤200m away, 361 patients 200 to ≤400m and 494 participants living >400m away. People living closer to a major roadway were more likely to live in areas with greater socioeconomic deprivation. Clinical characteristics were similar across categories of distance to roadway.

There were 950 deaths through June 2012 (median follow up time: 4.8 years, maximum 13.2 years). The unadjusted Kaplan-Meier curves are shown in Figure 1A. We observed that living closer to a major road was associated with reduced survival in all categories compared to the reference category (living >400m from a major road). In unadjusted analyses, living ≤100m, 100 to ≤200m, and 200 to ≤400m away were associated with 55% higher rate of mortality (95% CI: 33%, 84%), 35% higher mortality (11%, 63%) and 24% higher mortality (3%, 50%) respectively.

After adjustment for covariates, patients living ≤100m from high traffic roadways had a 20% (95% CI: 1%, 43%) higher rate of post-stroke mortality than patients living >400m away (Table 2). The predicted hazard curves for living ≤100m from a high traffic road and 100 to ≤200m are distinct, while the hazard ratios for living 200 to ≤400 meters from a high traffic road were similar to background levels (>400m) (Figure 1B). In our analysis of log transformed proximity to a high traffic roadway (continuous), living at the median of the ≤100m category (20.6m away) versus the median of the >400m category (720m away) was associated with a 15.8% higher mortality rate (95% CI: 1.2%, 28.26%, p=0.04). Log linearity was visually confirmed by assessing exposure response using penalized splines to examine the association between the logarithm of distance and mortality. In Table 3 we present stratified analyses for the association between living ≤100m of a major road and characteristics of participants. There was a lower mortality rate among people with diabetes at the time of stroke (p=0.004) and no evidence to suggest differences across any of the other characteristics examined.

In sensitivity analyses to examine the effect of age, there were no material changes to the results. Similarly, using natural splines to model socioeconomic factors did not alter conclusions. We also found no differences in the estimates when we controlled for year of stroke onset with a strata statement. Adjusting for length of hospital stay (continuous or ≥4 days) as an indicator of stroke severity did not change our point estimates.

Discussion

In this study of 1683 stroke patients, we observed that living close to a high-traffic road was associated with a higher rate of post-stroke mortality in both categorical and in log-linear continuous models. The strongest associations were observed among individuals living <100m of a high traffic road in categorical analysis and remained consistent with a log-linear association. Our findings are also consistent with the results of previous studies that have shown that living close to a major road is associated with higher mortality rate [16–18].

Studies in other susceptible populations have shown that living near a major roadway is associated with all-cause mortality [19], cardiopulmonary mortality [20], post-myocardial infarction mortality [18], and deep vein thrombosis [21]. Evidence also suggest that there may be chronic effects of living in a location with higher exposure to air pollution, and one study in women found that living in close proximity to a roadway was also associated with elevated incidence of stroke (Hazard Ratio (HR) 2.08 (95%CI: 1.25, 3.48) and death from cerebrovascular disease (HR 2.93 (95%CI: 1.03, 8.38) [22]. There is only one previous study that has examined associations between ambient pollution and post-stroke mortality. Maheswaran and colleagues evaluated associations between modeled PM_{10} and NO_2 and post-stroke mortality, assigning air pollution by postal code using a 20×20m grid-based approach, and observed an adjusted HR for a 10μg/m^3 increase in NO_2 of 1.28 (95% CI, 1.11,1.48) . For PM_{10} the HR was 1.52 (95%CI, 1.06, 2.18) [12]. The findings in this study of higher mortality rates among individuals living close to high traffic roads, which is associated with higher NO_2 levels [23], also suggest that traffic exposure may be particularly relevant in predicting mortality following stroke.

There are a number of potential mechanisms which may in part explain this observed association. Stroke may impair respiratory function [12, 24, 25] and thereby increase susceptibility to the effects of air pollution [26, 27]. Air pollution has also been linked with neuroinflammation [28] and systemic inflammation [29, 30]. Long-term exposure to air pollution may also be associated with higher mortality rates through inflammation, atherosclerotic progression and changes in autonomic function [31]; it is likely that several factors play a role in elevating risk of mortality related to traffic and other ambient air pollution exposures [32]. In analyses stratified by participant characteristics we attempted to identify susceptibility and vulnerability factors. We observed a lower mortality rate among people with diabetes living close to a major road as compared to people without diabetes, but did not observe differences by the other factors examined. It is possible that there was a higher mortality rate among people with diabetes and therefore little increased risk from living near a high traffic roadway, although this finding could be due to chance. On the other hand, among people without diabetes, we observed higher mortality rates attributable to high traffic exposure.

There are some other limitations to this study that should be addressed. We used geocoded home addresses at the time of symptom onset to assign exposure. We do not have data on how much time patients spent away from home, or duration of residence at the address, although a previous study has shown that Americans spend an average of 68% of their time at home[33] and that residential mobility among older individuals is low. For example, the overall moving rate among Americans was 12.5% per year, but was only 3% of those ≥60 years of age [34]. In addition, in this study we cannot distinguish between exposure to air pollution and other factors associated with living near a high traffic road. In particular, noise may be an important exposure [35]. One study found that residential traffic noise was associated with a higher risk of stroke among older people [36] and several studies have reported associations between roadway noise and cardiovascular outcomes and public health implications [37, 38]. Finally, this study may have limited generalizability. While it may also be possible that living in areas with greater socioeconomic deprivation could be associated with greater vulnerability to the effects of traffic exposure on mortality, we did not observe differences here. One possible explanation may be limited variation in race, ethnicity and poverty in this study, which was restricted to the population living within 40km of the Boston metropolitan area.

In conclusion, in this cohort of ischemic stroke survivors, we observed that living close to a high traffic roadway at the time of the stroke onset was associated with an increased rate of all-cause mortality. This study supports the hypothesis that residential proximity to a high traffic road at the time of stroke onset is associated with elevated mortality risk. Additional work is needed to determine whether long-term exposure to environmental pollution may play a role in part in determining post-stroke prognosis and whether the regulation of these exposures may improve long-term survival.

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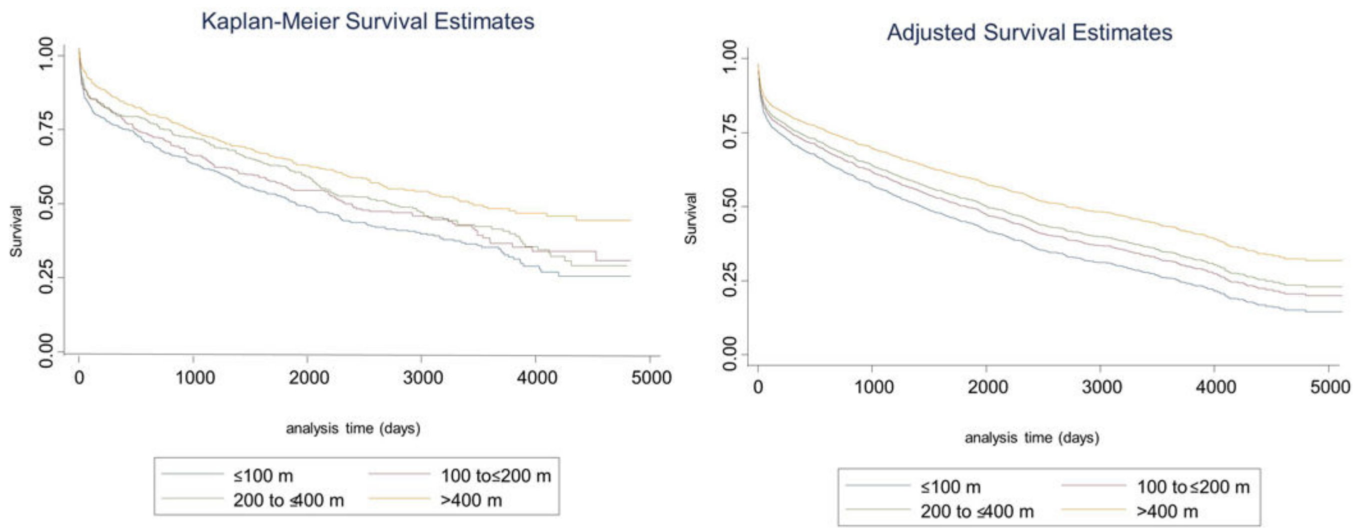

Figure 1.
Survival Curves for Residential Proximity to a High Traffic Roadway (>10,000 Vehicles/ Day).

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Table 1

Characteristics of Study Participants by Categories of Residential Proximity to High Traffic Roadway.

	Proximity to a roadway with >10,000 vehicles/day			
	<100 (n=499)	**100–200 m (n=329)**	**200–400m (n=361)**	**>400m (n=494)**
Age [median (IQR)]	79 (20)	77 (19)	76 (20)	72 (21)
White	342 (69)	241 (73)	247 (68)	323 (65)
Hispanic	20 (4)	10 (3)	9 (2)	18 (4)
Smoking Status				
Current smokers	58 (12)	43 (13)	56 (16)	76 (15)
Former Smokers	132 (26)	78 (24)	92 (25)	146 (30)
Never Smokers	309 (62)	208 (63)	213 (59)	272 (55)
Stroke Etiology				
Large vessel	105 (21)	73 (22)	66 (18)	89 (18)
Small vessel	124 (25)	88 (27)	93 (26)	138 (28)
Cardioembolic	116 (23)	79 (24)	103 (29)	123 (25)
Other or Undertermined	154 (31)	89 (27)	99 (27)	144 (29)
Clinical Characteristics				
Previous Stroke	141 (28)	94 (29)	95 (26)	140 (28)
Coronary Artery Disease	134 (27)	92 (28)	95 (26)	104 (21)
Atrial Fibrillation	125 (25)	81 (25)	91 (25)	123 (25)
Heart Failure Diagnosis	71 (14)	47 (14)	50 (14)	51 (10)
Diabetes	151 (30)	95 (29)	98 (27)	145 (29)
Dyslipidemia	197 (39)	133 (40)	146 (40)	227 (46)
Hypertension	357 (72)	243 (74)	257 (71)	344 (70)
% Adults >25 without High School Diploma (Tertiles)				
0%–6.5%	146 (29)	114 (35)	106 (29)	192 (39)
6.6%–17.7%	146 (29)	110 (33)	141 (39)	172 (35)
17.8%–62.8%	207 (41)	105 (32)	114 (32)	130 (26)
Median Household Income (Quartiles)				
$24,990 –$ 39,063	130 (26)	105 (32)	94 (26)	90 (18)
$39,280 – $56,343	120 (24)	99 (30)	97 (27)	105 (21)
$56,364—$72,969	168 (34)	56 (17)	72 (20)	124 (25)
$72,989 – $200,001	81 (16)	69 (21)	98 (27)	175 (35)

Values are Median (IQR) or n (percent).

Table 2

Adjusted* HRs for All-Cause Mortality by High Traffic Roadway Proximity.

Model		HR	95% CI	p-value
Categorical analyses	≤100m	1.20	[1.01, 1.43]	0.04
	>100 to ≤200m	1.08	[0.88, 1.31]	0.47
	>200 to ≤400m	0.99	[0.82, 1.20]	0.94
	>400m	--	--	--
p-trend				0.02

*Models were adjusted for age (continuous), gender, race (white vs other or unknown), Hispanic ethnicity (yes or no), current smoking status, former smoking status, history of stroke, coronary artery disease, atrial fibrillation, heart failure, diabetes, dyslipidemia, or hypertension, tertiles of percent of people age 25 or older without a high school diploma and quartiles of median income at the block group level [n=1683, events=950].

Table 3

Adjusted* HRs for residence within 100m of a high traffic roadway and All-Cause Mortality Stratified by Population Characteristics.

Characteristic	N†	Events	HR	95% CI	p-value
Age <75	794	263	1.28	[0.97,1.68]	0.65
Age ≥75	889	687	1.18	[1.00,1.40]	
Women	918	563	1.15	[0.95,1.38]	0.66
Men	765	387	1.19	[0.95,1.48]	
White race	1153	667	1.10	[0.93,1.31]	0.24
Nonwhite or unknown race	530	283	1.33	[1.02,1.72]	
Non-Smoker	1002	593	1.15	[0.96,1.38]	0.99
Past or Current Smoker	681	357	1.16	[0.92,1.46]	
Median Household Income <$39,063	1264	713	1.06	[0.80,1.41]	0.41
Median Household Income ≥$39,063	419	237	1.23	[1.05,1.43]	
Clinical characteristics					
No Diabetes	1194	653	1.36	[1.15,1.62]	0.004
Diabetes	489	297	0.90	[0.69,1.16]	
No Coronary Artery Disease	1258	653	1.18	[0.99,1.40]	0.90
Coronary Artery Disease	494	297	1.21	[0.94,1.57]	
No History of Stroke	1213	632	1.12	[0.94,1.33]	0.58
Previous Stroke	470	318	1.45	[1.13,1.86]	
Stroke Etiology					
Large Vessel Stroke	333	189	1.37	[1.0,1.87]	0.28
Cardioembolic stroke	443	218	1.15	[0.84,1.56]	
Small vessel stroke	421	267	1.08	[0.82,1.42]	
Other/undetermined	486	276	1.0	[0.77,1.32]	

*Models were adjusted for the following covariates, except that each stratified model was not adjusted for the stratification variable: age (continuous), gender, race (white vs other or unknown), Hispanic ethnicity (yes or no), current smoking status, former smoking status, history of stroke, coronary artery disease, atrial fibrillation, heart failure, diabetes, dyslipidemia, or hypertension, tertiles of percent of people age 25 or older without a high school diploma and quartiles of median income at the block group level.

†Number of participants.