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Airborne particulate matter exposure and urinary albumin excretion: the Multi-Ethnic Study of Atherosclerosis

M S O'Neill^{1,2}, A V Diez-Roux¹, A H Auchincloss¹, T G Franklin¹, D R Jacobs Jr^{3,4}, B C Astor⁵, J T Dvorchak², and J Kaufman⁶

¹Department of Epidemiology, University of Michigan School of Public Health, Ann Arbor, MI, USA

²Department of Environmental Health Sciences, University of Michigan School of Public Health, Ann Arbor, MI, USA

³Division of Epidemiology and Community Health, University of Minnesota School of Public Health, Minneapolis, MN, USA

⁴Department of Nutrition, University of Oslo, Oslo, Norway

⁵Department of Epidemiology, Johns Hopkins University Bloomberg School of Public Health, Baltimore, MD, USA

⁶Department of Environmental and Occupational Health Sciences, University of Washington School of Public Health, Seattle, WA, USA

Abstract

Objectives—Understanding mechanistic pathways linking airborne particle exposure to cardiovascular health is important for causal inference and setting environmental standards. We evaluated whether urinary albumin excretion, a subclinical marker of microvascular function which predicts cardiovascular events, was associated with ambient particle exposure.

Methods—Urinary albumin and creatinine were measured among members of the Multi-Ethnic Study of Atherosclerosis at three visits during 2000–2004. Exposure to PM_{2.5} and PM₁₀ (μg/m³) was estimated from ambient monitors for 1 month, 2 months and two decades before visit one. We regressed recent and chronic (20 year) particulate matter (PM) exposure on urinary albumin/creatinine ratio (UACR, mg/g) and microalbuminuria at first examination, controlling for age, race/ethnicity, sex, smoking, second-hand smoke exposure, body mass index and dietary protein (n = 3901). We also evaluated UACR changes and development of microalbuminuria between the first, and second and third visits which took place at 1.5- to 2-year intervals in relation to chronic PM exposure prior to baseline using mixed models.

Results—Chronic and recent particle exposures were not associated with current UACR or microalbuminuria (per 10 μg/m³ increment of chronic PM₁₀ exposure, mean difference in log UACR = -0.02 (95% CI -0.07 to 0.03) and relative probability of having microalbuminuria = 0.92 (95% CI 0.77 to 1.08)). We found only weak evidence that albuminuria was accelerated among those chronically exposed to particles: each 10 μg/m³ increment in chronic PM₁₀ exposure was associated with a 1.14 relative probability of developing microalbuminuria over 3–4 years, although 95% confidence intervals included the null (95% CI 0.96 to 1.36).

Correspondence to: Dr Marie S O'Neill, University of Michigan School of Public Health, 6631 SPH Tower, 109 South Observatory, Ann Arbor, MI 48109-2029, USA; marieo@umich.edu.

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Conclusions—UACR is not a strong mechanistic marker for the possible influence of air pollution on cardiovascular health in this sample.

METHODS

Study population

MESA is an ongoing longitudinal study of subclinical atherosclerosis funded by the National Heart Lung and Blood Institute.²⁰ The cohort consists of 6814 men and women aged 44–84 years who were free of clinical cardiovascular disease at baseline. Individuals were recruited from six field centres: Baltimore, MD (Johns Hopkins), Chicago, IL (Northwestern), Forsyth County, NC (Wake Forest), Los Angeles, CA (University of California-Los Angeles), New York, NY (Columbia) and St. Paul, MN (University of Minnesota). Additional details on study design are provided elsewhere.²⁰ These analyses are based on data collected at the baseline visit (June 2000–August 2002) and the second and third visits, which took place at 1.5- to 2-year intervals after baseline.

Creatinine-adjusted urinary albumin excretion

Our outcome of interest was creatinine-adjusted urinary albumin excretion. For MESA participants, urinary albumin and creatinine levels (mg/dl) were measured in a spot sample taken in a fasting state at the baseline examination. Samples were analysed using nephelometry (albumin) and the rate Jaffe reaction (creatinine) at a central laboratory following standard quality assurance and control procedures and uniform storage and transport protocols.²¹ The urinary albumin/creatinine ratio (UACR) was calculated and adjusted for sex-specific differences in creatinine excretion by dividing the ratio by 0.68 for men because of their typically larger size and muscle mass.²² MESA participants were classified into four categories of urine albumin excretion (normal, high normal, microalbuminuria and macroalbuminuria), following Murtaugh *et al.*²³

Air pollution exposure

Both recent and chronic PM exposures were investigated. Recent exposure was assigned based on the participant's place of residence at the time of the baseline examination. Chronic exposure was estimated based on a residential history reported by each participant as part of an study ancillary to MESA. Participants reported all residential addresses since January 1982, including move dates (month and year). All addresses were geocoded, creating a file containing the residential location for each participant for each month between January 1982 and the date of the baseline examination.

Data on air pollution from community monitors sited for regulatory purposes were obtained from the Environmental Protection Agency (EPA) Aerometric Information Retrieval Service (AIRS) database. For recent exposures we investigated mean concentrations, in $\mu\text{g}/\text{m}^3$, of particles less than 10 and 2.5 μm in aerodynamic diameter, respectively (PM_{10} , $\text{PM}_{2.5}$) for two time periods prior to the baseline examination: the average of the previous month and the average of the previous 2 months. Particle monitors collected 24-h integrated samples, some daily but most every third day. Based on the reported residence of MESA participants at the time of the baseline examination, average monthly exposures were assigned using the nearest monitor with available data on that day (ie, for each day of the previous month or 2 months). The mean distance to the nearest monitor was 9 km (range 0.45–51 km).

Longer-term exposure was estimated for PM_{10} and $\text{PM}_{2.5}$ in two ways. The EPA monitoring network has made direct measurements of PM_{10} over a longer time frame than $\text{PM}_{2.5}$, so one metric of cumulative 20-year PM_{10} exposure was estimated with data from those direct monitor readings. The nearest monitor to each participant's residential address was used to compute

monthly exposure averages from January 1982 to December 2002 (or the date of the baseline examination, if it came first). An area under the curve (AUC) calculation is used to represent an average concentration over a time interval, which in our study was 20 years. If we plot the monthly average estimated pollution concentration for each participant over the period of the study, and take the area under that curve, we have an estimate of his or her exposure in $\mu\text{g}/\text{m}^3$. This method has an advantage over a simple average of concentrations over the time period because it allows interpolation of exposure over months with missing data, although this was a very small number in our dataset. However, we chose to use this AUC method for comparability with our imputed PM exposures (described next). The specific calculation was done as follows. Starting with the first available date, each average monthly PM_{10} value was multiplied by the number of months the subject was exposed to this value. If PM_{10} information was missing (skips), the missing month(s) were given the average of the PM_{10} value from immediately before the skip and immediately after the skip. This average value was multiplied by the size of the skip. All values were summed and then divided by the overall number of exposure months to get a cumulative monthly average over the 20 years. The results were reported per 10 $\mu\text{g}/\text{m}^3$ increments in PM_{10} , as is standard in air pollution epidemiology.

In addition to long-term PM_{10} estimates based solely on direct monitor readings, cumulative $\text{PM}_{2.5}$ and PM_{10} exposures were imputed using a space–time model which yielded a three-dimensional exposure “surface” of pollution concentrations over continental USA for each month during the 20-year exposure period. Predictor variables for this estimated surface included monitored PM levels and other covariates, including temperature and airport visibility data obtained from the National Climatic Data Center, total suspended particle measures from the EPA’s network, and population density from the 1990 U.S. Census.²⁴ This space–time model captured variation over time using trend, cyclic and autoregressive terms, and thin plate splines were used to capture variation over space. With the nationwide exposure surface created from the space–time model, each MESA participant was assigned a multiply-imputed cumulative exposure based on the months and locations represented in the residential history data. Using multiple imputation has an advantage over single imputation in that the standard errors correctly reflect the level of uncertainty inherent in estimating missing values²⁵; we followed standard multiple imputation procedures for this model. The overall fit of the space–time model with the observed data (for PM_{10}) is characterised by an R-square of 58%. The model was also validated by deleting 10% of the observed values, imputing them and then comparing the distributions of imputed and observed values. A scatter-plot of the imputed and observed values showed a scatter around a 45° line. The cumulative imputed 20-year exposures to $\text{PM}_{2.5}$ and PM_{10} were represented by an AUC, as for the directly-monitored PM_{10} estimate.

Other covariates

During the baseline MESA examination, participants provided detailed information on personal characteristics (sex, age, race/ethnicity, cigarette smoking (never, former, current) and dietary protein). Height and weight were measured using standard procedures and used to calculate body mass index (BMI). MESA participants also reported ETS exposure in the year prior to the baseline examination (were they in “close quarters” with a person who smoked, at home, at work, in a car, etc), in hours per week.

Analytical approach

We evaluated associations of chronic and recent PM exposure with two outcomes measured at the MESA baseline visit: continuous log UACR and clinically defined micro- or macroalbuminuria²³ ($\text{UACR} \geq 25 \text{ mg/g}$) versus normal levels. We used scatter-plots to examine associations of the exposure measures with the baseline log UACR and calculated descriptive statistics and correlations between air pollution variables, and bivariate associations between covariates and log-transformed UACR. We used multiple linear regressions to

estimate associations of PM exposures with log UACR after adjustment for age, sex, race/ethnicity, BMI, per cent dietary protein, cigarette smoking (never, former, current) and ETS exposure (<1 h/week, ≥1 h/week). Although systolic and diastolic blood pressure, use of blood pressure medication, inflammatory markers and diabetes status were available as potential covariates, we did not adjust for them, as they have been associated with air pollution exposure in previous studies and are potentially along the mechanistic pathway linking air pollution exposure to UACR. We expressed results as mean differences in log UACR at the baseline examination associated with a 10 $\mu\text{g}/\text{m}^3$ increase in particle exposure. We used binomial regression²⁵ to evaluate whether air pollution was associated with microalbuminuria compared to normal and high-normal UACR levels, expressed as a relative probability per 10 $\mu\text{g}/\text{m}^3$ increase in PM exposure. Analyses using imputed datasets used appropriate methods to account for uncertainty in the imputations.²⁶

To evaluate whether long-term PM exposure was associated with albumin changes over the three examination visits, we fit repeated measures model with random subject effects to estimate 3-year changes in log UACR by levels of exposure. The repeat measures models included time in years, quartiles of long-term PM exposure (based on the directly estimated PM₁₀ AUC measures), interactions between time and PM₁₀ exposure category, and all the baseline covariates included in the cross-sectional analyses. We also examined the sensitivity of results to the inclusion of time-by-baseline covariate interactions to allow the change over time to differ by covariate levels. The 3-year change in log UACR among participants in each exposure quartile was represented by the slope associated with time plus the corresponding time-by-exposure interaction. We also estimated the relative probability that MESA participants who did not have microalbuminuria at baseline would develop the condition at examinations 2 or 3, per 10 $\mu\text{g}/\text{m}^3$ increase in estimated long-term exposure to directly-monitored PM₁₀, using log-binomial regression models fit with SAS PROC GENMOD (SAS, Cary, NC, USA).²⁶

We examined heterogeneity of effects by sex, race/ethnicity, study site and age in all models by including the corresponding interaction term(s) in fully adjusted models. Albumin excretion differs by sex,⁹ and associations between particle pollution and carotid intima-media thickness (CIMT), another subclinical indicator of cardiovascular function, were stronger among women.²⁷ Associations between air pollution and heart rate variability have differed by race and ethnicity.²⁸ Study site was evaluated because pollutant mix and composition (including oxidative properties of PM_{2.5}) can vary greatly by location. Age may indicate differing susceptibility to the effects of air pollution on vascular function. We defined effect modification as present if the p value for the interaction term was less than 0.01.

In sensitivity analyses, we examined these associations among individuals whose exposure to directly monitored PM_{2.5} and PM₁₀ was estimated from monitors located within 10 km of their residences, for all exposure timeframes. For two decade exposures we also contrasted results using observed PM data to those obtained with multiply-imputed exposures from the space-time model.

Of the 6814 participants recruited to MESA, 5229 had complete data on the outcome and clinical covariates used for the analyses and had completed the residential history questionnaire. Of these, 4343 had geocodes available for all residential addresses between August 1982 and August 2002 and thus complete data on chronic exposures. For comparability between the estimates for the long-term exposure and estimates for short-term exposure, analyses were further restricted to individuals for whom exposure could be assigned on all timescales. This yielded a total of 3901 participants for analysis.

RESULTS

The demographic and clinical characteristics of the sample are provided in table 1. Just over half the study sample were women, and the average age of participants was 63 years. Fifty per cent of the participants had ever smoked, and about 36% reported any ETS exposure. On average, dietary protein made up approximately 16% of daily energy intake, and the mean BMI of the analysis population was 28.4. The majority of the participants (78.7%) had normal UACR, and around 20% were classified as having microalbuminuria or high-normal levels, with just 1% at the macroalbuminuria level. There were no important differences in key characteristics when the analysis sample was compared with the full MESA cohort ($n = 6814$). The study sample had a lower representation from St. Paul compared to the full sample (8.0% vs 15.6%), and less Chinese and Hispanic participants than the full cohort (11.8% vs 21.9%) because many of these people were recent immigrants whose chronic exposure could not be estimated.

Pollution levels measured during the two decades and month prior to the MESA baseline examination are reported in table 2. The 5-year increments that comprise the 20-year cumulative PM_{10} assigned to participants reflect overall decreasing trends in PM_{10} levels across the USA during these decades.

In a linear regression model not including the pollutant values, UACR was significantly higher among older participants, men, those of Chinese and Hispanic ethnicity compared to Caucasians, those with higher dietary protein intake, and those with higher BMI. Current smokers had an adjusted mean difference in UACR of 0.145 (95% CI 0.033 to 0.257) compared to never smokers. For former smokers compared to never smokers, the adjusted mean difference was 0.025 (95% CI -0.048 to 0.098). The point estimate of the association of UACR with ETS was positive although the confidence intervals included the null value. Scatter-plots of the albumin variables and pollution exposures revealed no apparent patterns of associations (not shown).

Adjusted mean differences in log UACR associated with the pollutant exposures studied are shown in table 3 for the total sample and the 2611 participants living within 10 km of a monitor for all exposure metrics. The estimated associations are mostly negative, and for all but one of the models examined (60-day previous PM_{10} exposures) confidence intervals included the null. Except for the association with imputed cumulative $PM_{2.5}$ exposure, restricting to the population living in closer proximity to monitors pulled the point estimates of effect consistently closer to 0 or upward.

The adjusted relative probabilities of having microalbuminuria at baseline according to recent and chronic PM exposures are shown in table 4. As for the continuous UACR, the majority of the point estimates of effect were in the opposite of the hypothesised direction, and all but one of the estimates (for PM_{10} exposure in the previous 60 days) had a confidence interval including the null.

Similarly, when analysing albumin levels at all three examinations, the adjusted relative probability of developing microalbuminuria over the follow-up period associated with a $10 \mu g/m^3$ difference in chronic PM_{10} exposure was elevated (1.14, 95% CI 0.96 to 1.36) but confidence intervals included the null, even when the population was restricted by monitor proximity (1.06, 95% CI 0.84 to 1.35). Results using discrete survival analysis, with and without accounting for unequal examination intervals, were virtually identical to those reported above using binomial regression (not shown).

The repeated-measures analysis of change in continuous log UACR by quartile of long-term exposure showed a positive slope among all exposure quartiles (table 5). Restricting the models

to participants living closer to ambient monitors did not have a consistent influence on the estimated slopes. The slopes increased monotonically by increasing exposure quartile for the full-sample analyses, but the p value for trend in that set of analyses was 0.42, and p values for trend were similarly non-significant in the other model. Inclusion of interaction terms between time and other covariates had little influence on the pattern or significance of the estimates.

Heterogeneity by gender, age, race/ethnicity and site was examined in fully adjusted models for both shorter-term exposures and 20-year PM₁₀ exposure. Interactions with PM exposure were not significant (by the $p < 0.01$ criterion) by gender, age, race/ethnicity or study site.

DISCUSSION

Chronic and recent exposures to ambient particles were not associated with urinary albumin excretion in our sample. There was only weak evidence that long-term exposure is associated with changes in microalbuminuria over time. This study is the first that we know of to examine albumin excretion as a subclinical indicator of the potential impact of air pollution on vascular function in a multi-ethnic population. Our results suggest that urinary albumin is not a marker for a primary mechanism underlying the population-level observations of increased cardiovascular morbidity and mortality associated with air pollution exposure. Associations showed little evidence for effect modification by sex, race/ethnicity, study site or age.

Although several studies have examined short-term pollution exposure and biomarkers of cardiovascular function, few studies of subclinical disease indicators and chronic pollution exposure exist. Higher CIMT, a structural marker of subclinical cardiovascular disease, was seen among those living in areas of Los Angeles with higher estimated outdoor fine particle levels.²⁷ Urinary albumin provides information about both functional and structural aspects of cardiovascular health, specifically marking smaller arteries, and complements this research.
30 31

Urinary albumin excretion has traditionally been used as a screening tool to determine the progression of deteriorating vascular function. Higher levels of albumin in urine result from physiological changes including increased blood pressure in the glomerulus, and charge changes in the glomerular capillary basement membrane, possibly due to glycosylation of proteins in the membrane.¹⁶ Albumin levels are well-correlated with microvascular dysfunction.¹⁹

Within-individual fluctuations in levels of albumin excretion occur (even including reductions in albumin excretion, termed “regression”, from microalbuminuria to normoalbuminuria).¹⁸ Predictors of acute changes in albumin excretion include protein intake, blood pressure, CRP and insulin resistance^{32–34} and changes have typically been evaluated at intervals of weeks to months. Because of limited knowledge of the timescale of changes in urinary albumin excretion, we evaluated air pollution exposure at various timescales ranging from the potential effects of long-term cumulative exposures over 20 years, to more recent exposures in the previous 2 months.

Albumin excretion measures have limitations. We had only a single spot urine sample for this study, and important variations may not be captured properly by this technique, even with adjustment for creatinine.²¹ Urinary albumin excretion can be measured using a timed collection interval (considered the gold standard) or a single sample collected in a morning visit and adjusted for urinary creatinine, a metabolic by-product of muscle.³⁵ Adjusting the albumin concentration for creatinine levels is common practice for a spot sample, since creatinine concentration is fairly constant throughout the day and a good indicator of urine flow rate.³⁶ Although some variation by race exists in creatinine excretion, these differences have been evaluated only for black and white subjects, but not for Asian or Hispanic subjects,

so no race-specific adjustment was carried out, consistent with a previous analysis in the MESA cohort.²¹ In spite of the limitations of spot samples,³⁷ many previous studies show their predictive power for cardiovascular events, and the UACR values in this population were associated with known risk factors for microalbuminuria in the expected direction.

Measurement error in assigning environmental exposure to participants may have hampered our ability to detect associations with albumin, especially if any true causal effects are small. The ideal exposure metric would be a direct measure of personal air pollution exposure of MESA participants over the months and two decades prior to the baseline examination. No study has yet measured personal pollution exposure for such a long period of time. While our PM measure is imperfect, previous studies have found associations between PM exposure and cardiovascular events and mortality using exposure measures cruder than ours (eg, a single urban monitor, average of a few urban monitors), controlling for other known risk factors.^{1 2} Assigning exposures for each month based on the nearest monitor is an improvement over a single monitor approach. Although strong evidence exists that daily fluctuations in ambient PM may precipitate cardiovascular events, the effect of PM on the process of developing cardiovascular disease is likely to be a weaker signal and thus difficult to detect.

This study did not account for exposures occurring during commuting or at the workplace. However, ambient (background) PM tends to be a spatially homogeneous pollutant, relative to gaseous pollutants, so background exposures are likely to be fairly well-represented by ambient monitor measures³⁸ and the majority of MESA participants report spending 60% of their time at home or within 2 km of their home.³⁹ We found no differences in the results when analyses were restricted to persons within 10 km of a monitor for the full exposure period, or when using space–time models to impute cumulative exposure to both PM size fractions. Outdoor ambient measures of PM were more strongly associated with cardiopulmonary health outcomes than indoor or non-ambient personal exposures,⁴⁰ thus supporting the importance of our analysis using ambient PM measurements used to enforce community air pollution standards.

A new study linked to the MESA cohort will allow much more detailed assessment of exposure using time–activity diaries and additional fixed and person-level monitoring. These data will allow assessment of the relationship between short-term changes in PM and short-term changes in albumin excretion as cohort follow-up continues. More complex exposure assignment schemes, including incorporating distance to roadways and traffic counts, may yield different results in future efforts to model chronic exposure in MESA, and facilitate detection of the signal of air pollution's impact on subclinical disease processes. However, exposure assignment techniques similar to those used in the present study have been used in landmark studies showing robust associations between long-term pollution exposure and mortality.^{1 2}

Our longitudinal analyses examined the relationship between long-term cumulative exposure and subsequent changes in albumin excretion over a 3–4-year period. The objective was to determine whether long-term cumulative exposure places persons on a trajectory of deteriorating vascular function. These analyses examine the relationship between long-term exposure and within-person change. Although imprecise, the point estimates for development of microalbuminuria and slopes for change in continuously measured UACR were consistent with our hypothesis that vascular deterioration would be accelerated among those with higher chronic exposures to pollution.

Main messages

- Hospitalisations and deaths due to cardiovascular events have been linked to exposure to particulate air pollution, so we explored urinary albumin levels as a

novel potential marker for the contribution of pollution exposure to the development of cardiovascular disease.

- In this study, albumin excretion was not linked with either short- or long-term exposure to particulate air pollution, and does not appear to be a strong mechanistic marker for a possible influence of air pollution on cardiovascular health.

Policy implications

- Understanding the biological mechanisms by which air pollution may contribute to cardiovascular morbidity and mortality is important for causal inference and helps form the evidence base for setting and enforcing protective air quality standards.
- Studying the effects of air pollution on the cardiovascular health of a broadly representative multi-ethnic population is also important as many existing studies and cohorts do not reflect gender or race/ethnic diversity.
- Although our study did not show associations between air pollution exposure and albumin, ample evidence exists that pollution adversely affects the cardiovascular system, so other study designs or mechanistic pathways may be required to detect the signal of air pollution's contribution to deterioration in cardiovascular health.

CONCLUSIONS

We examined associations between air pollution and UACR in a large, multi-ethnic sample with a substantial age range and ethnic diversity, and information on a variety of covariates. Our objective was to explore a novel potential mechanistic pathway to aid in evaluating the causal links between pollution exposure and cardiovascular health seen in numerous epidemiological studies. Although prior evidence from other studies suggests that particulate pollution exposure may contribute to progression of renal disease and vascular dysfunction over and above the standard risk factors, we did not see evidence for this in MESA. Our findings do not strongly support the use of UACR as a marker of microvascular function to understand the cardiovascular effects of air pollution exposure, but pollution exposure may be associated with increased albumin excretion in vulnerable subgroups, or in studies with more detailed measures of personal exposures.

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Table 1

Demographic and clinical characteristics and urinary albumin/creatinine ratio for participants included in the analyses (n = 3901), MESA 2000–2002

Age, years, mean (SD)	63.04 (9.9)
% Female	52.4%
Race/ethnicity (% distribution)	
Caucasian	41.2%
Chinese	8.5%
African American	30.5%
Hispanic	19.8%
Study site (% distribution)	
Baltimore	17.8%
Chicago	21.0%
Forsyth County	18.8%
Los Angeles	18.5%
New York City	15.9%
St Paul	8.0%
Body mass index (kg/m ²), mean (SD)	28.4 (5.3)
Dietary protein, mean (SD)	
Per cent of total calories	16.0 (3.7)
Smoking status (% distribution)	
Never	50.2%
Former	38.4%
Current	11.4%
ETS exposure	
None	64.1%
At least 1 h per week	35.9%
UACR (mg/g [*]), median (SD)	
Visit 1	4.6 (99.1)
Visit 2	4.8 (97.5)
Visit 3	5.4 (100.3)
UACR categories (based on visit 1 levels)	
Normal (<15 mg/g)	78.7%
High normal (≥15 mg/g, <25 mg/g)	10.3%
Microalbuminuria (>25 mg/g, <250 mg/g)	10.0%
Macroalbuminuria (>250 mg/g)	1.0%

* Examination 1, n = 3901; examination 2, n = 3899; examination 3, n = 3708.

ETS, environmental tobacco smoke; UACR, urinary albumin/creatinine ratio; SD, standard deviation.

Pollutant exposures for study participants by enrolment site for previous month and previous 20 years (based on residential history)

Table 2

Pollutant	Exposure period	Location	n	Mean (µg/m ³)	SD
PM ₁₀	1982–2002	All sites	3901	34.7	7.0
	1982–1987	All sites	3901	40.5	7.5
	1988–1992	All sites	3901	38.0	8.9
	1993–1997	All sites	3901	30.6	7.3
	1998–2002	All sites	3901	29.7	6.9
	Previous month	All sites	3901	27.5	7.9
		Baltimore	695	22.7	6.4
		Chicago	818	31.7	7.9
		Forsyth	733	22.4	5.2
		Los Angeles	721	33.1	7.0
PM _{2.5}		New York	621	25.2	6.1
		St Paul	313	31.3	4.0
	Previous month	All sites	3901	16.5	4.8
		Baltimore	695	15.9	3.6
		Chicago	818	16.7	3.9
		Forsyth	733	15.2	3.4
		Los Angeles	721	21.8	5.3
		New York	621	15.5	2.8
		St Paul	313	10.4	2.5

SD, standard deviation.

Table 3

Adjusted* mean differences in log urinary albumin/creatinine ratio (mg/g) per 10 $\mu\text{g}/\text{m}^3$ increase in particulate matter among MESA participants seen at their baseline visit, 2000–2002

Pollutant and exposure period	Population [†]	Mean difference (95% CI)
PM _{2.5}		
Previous 30 days	Full sample	−0.017 (−0.087 to 0.052)
	Within 10 km	0.026 (−0.067 to 0.119)
Previous 60 days	Full sample	−0.040 (−0.121 to 0.042)
	Within 10 km	−0.013 (−0.122 to 0.097)
PM ₁₀		
Previous 30 days	Full sample	−0.042 (−0.085 to 0.002)
	Within 10 km	−0.023 (−0.079 to 0.034)
Previous 60 days	Full sample	−0.056 (−0.106 to −0.005)
	Within 10 km	−0.040 (−0.106 to 0.025)
Previous two decade exposure (1982–2002), from AUC for monthly levels		
PM ₁₀ from nearest monitors	Full sample	−0.019 (−0.072 to 0.033)
	Within 10 km	0.009 (−0.067 to 0.085)
Imputed exposures [‡]		
PM ₁₀	Full sample	−0.002 (−0.038 to 0.035)
	Within 10 km	0.016 (−0.033 to 0.066)
PM _{2.5}	Full sample	0.002 (−0.048 to 0.052)
	Within 10 km	−0.012 (−0.076 to 0.053)

* Adjustment: baseline covariates (degrees of freedom): age (1), gender (1), race (3), BMI (1), cigarette status (never, former, current) (2), environmental tobacco smoke exposure (1), per cent dietary protein (1).

[†] Population: full sample (n = 3901) had exposure estimated using nearest monitor, regardless of distance from reported residential address. 2611 participants lived within 10 km of a monitor.

[‡] Imputations from time–space model using monitor data, temperature and visibility (see text). These imputations did not use the nearest monitor approach but are reported for the two populations, defined by monitor proximity, for comparison with the other estimates.

AUC, area under the curve; 95% CI, 95% confidence interval; UACR, urinary albumin/creatinine ratio.

Table 4

Adjusted* relative prevalence of microalbuminuria[†] vs high-normal and normal levels (below 25 mg/g), per 10 $\mu\text{g}/\text{m}^3$ increment in particulate matter, among 3864 MESA participants without macroalbuminuria seen at baseline visit, 2000–2002

Pollutant and exposure period	Relative prevalence (95% CI)
PM _{2.5}	
Previous 30 days	0.94 (0.77 to 1.16)
Previous 60 days	0.90 (0.71 to 1.14)
PM ₁₀	
Previous 30 days	0.88 (0.76 to 1.02)
Previous 60 days	0.83 (0.70 to 0.99)
Previous two decade exposure (1982–2002), from AUC for monthly levels	
PM ₁₀ from nearest monitors	0.92 (0.77 to 1.08)
Imputed exposures [‡]	
PM ₁₀	0.98 (0.87 to 1.10)
PM _{2.5}	0.98 (0.84 to 1.14)

* Adjustment: baseline covariates (degrees of freedom): age (1), gender (1), race (3), BMI (1), cigarette status (never, former, current) (2), environmental tobacco smoke exposure (1), per cent dietary protein (1).

[†] Albuminuria defined as UACR ≥ 25 mg/g; macroalbuminuria ≥ 250 mg/g.

[‡] Imputations from time-space model (see text).

AUC, area under the curve; 95% CI, 95% confidence interval.

Table 5

Adjusted* mean 3-year change in log UACR (mg/g) by quartiles of 1982–2002 exposure to PM₁₀ from ambient monitors among MESA participants seen in 2000–2004

Population [†]	Quartile of PM ₁₀ in µg/m ³ from AUC, range	Slope	Standard error	Test for trend (p value)
Full sample	18.5 to <29.3	0.147	0.024	0.42
	29.3 to <33.1	0.159	0.024	
	33.1 to <36.3	0.163	0.024	
	36.3 to 55.7	0.174	0.023	
Within 10 km	18.5 to <29.3	0.159	0.030	0.99
	29.3 to <33.1	0.155	0.031	
	33.1 to <36.3	0.167	0.028	
	36.3 to 55.7	0.152	0.036	

* Adjustment variables: baseline covariates (degrees of freedom): age (1), gender (1), race (3), BMI (1), cigarette status (never, former, current) (2), environmental tobacco smoke exposure (1), per cent dietary protein (1) and interaction terms between time (years) and PM₁₀ exposure.

[†] Population: the full sample (n = 3901) had exposure estimated using the nearest monitor, regardless of distance from reported residential address. 2611 participants lived within 10 km of a monitor; 2497 had examination 3 data.