Brief Report

# Cardiovascular and Cerebrovascular Mortality Associated With Acute Exposure to $PM_{2.5}$ in Mexico City

Iván Gutiérrez-Avila, MSc; Leonora Rojas-Bracho, ScD; Horacio Riojas-Rodríguez, PhD; Itai Kloog, PhD; Allan C. Just, PhD; Stephen J. Rothenberg, PhD

***Background and Purpose***—Acute exposure to particulate matter with aerodynamic diameter <2.5 µm ($PM_{2.5}$) is associated with acute cardiovascular and cerebrovascular mortality. The aim of this study was to evaluate these associations with specific causes of cardiovascular and cerebrovascular mortality in Mexico City.

***Methods***—We obtained daily mortality records for Mexico City from 2004 to 2013 for cardiovascular and cerebrovascular causes in people ≥25 and ≥65 years old. Exposure to $PM_{2.5}$ was assessed with daily estimates from a new hybrid spatiotemporal model using satellite measurements of aerosol optical depth $PM_{2.5}$ and compared to ground level $PM_{2.5}$ measurements with missing data estimated with generalized additive models $PM_{2.5}$. We fitted Poisson regression models with distributed lags for all mortality outcomes.

***Results***—An increase of 10 µg/m$^3$ in aerosol optical depth $PM_{2.5}$ was associated with increased cardiovascular (1.22%; 95% confidence interval, 0.17–2.28) and cerebrovascular mortality (3.43%; 95% confidence interval, 0.10–6.28) for lag days 0 to 1 (lag 0–1). Stronger effects were identified for hemorrhagic stroke and people ≥65 years. Associations were slightly smaller using generalized additive models $PM_{2.5}$.

***Conclusions***—These results support the evidence that acute exposure to $PM_{2.5}$ is associated with increased risk of specific cardiovascular and cerebrovascular mortality causes. (***Stroke*. 2018;49:1734-1736. DOI: 10.1161/STROKEAHA.118.021034.**)

**Key Words:** cardiovascular mortality ■ particulate matter ■ stroke



Acute exposure to airborne particles with aerodynamic diameter ≤2.5 µm ($PM_{2.5}$) can trigger cardiovascular and cerebrovascular mortality.[1] In developing countries, the region with the highest burden of stroke,[2] such evidence is limited[3] and possibly related to lack of ground level monitoring of $PM_{2.5}$.[4]

Mexico City, once considered the most polluted in the world, has improved its air quality because of various programs prioritizing public health.[5] However, it continues to be among the most polluted cities in Latin America[6] and over the past decades it has recorded an increasing rate of cardiovascular and cerebrovascular diseases, which are among the 5 leading causes of death.[7]

Despite the large body of scientific evidence about adverse health effects of particulate matter in Mexico City,[8] epidemiological research about cardiovascular and cerebrovascular mortality associated with $PM_{2.5}$ exposure remains limited. We therefore evaluated acute $PM_{2.5}$ exposure associated with specific causes of cardiovascular and cerebrovascular mortality.

## Methods

The data that support the findings of this study are available from the corresponding author on reasonable request. The present article also adheres to the American Heart Association Journals' implementation of the Transparency and Openness Promotion guidelines.

### Mortality Data and Exposure Assessment

We used an ecological design with public mortality records for Mexico City from 2004 to 2013. Our research was ruled exempt from human subjects review by the ethics board of the National Institute of Public Health of Mexico. Detailed methods are provided in the online-only Data Supplement. Deaths in people ≥25 and ≥65 years old, classified according to the *International Classification of Diseases*, Tenth Revision codes, were aggregated to obtain daily counts for specific mortality causes. To improve the quality of ischemic heart disease mortality data, we applied redistribution of misclassified cause of death by using the proportions estimated by Naghavi et al[9] (Table I in the online-only Data Supplement). Daily citywide exposure to $PM_{2.5}$ was assessed with estimates from a new hybrid spatiotemporal model using satellite measurements of aerosol optical depth (AOD-$PM_{2.5}$) developed by Just et al.[10] We also calculated daily $PM_{2.5}$ averages from 3 monitoring stations of the Mexico City atmospheric monitoring system. On days with missing data, $PM_{2.5}$ concentration

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was estimated with generalized additive models (GAM-PM$_{2.5}$), with Methods described in the online-only Data Supplement.

### Statistical Analysis

Associations were estimated using generalized linear models with Poisson regressions and distributed lags. Our base models included dummy variables for season of year, day of the week, penalized splines to address long-term trends in mortality and a natural cubic spline of apparent temperature. We alternatively included linear terms of $NO_2$ and $SO_2$ to investigate potential confounding effects of copollutants. Deviations from linearity in the concentration-response functions between PM$_{2.5}$ and cardiovascular and cerebrovascular mortality featured comparison between models using linear PM$_{2.5}$ and log-transformed PM$_{2.5}$.

## Results

The mean±SD for all deaths because of cardiovascular and cerebrovascular causes per day was 39±8.2. Ischemic heart disease mortality accounted for the highest proportion of all daily cardiovascular deaths (55%). Daily average counts for deaths because of ischemic and hemorrhagic stroke were 1.1±1.1 and 2.7±1.6, respectively. Daily averages for AOD-PM$_{2.5}$ and GAM-PM$_{2.5}$ were 24.4±8.2 μg/m$^3$ and 25.9±10.3 μg/m$^3$, respectively (Table II in the online-only Data Supplement describes mortality and environmental characteristics for the study period).

Table shows results on same day exposure (lag 0), cumulative effects over 2 (lag 0–1) and 6 days (lag 0–6) for AOD-PM$_{2.5}$ and GAM-PM$_{2.5}$. Significant mortality increments were observed for all cardiovascular and cerebrovascular mortality causes using AOD-PM$_{2.5}$ (lag 0–1). No deviations from linearity were observed in the concentration-response functions in the associations assessed (exposure range of 3–99.5 μg/m$^3$). Slightly lower risks were observed using GAM-PM$_{2.5}$ compared with AOD-PM$_{2.5}$, but no significant differences in health effects parameters and SEs were identified (Table IV in the online-only Data Supplement).

## Discussion

This is the first study showing that acute exposure to PM$_{2.5}$ is associated with specific cardiovascular and cerebrovascular

**Table. Percent Increase and 95% CIs in Mortality Associated With 10 μg/m$^3$ Increase in AOD-PM$_{2.5}$ and GAM-PM$_{2.5}$**

| | | AOD-PM$_{2.5}$ | | GAM-PM$_{2.5}$ | |
|---|---|---|---|---|---|
| | | Base Model | Fully Adjusted | Base Model | Fully Adjusted |
| | Overall | % Change (95% CI) | % Change (95% CI) | % Change (95% CI) | % Change (95% CI) |
| Cardiovascular ≥25 y old | Lag 0 | 1.32 (0.50 to 2.15) | 1.02 (0.04 to 2.02) | 1.04 (0.38 to 1.70) | 0.76 (–0.02 to 1.55) |
| | Lag 0–1 | 1.50 (0.64 to 2.38) | 1.22 (0.1 to 2.28) | 1.22 (0.52 to 1.92) | 0.94 (0.11 to 1.79) |
| | Lag 0–6 | 1.24 (0.25 to 2.24) | 0.99 (–0.10 to 2.10) | 0.77 (–0.09 to 1.64) | 0.59 (–0.34 to 1.53) |
| Cerebrovascular ≥25 y old | Lag 0 | 2.92 (0.36 to 5.55) | 3.16 (0.13 to 6.27) | 2.05 (0.04 to 4.11) | 2.21 (–0.18 to 4.66) |
| | Lag 0–1 | 3.15 (0.37 to 6.00) | 3.43 (0.10 to 6.28) | 2.48 (0.27 to 4.75) | 2.68 (0.01 to 5.42) |
| | Lag 0–6 | 2.54 (–0.60 to 5.78) | 2.76 (–0.68 to 6.33) | 2.07 (–0.59 to 4.80) | 2.22 (–0.69 to 5.22) |
| Ischemic heart disease | Lag 0 | 0.61 (–0.47 to 1.70) | 0.51 (–0.77 to 1.82) | 0.70 (–0.16 to 1.57) | 0.66 (–0.36 to 1.70) |
| | Lag 0–1 | 1.10 (–0.07 to 2.29) | 1.00 (–0.43 to 2.44) | 1.03 (0.09 to 1.98) | 1.00 (–0.14 to 2.14) |
| | Lag 0–6 | 0.75 (–0.55 to 2.07) | 0.67 (–0.77 to 2.13) | 0.47 (–0.65 to 1.61) | 0.44 (–0.79 to 1.70) |
| Ischemic heart disease (improved by potential misclassification in death cause) | Lag 0 | 0.89 (–0.19 to 1.97) | 0.86 (–0.41 to 2.14) | 0.77 (–0.09 to 1.63) | 0.86 (–0.16 to 1.89) |
| | Lag 0–1 | 1.37 (0.21 to 2.54) | 1.32 (–0.07 to 2.72) | 1.17 (0.24 to 2.10) | 1.20 (0.09 to 2.33) |
| | Lag 0–6 | 0.78 (–0.49 to 2.06) | 0.81 (–0.60 to 2.23) | 0.41 (–0.69 to 1.51) | 0.53 (–0.69 to 1.75) |
| Ischemic stroke | Lag 0 | –0.86 (–5.64 to 4.15) | –0.60 (–6.60 to 5.78) | –0.75 (–4.45 to 3.09) | 1.01 (–3.43 to 5.66) |
| | Lag 0–1 | 0.90 (–4.19 to 6.25) | 1.12 (–5.45 to 8.14) | 0.33 (–3.70 to 4.53) | 2.28 (–2.59 to 7.39) |
| | Lag 0–6 | 5.68 (–0.40 to 12.13) | 5.82 (–1.27 to 13.41) | 4.87 (–0.27 to 10.28) | 6.49 (0.77 to 12.54) |
| Hemorrhagic stroke | Lag 0 | 3.80 (0.74 to 6.94) | 4.01 (0.37 to 7.77) | 2.72 (0.33 to 5.17) | 2.84 (–0.01 to 5.77) |
| | Lag 0–1 | 3.16 (–0.08 to 6.50) | 3.36 (–0.58 to 7.46) | 2.72 (0.16 to 5.35) | 2.86 (–0.25 to 6.07) |
| | Lag 0–6 | 0.25 (–3.38 to 4.02) | 0.33 (–3.62 to 4.45) | –0.15 (–3.19 to 2.98) | –0.08 (–3.38 to 3.32) |
| Cardiovascular ≥65 y old | Lag 0 | 1.65 (0.65 to 2.66) | 0.91 (–0.27 to 2.10) | 1.20 (0.41 to 1.99) | 0.53 (–0.41 to 1.48) |
| | Lag 0–1 | 1.86 (0.80 to 2.92) | 1.05 (–0.20 to 2.32) | 1.41 (0.57 to 2.25) | 0.67 (–0.33 to 1.67) |
| | Lag 0–6 | 2.92 (1.72 to 4.13) | 2.29 (0.98 to 3.63) | 1.84 (0.83 to 2.86) | 1.22 (0.11 to 2.34) |
| Cerebrovascular ≥65 y old | Lag 0 | 2.59 (–0.52 to 5.81) | 2.66 (–1.02 to 6.47) | 1.82 (–0.60 to 4.31) | 1.91 (–0.98 to 4.89) |
| | Lag 0–1 | 4.01 (0.54 to 7.60) | 4.24 (0.12 to 8.52) | 3.19 (0.44 to 6.01) | 3.37 (0.09 to 6.76) |
| | Lag 0–6 | 4.54 (0.56 to 8.68) | 4.70 (0.39 to 9.19) | 3.87 (0.49 to 7.37) | 3.97 (0.32 to 7.75) |

Base model: adjusted by apparent temperature, day of the week, season of year, holidays, long-term trends. Fully adjusted: includes linear terms of $SO_2$ and $NO_2$ stratified at the mean. AOD-PM$_{2.5}$ indicates aerosol optical depth; CI, confidence interval; and GAM-PM$_{2.5}$, generalized additive models.

mortality causes in Mexico City, the most populated city in North America. We found results consistent with previous studies with daily increments in cardiovascular mortality of 1%–2% for every 10 μg/m$^3$ increase in $PM_{2.5}$ (lag 0–1).[11] For cerebrovascular mortality, our findings seemed larger than the 1.4% summary (95% confidence interval, 0.9%–1.9%) reported for cities in Europe, Asia, and North America (lag 0–1).[12] Also, our results for people ≥65 years old are consistent with the conclusions from a meta-analysis, pointing out strong evidence of higher mortality risks in older populations associated with acute exposure to particulate matter than in younger populations.[13]

Most studies have presented combined results for stroke types associated with acute exposure to $PM_{2.5}$; with weaker evidence for associations with different types of stroke. We observed greater effects for hemorrhagic stroke than for ischemic stroke. Possible explanations are higher frequency of hemorrhagic stroke observed in Mexico City and distribution of cofactors making its inhabitants more liable to suffer hemorrhagic stroke.

Limitations in our investigation include citywide exposure assessment to $PM_{2.5}$. We may have failed to capture the spatiotemporal $PM_{2.5}$ variability within Mexico City possibly biasing point estimates toward the null (Berkson type error).[14] Also, the association between exposure to $PM_{2.5}$ and onset of acute cardiovascular events might be subject to substantial underestimation related to exposure misclassification. We used date of death instead of time of symptom onset to assign exposure to $PM_{2.5}$.

Time series studies in air pollution epidemiology generally rely on correct classification of death causes from government records. Even though we performed proportional redistribution of potentially misclassified death causes to ischemic heart disease mortality to reduce measurement error, there are other mortality outcomes subject to correction that were not addressed in our research.

$PM_{2.5}$ toxicity depends on different factors besides concentration levels. Further research assessing the spatial distribution and composition of $PM_{2.5}$ within Mexico City is needed to further refine our findings.

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## Disclosures

None.

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**SUPPLEMENTAL MATERIAL**

# Cardiovascular and cerebrovascular mortality associated with acute exposure to $PM_{2.5}$ in Mexico City

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Allan C. Just, Stephen J. Rothenberg

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## Methods

### Mortality data

We used public mortality information that is available online without individually identifiable information and thus was ruled exempt from human subjects review by the ethics board of the National Institute of Public Health of Mexico. We obtained mortality records from the Mexican National Institute of Statistics and Geography classified according to the tenth version of the International Classification of Diseases (ICD-10) for the period of 2004─2013. Deaths in Mexico City in people ≥25 years old were aggregated to obtain daily counts for the cause categories of all cardiovascular (ICD-10 codes I00-I99), ischemic heart disease (ICD-10 codes I20-I25), all cerebrovascular (ICD-10 codes I60-I63), ischemic stroke (ICD-10 codes I63) and hemorrhagic stroke (ICD-10 codes I60-I62). Since the elderly are at higher risk of mortality, we also evaluated these associations in people ≥65 years old.

To improve the quality of ischemic mortality data related to possible errors in coding the causes of death, we applied the methods developed by Naghavi et al.[1] This task involves proportional redistribution of "Garbage Codes" (GC) that cannot be considered underlying causes of death and should be redistributed to "Target Codes" (TC) which represent actual underlying causes of death. Ischemic heart disease has been recognized as the most affected TC by the use of GC, given the amount of misclassified deaths with heart failure-GC (ICD-10 codes I50).[2] Table I shows the reassigned daily proportions of heart failure-GC to improve ischemic heart disease mortality that we used for the entire period of study.

### Exposure assessment

Exposure to $PM_{2.5}$ was assessed using data from a new hybrid spatiotemporal model developed by Just et al.[3] The model was designed for estimating daily $PM_{2.5}$ concentration in Mexico City using satellite measurements of Aerosol Optical Depth (AOD) from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) platform, using the new Multi-Angle Implementation of Atmospheric Correction (MAIAC) data with a spatial resolution of 1 km x 1 km. This model calibrates the association of AOD to $PM_{2.5}$ with ground level monitors, meteorological and land use variables (AOD-$PM_{2.5}$). Model fits were excellent with out-of-sample cross validation $R^2$ of 0.72. More in-depth details can be found in Just et al[3] The 1 km x 1 km cells with daily AOD-$PM_{2.5}$ corresponding to the Mexico City urban area were averaged to estimate daily citywide exposure.

We also calculated daily $PM_{2.5}$ averages using hourly records from three monitoring stations of the Mexico City Atmospheric Monitoring System that achieved 75% data sufficiency for the study period. On days with missing data, $PM_{2.5}$ concentration for each station was estimated by Generalized Additive Models (GAM) adjusted by meteorological variables (temperature, relative humidity and wind speed), air pollutants [particles with aerodynamic diameter ≤10 micrometers ($PM_{10}$), nitrogen dioxide ($NO_2$) and sulfur dioxide ($SO_2$)] and temporal terms (long-term and seasonal trends, holidays and weekdays). Meteorological and air pollutant variables were modeled with penalized splines, to characterize nonlinear relationships with $PM_{2.5}$. For each monitoring station, we selected the model minimizing the Akaike Information Criterion (AIC) and whose $PM_{2.5}$ estimates minimized the Root Mean Squared Error (RMSE). When missing values remained due to

missing covariates, daily $PM_{2.5}$ was estimated through ARIMA models using each monitoring station as dependent variable and the remaining monitoring stations as explanatory. Finally, citywide average of $PM_{2.5}$ were calculated from $PM_{2.5}$ measurements, GAM and ARIMA estimates in each monitoring station (GAM-$PM_{2.5}$).

To consider the effect of weather on mortality we calculated daily mean apparent temperature (AT) as described by Basu et al[4] as follows:

$$AT = -2.653 + 0.994 \times T + 0.0153 \times DT^2,$$

where T corresponds to air temperature and DT corresponds to dew point.

**Statistical analysis**

We used a time-series design. $PM_{2.5}$-mortality associations were estimated using Generalized Linear Models (GLM) for count data with Poisson regressions and distributed lags.

Our base models included dummy variables for season of year, day of the week, holidays, penalized splines to address long-term trends in mortality and improve stationarity,[5-7] and a natural cubic spline of apparent temperature (AT) to account for nonlinear relationships with mortality. Spearman correlation coefficients between air pollutants and AT are shown in Table III. To investigate potential confounding effects of other air pollutants, we conducted a sensitivity analysis including linear terms of $NO_2$ and $SO_2$ concentrations. The assessment of nonlinearities in the concentration-response function between $PM_{2.5}$ and mortality featured comparison between linear $PM_{2.5}$ and log-transformed $PM_{2.5}$, based on the overall fit of the regression models.[8-9] Diagnostic criteria included the AIC, normality of residuals, partial autocorrelation functions and presence of residual white noise.[6-7]

All analysis were fit in STATA 13 (Stata Corp, College Station, Texas, E.U.) and R 3.2.3 (R Development Core Team 2015).

**Table I. Heart failure "Garbage Codes" proportions redistributed to ischemic heart disease "Target Codes"**

| Garbage Codes | | Target Codes | Proportions according to sex | | | |
|---|---|---|---|---|---|---|
| | | | Men | | Women | |
| | | | 25-49 years | >50 years | 25-49 years | >50 years |
| **I50** | Heart failure | I21-I25 Ischemic Heart Disease | 0.8 | 0.955 | 0.71 | 0.88 |
| **I50.0** | Congestive heart failure | | | | | |
| **I50.1** | Left ventricular failure | | | | | |
| **I50.9** | Heart failure, unspecified | | | | | |

**Table II. Daily mortality outcomes and environmental variables in Mexico City for 2004-2013**

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| All cardiovascular (ICD codes:I00-I99) | 39.0 | 8.2 | 16.0 | 79.0 |
| All cerebrovascular (ICD codes:I60-I63) | 3.8 | 2.0 | 0.0 | 12.0 |
| Ischemic heart disease (ICD codes:I20-I25) | 21.4 | 5.9 | 6.0 | 47.0 |
| Ischemic heart disease considering heart failure-GC | 22.9 | 6.1 | 6 | 49 |
| Ischemic stroke (ICD codes:I63) | 1.1 | 1.1 | 0.0 | 7.0 |
| Hemorrhagic stroke (ICD codes:I60-I62) | 2.7 | 1.6 | 0.0 | 10.0 |
| All cardiovascular≥65 years old | 30.4 | 7.1 | 11 | 64 |
| All cerebrovascular≥65 years old | 2.6 | 1.6 | 0 | 10 |
| AOD-$PM_{25}$, $\mu g/m^{3,}$ * | 24.4 | 8.2 | 6.4 | 76.1 |
| GAM-$PM_{25}$, $\mu g/m^{3,}$ † | 25.9 | 10.3 | 3 | 99.5 |
| Apparent temperature, °C | 14.3 | 2.9 | 3.7 | 22.3 |
| $NO_2$, ppb | 58.8 | 20.2 | 18.0 | 153.0 |
| $SO_2$, ppb | 6.5 | 5.4 | 0.0 | 56.0 |

*$PM_{2.5}$ derived from the calibrated satellite AOD measurements
†$PM_{2.5}$ derived from Generalized Additive Models

**Table III. Spearman correlation coefficients among environmental variables**

| | **AOD-$PM_{2.5}$** | **$NO_2$** | **$SO_2$** | **AT** |
|---|---|---|---|---|
| **AOD-$PM_{2.5}$** | 1 | 0.73 | 0.55 | -0.12 |
| **$NO_2$** | | 1 | 0.45 | -0.27 |
| **$SO_2$** | | | 1 | -0.22 |
| **AT** | | | | 1 |
| | **GAM-$PM_{2.5}$** | **$NO_2$** | **$SO_2$** | **AT** |
| **GAM-$PM_{2.5}$** | 1 | 0.74 | 0.53 | -0.12 |
| **$NO_2$** | | 1 | 0.45 | -0.27 |
| **$SO_2$** | | | 1 | -0.22 |
| **AT** | | | | 1 |

AOD-$PM_{2.5}$, $PM_{2.5}$ derived from the calibrated satellite AOD measurements; GAM-$PM_{2.5}$, $PM_{2.5}$ derived from Generalized Additive Models; $NO_2$, nitrogen dioxide; $SO_2$, sulfur dioxide; AT, apparent temperature.

**Table IV. Relative Risks and 95% confidence intervals (CIs) in cardiovascular and cerebrovascular mortality associated with 10 μg/m$^3$ increase in AOD-$PM_{2.5}$ and GAM- $PM_{2.5}$**

| Outcome | | Model $R^2$ | *p* valuez* | Relative Risk | Lower bound | Upper bound | Standard error | Relative Risk | Lower bound | Upper bound | Standard error | Relative Risk | Lower bound | Upper bound | Standard error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Lag 0* | | | | *Lag 0-1* | | | | *Lag 0-6* | | | |
| **Cardiovascular mortality** | **AOD** | 0.72 | **0.17** | 1.010 | 1.000 | 1.020 | 0.005 | 1.012 | 1.002 | 1.023 | 0.005 | 1.010 | 0.999 | 1.021 | 0.006 |
| | **GAM** | 0.84 | | 1.008 | 1.000 | 1.015 | 0.004 | 1.009 | 1.001 | 1.018 | 0.004 | 1.006 | 0.997 | 1.015 | 0.005 |
| **Cerebrovascular mortality** | **AOD** | 0.72 | **0.20** | 1.032 | 1.001 | 1.063 | 0.015 | 1.034 | 1.001 | 1.069 | 0.017 | 1.028 | 0.993 | 1.063 | 0.017 |
| | **GAM** | 0.84 | | 1.022 | 0.993 | 1.052 | 0.015 | 1.027 | 1.000 | 1.054 | 0.013 | 1.022 | 0.993 | 1.052 | 0.015 |
| **Ischemic heart disease** | **AOD** | 0.72 | **0.92** | 1.005 | 0.992 | 1.018 | 0.007 | 1.010 | 0.996 | 1.024 | 0.007 | 1.007 | 0.992 | 1.021 | 0.007 |
| | **GAM** | 0.84 | | 1.007 | 0.996 | 1.017 | 0.005 | 1.010 | 0.999 | 1.021 | 0.006 | 1.004 | 0.992 | 1.017 | 0.006 |
| **Ischemic heart disease (improved by correction in death cause)** | **AOD** | 0.72 | **0.83** | 1.009 | 0.996 | 1.021 | 0.006 | 1.013 | 0.999 | 1.027 | 0.007 | 1.008 | 0.994 | 1.022 | 0.007 |
| | **GAM** | 0.84 | | 1.009 | 0.998 | 1.019 | 0.005 | 1.012 | 1.001 | 1.023 | 0.006 | 1.005 | 0.993 | 1.018 | 0.006 |
| **Ischemic stroke** | **AOD** | 0.72 | **0.83** | 0.994 | 0.934 | 1.058 | 0.032 | 1.011 | 0.945 | 1.081 | 0.034 | 1.058 | 0.987 | 1.134 | 0.035 |
| | **GAM** | 0.84 | | 1.010 | 0.966 | 1.057 | 0.023 | 1.023 | 0.974 | 1.074 | 0.025 | 1.065 | 1.008 | 1.125 | 0.028 |
| **Hemhorragic Stroke** | **AOD** | 0.72 | **0.55** | 1.040 | 1.004 | 1.078 | 0.018 | 1.034 | 0.994 | 1.075 | 0.020 | 1.003 | 0.964 | 1.044 | 0.020 |
| | **GAM** | 0.84 | | 1.028 | 1.000 | 1.058 | 0.014 | 1.029 | 0.997 | 1.061 | 0.016 | 0.999 | 0.966 | 1.033 | 0.017 |
| **Cardiovascular mortality ≥65** | **AOD** | 0.72 | **0.01** | 1.009 | 0.997 | 1.021 | 0.006 | 1.011 | 0.998 | 1.023 | 0.006 | 1.023 | 1.010 | 1.036 | 0.007 |
| | **GAM** | 0.84 | | 1.005 | 0.996 | 1.015 | 0.005 | 1.007 | 0.997 | 1.017 | 0.005 | 1.012 | 1.001 | 1.023 | 0.006 |
| **Cerebrovascular mortality ≥65** | **AOD** | 0.72 | **0.19** | 1.027 | 0.990 | 1.065 | 0.019 | 1.042 | 1.001 | 1.085 | 0.021 | 1.047 | 1.004 | 1.092 | 0.021 |
| | **GAM** | 0.84 | | 1.019 | 0.990 | 1.049 | 0.015 | 1.034 | 1.001 | 1.068 | 0.016 | 1.040 | 1.003 | 1.077 | 0.018 |

*The Wald test was used for cross-model hypotheses of same effect size effect estimates for lag-0 from models using AOD-$PM_{2,5}$ and GAM-$PM_{2,5}$ as exposure

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