CURRENT STATUS OF NON-TAILPIPE PM EPIDEMIOLOGY, AND MOVING FORWARD

HEI Annual Conference Webinar Series

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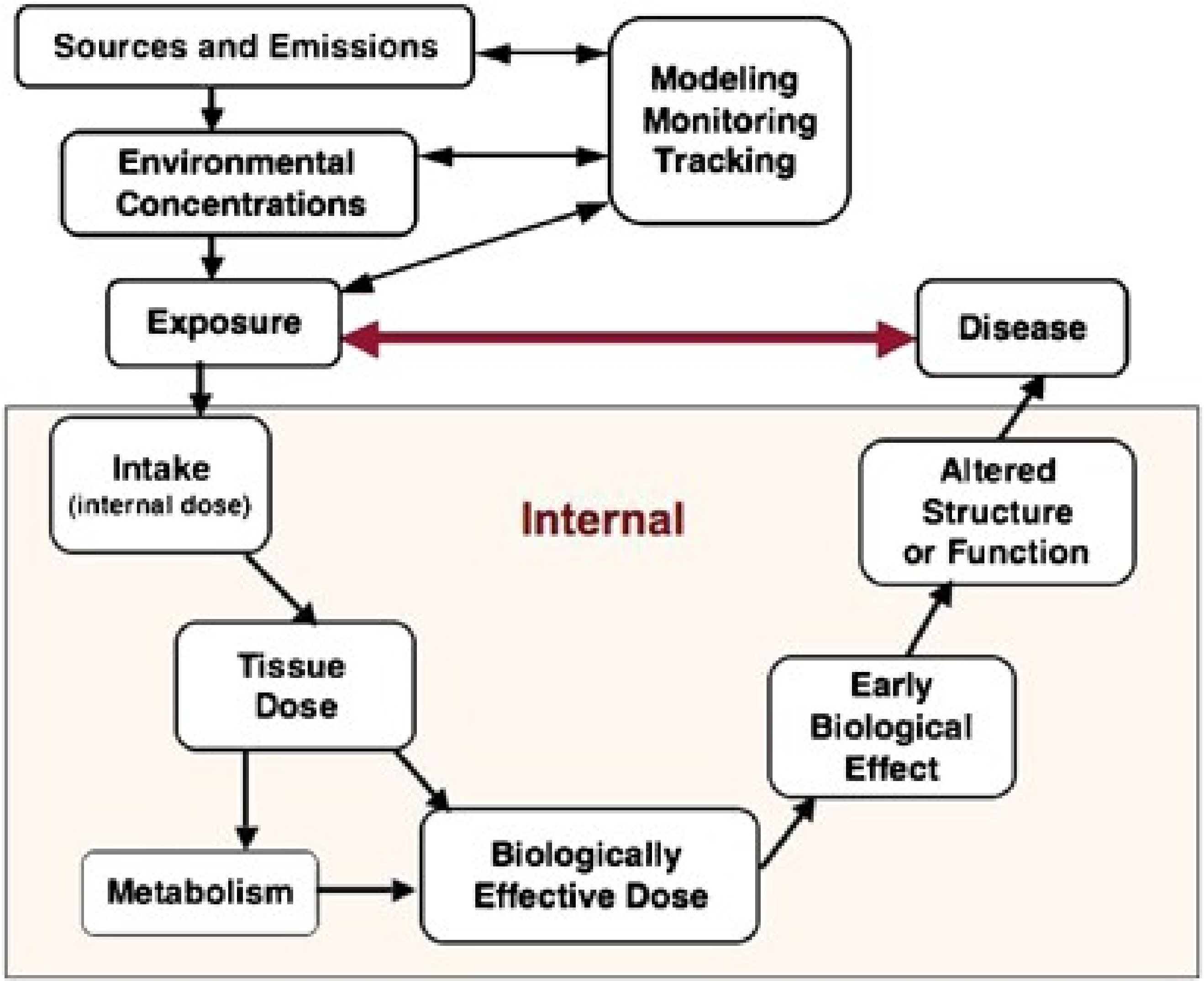
FROM SOURCE TO HEALTH EFFECTS



McKone, T., Ryan, P. & Özkaynak, H. Exposure information in environmental health research: Current opportunities and future directions for particulate matter, ozone, and toxic air pollutants. *J Expo Sci Environ Epidemiol* **19,** 30–44 (2009).

NON-TAILPIPE EMISSIONS

- Non-exhaust emissions particulate matter (both $PM_{2.5}$ and PM_{10})
  - Brake wear
    - Cu, Ba, Zn, Zr, Sn, Sb (potentially carcinogenic)
  - Tire wear
    - Zn, microplastics
  - Resuspended road dust
    - Fe, Al, Si, Ca

Emissions → Measurements → Models → Exposures

EXPOSURE ASSESSMENT FOR HEALTH EFFECTS STUDIES

- Methods for non-tailpipe exposure assessment used in existing health effects studies
  - Nearest monitor (use measurements directly) (Franklin et al 2008, Zanobetti et al 2009, Wang et al 2017)*
  - Nearest monitor and PCA for sources (Thurston et al 2016)*
  - Chemical transport models (Ostro et al 2015, Laurent et al 2014, 2016)**
  - Land-use regression (ESCAPE studies de Hoog et al 2013, series of health effects papers)***
  - Land-use regression and machine learning (ESCAPE Chen et al 2020, USC Intra-community variability study, Fruin et al 2014, Habre et al 2020)***

* $PM_{2.5}$, **$PM_{2.5}$ & $PM_{0.1}$, ***$PM_{2.5}$ & PM_{10} (or coarse PM)

INTERPRETATION OF HEALTH EFFECTS ESTIMATES

Exposures → ? → Health Effects

- **Acute studies:**
  - Time series and case-crossover models are typically used, with mortality or morbidity as a function of exposure adjusted for time, temperature, humidity, etc.
    - Effect estimates are typically reported as a % increase per 10ug/m^3 or IQR in PM (e.g. 0.74% (0.41-1.07%) increase in non-accidental mortality per IQR change in $PM_{2.5}$)
    - Speciation can be examined directly or accounted for as a proportion of the mass that modifies the $PM_{2.5}$ association (e.g. 0.75% additional increase in the $PM_{2.5}$ estimate when the proportion of mass is higher in Al)
    - When species examined directly the models are adjusted for mass
- **Long-term studies (often cohort studies):**
  - Cox proportional hazards models are typically used
    - Effect estimates are reported as Hazard Ratios (HR), or a change in risk associated with 10ug/m^3 or IQR increase in PM or PM species (e.g. higher risk for non-accidental mortality per IQR increase in $PM_{2.5}$ Cu [1.11 (1.06-1.17)])
    - Some studies examine the increase risk per relative concentration in species

ACUTE EXPOSURES AND HEALTH

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Short-term and long-term exposures to fine particulate matter constituents and health: A systematic review and meta-analysis☆

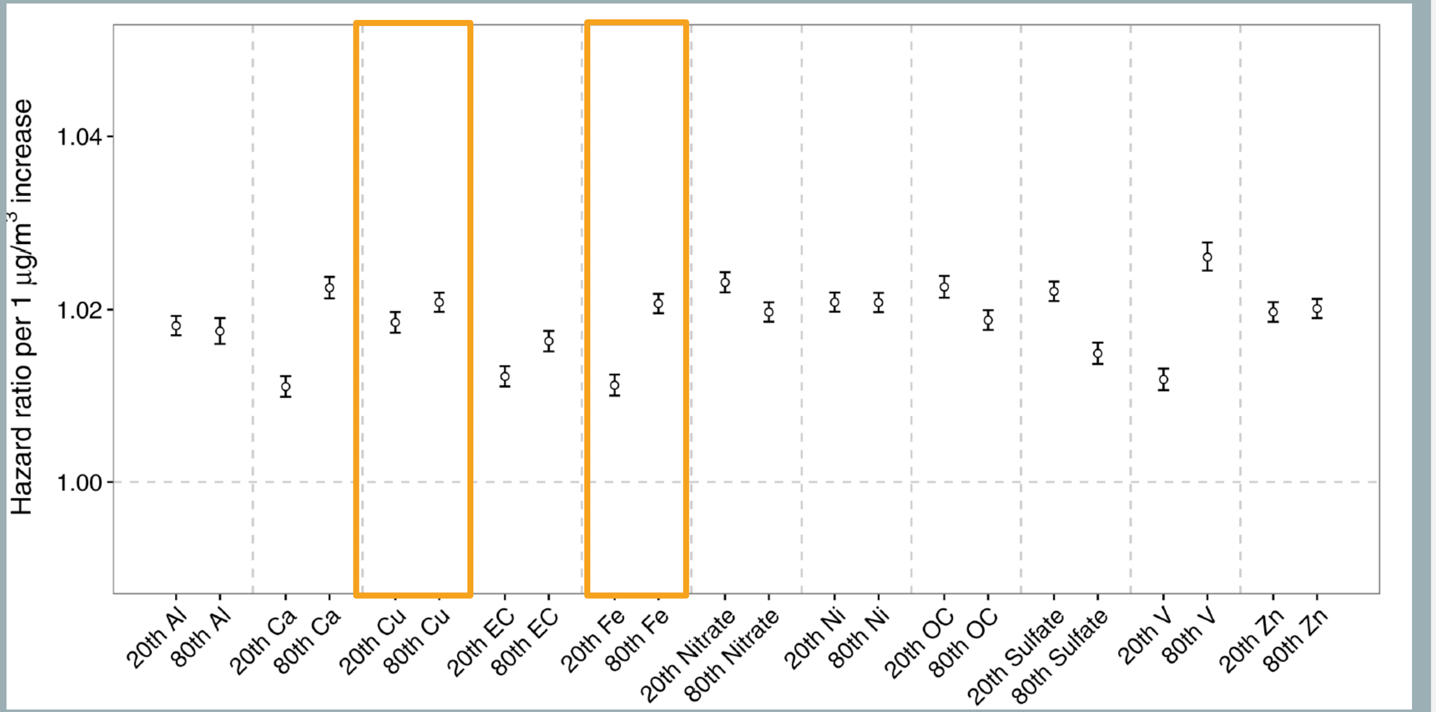
Check for updates

Yang Yang [a,1], Zengliang Ruan [b,1], Xiaojie Wang [b], Yin Yang [b], Tonya G. Mason [a], Hualiang Lin [b,*], Linwei Tian [a,**]

[a] School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong SAR, China
[b] Department of Medical Statistics and Epidemiology, School of Public Health, Sun Yat-sen University, Guangzhou, China

- Acute exposures and cardiovascular mortality: significant associations were observed for BC, OC, nitrate, sulfate, Zn, Si and K (represented as excess % increase per IQR increase in species, adjusted for $PM_{2.5}$ mass)
- Acute exposures and cardiovascular morbidity had significant heterogeneity in Fe and Zn
- Non-tailpipe markers not seen in respiratory-related causes of morbidity or mortality

LONG-TERM EXPOSURES AND HEALTH



- Long-term $PM_{2.5}$ association with mortality
- Examined for effect modification by chemical composition
- Increased risk with relative concentration of Cu, Fe

Wang, S., Lee, Y., Liu, L., Lee, M., Di, Q., Zanobetti, A., & Schwartz, J. (2017). Long-term exposure to $PM_{2.5}$ and mortality among older adults in the Southeastern US. *Epidemiology*, *28*(2), 207–214.

LONG-TERM EXPOSURES AND HEALTH

Associations of Mortality with Long-Term Exposures to Fine and Ultrafine Particles, Species and Sources: Results from the California Teachers Study Cohort

Bart Ostro,[1] Jianlin Hu,[2] Debbie Goldberg,[3] Peggy Reynolds,[3] Andrew Hertz,[3] Leslie Bernstein,[4] and Michael J. Kleeman[2]

- Kleeman CTM at 4x4 km resolution
- Ischemic HD mortality
- Associations with fine Cu and uf Cu, Fe

Table 3. Hazard ratios (HRs) and 95% CIs for associations of $PM_{2.5}$ and UF particles with IHD Mortality.

	$PM_{2.5}$ (µg/m^3)				UF (ng/m^3)			
	IQR	HR[a] (95% CI)	*p*-Value	AIC	IQR	HR[a] (95% CI)	*p*-Value	AIC
Pollutant								
Mass	9.6	1.18 (1.08, 1.30)	< 0.001	14,011	969	1.10 (1.02, 1.18)	0.01	13,896
Cu	0.4[b]	1.09 (1.04, 1.15)	< 0.001	14,015	0.02	1.06 (1.03, 1.09)	< 0.0001	13,890
Fe	0.2	1.06 (0.97, 1.16)	0.17	14,023	0.8	1.03 (1.00, 1.06)	< 0.05	13,899
Mn	4.0[b]	1.06 (0.99, 1.13)	0.12	14,023	0.03	1.00 (0.99, 1.01)	0.62	13,902
Nitrate	3.9	1.28 (1.16, 1.42)	< 0.0001	14,003	—	—		—
EC	0.8	1.14 (1.05, 1.24)	< 0.01	14,015	93	1.15 (1.06, 1.26)	< 0.001	13,891
OC	2.8	1.08 (0.99, 1.17)	0.07	14,022	731	1.08 (1.01, 1.15)	< 0.05	13,898
Other compounds	1.4	1.07 (0.99, 1.15)	0.08	14,022	29	1.10 (1.04, 1.16)	< 0.001	13,892
Other metals[c]	0.5	1.08 (0.99, 1.18)	0.09	14,022	17	1.13 (1.05, 1.21)	< 0.01	13,892
SOA_bio	0.1	1.08 (1.00, 1.17)	< 0.05	14,021	14	1.10 (1.02, 1.19)	< 0.01	13,896
SOA_ant	0.1	1.23 (1.11, 1.36)	< 0.0001	14,009	24	1.25 (1.13, 1.39)	< 0.001	13,884
Sources of primary particles								
On-road gasoline	0.3	1.12 (1.04, 1.22)	< 0.01	14,017	108	1.12 (1.04, 1.22)	< 0.01	13,894
Off-road gasoline	0.2	1.14 (1.04, 1.24)	< 0.01	14,016	33	1.14 (1.04, 1.24)	< 0.01	13,894
On-road diesel	0.4	1.13 (1.03, 1.23)	< 0.01	14,018	56	1.13 (1.03, 1.24)	< 0.01	13,895
Off-road diesel	0.8	1.13 (1.05, 1.23)	< 0.05	14,015	73	1.14 (1.05, 1.23)	< 0.01	13,892
Wood smoke	1.3	0.97 (0.90, 1.04)	0.38	14,024	332	0.95 (0.89, 1.02)	0.20	13,900
Meat cooking	1.2	1.08 (1.00, 1.17)	< 0.05	14,021	128	1.11 (1.03, 1.20)	< 0.01	13,895
High-sulfur fuel combustion	0.4	1.08 (1.02, 1.13)	< 0.05	14,017	54	1.08 (1.04, 1.12)	< 0.0001	13,888
Other anthropogenic	3.8	1.09 (1.00, 1.19)	0.05	14,021	400	1.06 (1.01, 1.10)	0.01	13,896

[a]HRs were stratified for age and race and adjusted for smoking status, smoking pack-years, adult secondhand smoke exposure, BMI, marital status, alcohol consumption, physical activity, menopausal status and HT use combined, family history of heart disease, hypertension medication/aspirin use, and dietary fat, fiber, and caloric intake. [b]Concentrations × 1,000. [c]Metals other than Cu, Fe, and Mn.

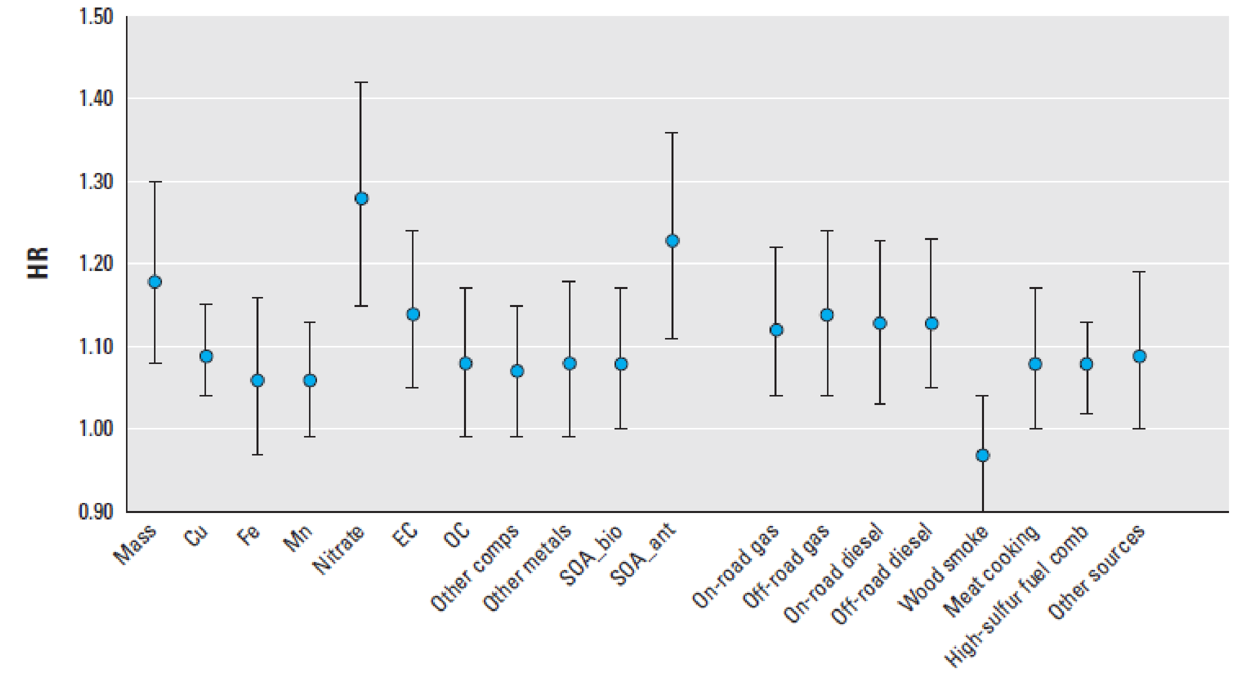


Figure 2. Association of $PM_{2.5}$ constituents and sources with IHD mortality (HRs and 95% CIs using interquartile range. Abbreviations: comb, combustion; comps, components.

ESCAPE STUDY

- 20 monitors in 20 European cities
- $PM_{2.5}$ and PM_{10} samples on14-day averages
- XRF for speciation
- Land use regression models for non-tailpipe exposures (2013)
- Supervised linear regression and random forest exposure models (2020)

De Hoogh, et al (2013). Development of land use regression models for particle composition in twenty study areas in Europe. *Environmental Science and Technology*, *47*(11), 5778–5786.

Chen, J., et al (2020). Development of Europe-Wide Models for Particle Elemental Composition Using Supervised Linear Regression and Random Forest. *Environmental Science and Technology*, *54*(24), 15698–15709.

LONG-TERM EXPOSURES AND HEALTH

- Examination of long-term non-tailpipe PM metals on cardiovascular mortality, respiratory mortality, lung cancer incidence.
- Used LUR exposure estimates based on $PM_{2.5}$ and PM_{10} measurements as part of the ESCAPE study.
- Markers of brake wear (Cu) and tire wear (Zn) significantly associated with cardiovascular and respiratory mortality

Table 2 Individual effects of metals, estimated with Poisson regression, on cardiovascular mortality, respiratory mortality and lung cancer incidence adjusted for tobacco weekly expenditure, IMD and percentage of Asian and white population. Mean and lower and upper bounds of the credible intervals of the IDR RR

	Metal	RR (95% CI)
Cardiovascular mortality	Cu PM_{10}	0.994 (0.987 to 1.001)
	Fe PM_{10}	0.319 (0.037 to 2.779)
	Zn PM_{10}	1.073 (0.985 to 1.169)
	Cu $PM_{2.5}$	1.005 (1.001 to 1.009)
	Fe $PM_{2.5}$	0.042 (0.002 to 0.995)
Respiratory mortality	Cu PM_{10}	0.988 (0.978 to 0.998)
	Fe PM_{10}	0.649 (0.033 to 12.767)
	Zn PM_{10}	1.136 (1.010 to 1.277)
	Cu $PM_{2.5}$	1.003 (0.998 to 1.009)
	Fe $PM_{2.5}$	0.980 (0.013 to 72.673)
Lung cancer incidence	Cu PM_{10}	0.998 (0.912 to 1.091)
	Fe PM_{10}	0.973 (0.830 to 1.142)
	Zn PM_{10}	0.995 (0.910 to 1.089)
	Cu $PM_{2.5}$	1.092 (0.943 to 1.225)
	Fe $PM_{2.5}$	0.969 (0.889 to 1.057)

Lavigne, A., Freni Sterrantino, A., Liverani, S., Blangiardo, M., De Hoogh, K., Molitor, J., & Hansell, A. (2019). Associations between metal constituents of ambient particulate matter and mortality in England: An ecological study. *BMJ Open*, *9*(12).

LONG-TERM EXPOSURES HEALTH ASSOCIATIONS

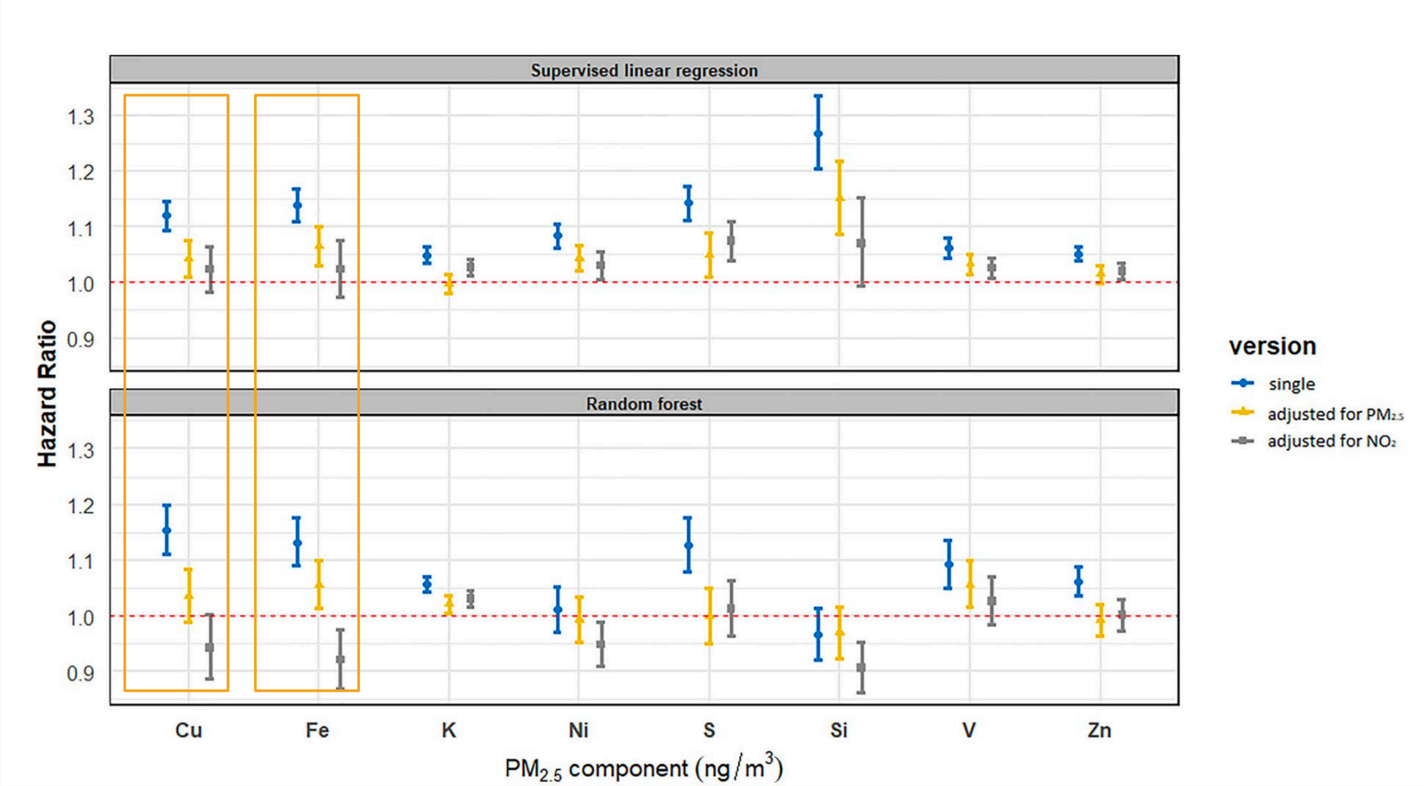
Table 3
Association between exposure to PM and metal components and cause-specific mortality: Results expressed per 5th–95th percentile range increments [HR (95% CI)].

		5^{th}–95^{th} Percentile range		Non-accidental causes (N = 142,327)		Cardiovascular disease (N = 59,434)		Ischemic heart disease (N = 22,234)	
Exposure		Components	Residuals of the components	Single constituent model[a]	PM-adjusted constituent model[b]	Single constituent model[a]	PM-adjusted constituent model[b]	Single constituent model[a]	PM-adjusted constituent model[b]
$PM_{2.5}$	μg/m^3	6.6		1.03 (1.01, 1.05)		1.05 (1.02, 1.08)		1.06 (1.01, 1.11)	
$PM_{2.5}$ abs	10^{-5}/m	1.50	1.04	1.05 (1.03, 1.06)	1.03 (1.02, 1.05)	1.06 (1.03, 1.09)	1.04 (1.01, 1.06)	1.08 (1.03, 1.12)	1.05 (1.01, 1.09)
$PM_{2.5}$Cu	ng/m^3	15.4	8.6	1.06 (1.04, 1.08)	1.04 (1.02, 1.06)	1.07 (1.04, 1.11)	1.04 (1.01, 1.07)	1.11 (1.06, 1.17)	1.08 (1.04, 1.13)
$PM_{2.5}$Fe	ng/m^3	275.5	158.7	1.05 (1.03, 1.07)	1.04 (1.02, 1.06)	1.05 (1.02, 1.08)	1.01 (0.99, 1.04)	1.07 (1.02, 1.12)	1.03 (0.99, 1.08)
$PM_{2.5}$Zn	ng/m^3	16.3	12.9	1.06 (1.04, 1.08)	1.04 (1.02, 1.06)	1.07 (1.04, 1.10)	1.04 (1.01, 1.07)	1.11 (1.06, 1.16)	1.08 (1.03, 1.13)
PM_{10}	μg/m^3	17.2		1.03 (1.01, 1.04)		1.04 (1.01, 1.07)		1.05 (1.00, 1.09)	
PM_{10}Cu	ng/m^3	97.5	49.0	1.05 (1.03, 1.07)	1.04 (1.02, 1.06)	1.07 (1.04, 1.10)	1.05 (1.02, 1.07)	1.09 (1.04, 1.14)	1.08 (1.03, 1.13)
PM_{10}Fe	ng/m^3	1,882.9	954.7	1.05 (1.03, 1.07)	1.04 (1.02, 1.06)	1.07 (1.04, 1.10)	1.06 (1.03, 1.09)	1.08 (1.04, 1.14)	1.08 (1.03, 1.13)
PM_{10}Zn	ng/m^3	42.8	22.5	1.05 (1.03, 1.06)	1.04 (1.02, 1.06)	1.05 (1.02, 1.08)	1.02 (1.00, 1.05)	1.07 (1.02, 1.12)	1.04 (1.00, 1.09)
PM_{10}Si	ng/m^3	933.8	819.3	1.04 (1.02, 1.06)	1.03 (1.01, 1.05)	1.05 (1.03, 1.08)	1.04 (1.01, 1.07)	1.10 (1.05, 1.15)	1.09 (1.04, 1.13)
PM_{10}K	ng/m^3	433.7	348.5	1.04 (1.02, 1.06)	1.02 (1.00, 1.04)	1.05 (1.02, 1.08)	1.03 (1.00, 1.05)	1.06 (1.01, 1.11)	1.03 (0.99, 1.08)
PM_{10}Ni	ng/m^3	3.9	3.9	1.07 (1.05, 1.09)	1.06 (1.04, 1.08)	1.08 (1.05, 1.11)	1.07 (1.04, 1.10)	1.13 (1.08, 1.18)	1.12 (1.07, 1.18)
PM_{10}V	ng/m^3	2.6	2.2	1.05 (1.04, 1.07)	1.04 (1.03, 1.06)	1.06 (1.03, 1.09)	1.04 (1.01, 1.07)	1.08 (1.03, 1.13)	1.06 (1.01, 1.10)

Increased risk with $PM_{2.5}$ and PM_{10} Cu, Fe, Zn over mass alone, highest for Cu and IHD

- Badaloni, C., Cesaroni, G., Cerza, F., Davoli, M., Brunekreef, B., & Forastiere, F. (2017). Effects of long-term exposure to particulate matter and metal components on mortality in the Rome longitudinal study. *Environment International*, *109*(September), 146–154.

LONG-TERM EXPOSURES AND HEALTH



- Examination of long-term non-tailpipe PM metals on mortality
- Used regression and random forest exposure estimates based on $PM_{2.5}$ measurements as part of the ESCAPE study.
- Non-tailpipe markers (Cu, Fe) significantly associated with natural mortality
- Effects attenuated when adjusted for $PM_{2.5}$ mass and NO_2

- Similar results for regression and RF exposure models for Cu and Fe
- Concern with Zn models being representative of industrial sources rather than non-tailpipe

Chen, J., et al (2021). Long-Term Exposure to Fine Particle Elemental Components and Natural and Cause-Specific Mortality—a Pooled Analysis of Eight European Cohorts within the ELAPSE Project. *Environmental Health Perspectives*, *129*(4), 1–12.

LONG-TERM EXPOSURES AND HEALTH

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Environmental Pollution

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Short-term and long-term exposures to fine particulate matter constituents and health: A systematic review and meta-analysis☆

Yang Yang [a,1], Zengliang Ruan [b,1], Xiaojie Wang [b], Yin Yang [b], Tonya G. Mason [a], Hualiang Lin [b,*], Linwei Tian [a,**]

[a] School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong SAR, China
[b] Department of Medical Statistics and Epidemiology, School of Public Health, Sun Yat-sen University, Guangzhou, China

- Long-term exposures and non-accidental mortality had significant associations were observed for Zn, Si
- Long-term exposure and cardiovascular mortality had <u>significant heterogeneity</u> in Cu, Fe and Zn

BIRTH OUTCOMES

Environmental Pollution 211 (2016) 38–47

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Environmental Pollution

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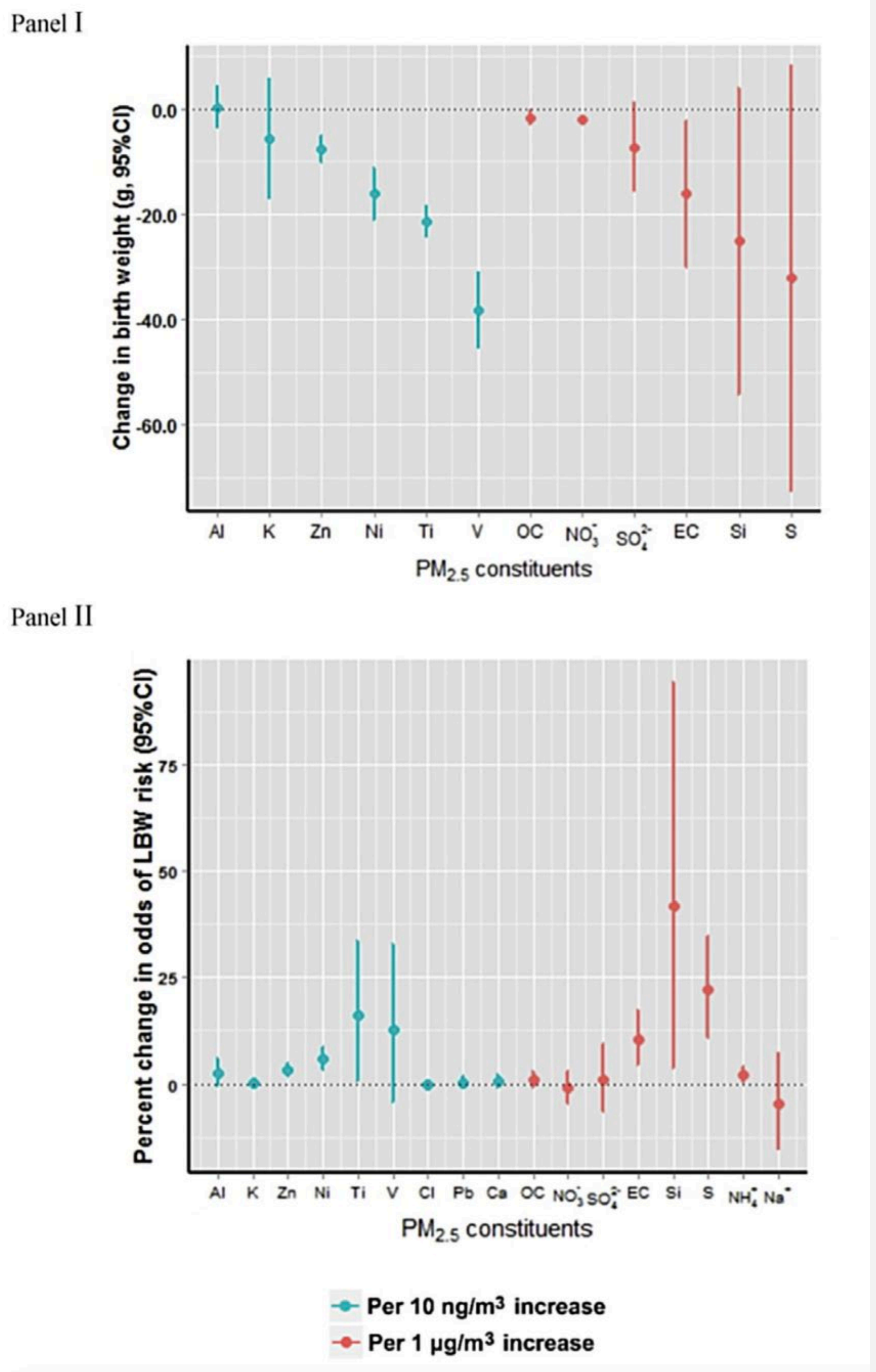
ELSEVIER

The associations between birth weight and exposure to fine particulate matter ($PM_{2.5}$) and its chemical constituents during pregnancy: A meta-analysis

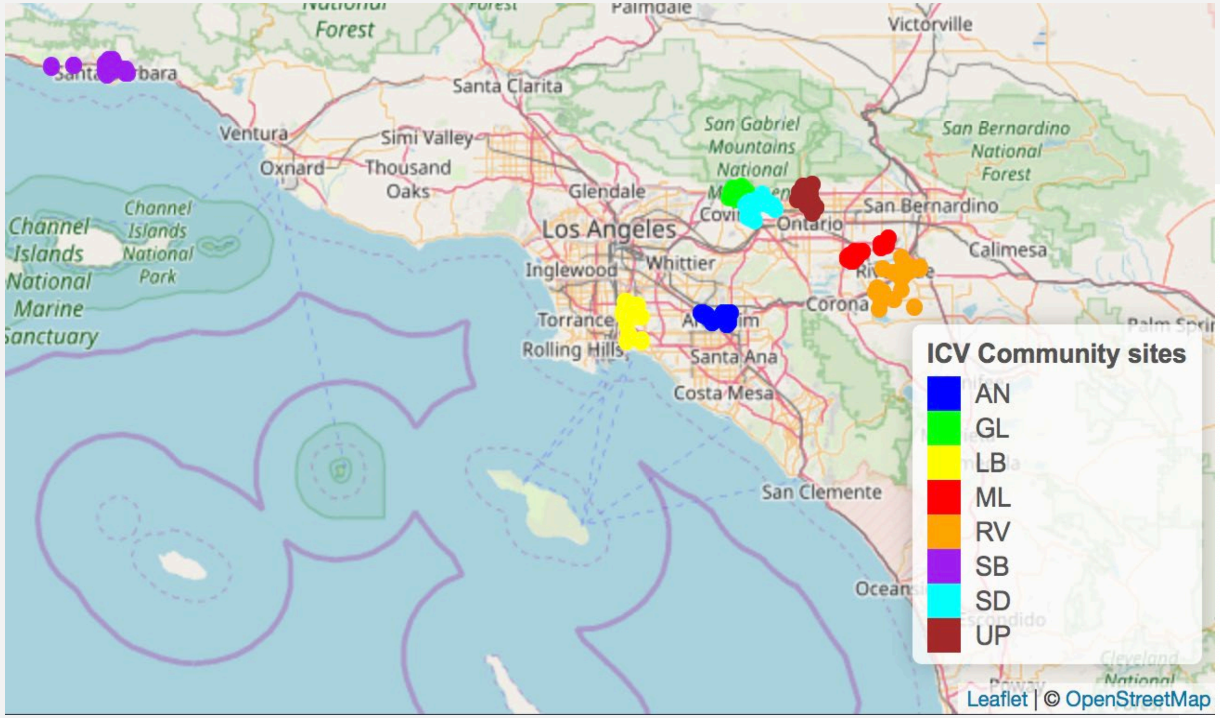
CrossMark

Xiaoli Sun [a], Xiping Luo [a, **], Chunmei Zhao [a], Bo Zhang [b], Jun Tao [c], Zuyao Yang [d], Wenjun Ma [e], Tao Liu [e, *]

- Decreased birth weight with increase in Zn
- Increased risk of low birth weight with increase in Zn



INTRA-COMMUNITY VARIABILITY STUDY AND THE CHILDREN'S HEALTH STUDY



- 20-25 samples in two seasons in each of 8 communities
- Measured $PM_{0.1}$, $PM_{0.1\text{-}2.5}$, $PM_{2.5\text{-}10}$ analyzed for components by ICPMS

Table 4. Freeway NO_x and PM metals exposures effect estimates and outcome (in mL per IQR)*.

Model *	Outcome	Effect Estimate (95% CI) **	Effect Estimate (95% CI)
$PM_{2.5}$ Cu	FVC	– 40.9 (– 90.7, 8.8)	– 35.8 (– 85.0, 13.5)
$PM_{2.5\text{-}10}$ Al	FVC	– 16.5 (– 33.6, 0.55)[a]	– 15.0 (– 32.1, 2.1)[a]
$PM_{2.5}$ Zn	FVC	– 52.6 (– 107.0, 1.82)[a]	– 47.5 (– 100.4, 5.5)[a]
$PM_{2.5\text{-}10}$ Zn	FVC	– 54.8 (– 106.0, – 3.6)[b]	– 49.2 (– 99.1, 0.6)[b]
NO_x	FVC	1.03 (– 25.5, 27.6	-
$PM_{2.5}$	FVC	– 19.6 (– 40.3, 1.1)	– 18.3 (– 39.6, 3.0)
$PM_{2.5\text{-}10}$	FVC	– 28.4 (– 65.0, 8.3)	– 25.3 (– 62.6, 12.0)
$PM_{2.5}$ Cu	FEV_1	– 23.3 (– 69.9, 23.2)	– 16.2 (– 64.6, 32.1)
$PM_{2.5\text{-}10}$ Al	FEV_1	– 5.9 (– 23.6, 11.7)	– 6.7 (– 25.4, 12.0)
$PM_{2.5}$ Zn	FEV_1	– 25.8 (–76.7, 25.1)	– 17.3 (– 69.5, 34.9)
$PM_{2.5\text{-}10}$ Zn	FEV_1	– 16.2 (– 65.3, 32.9)	– 10.1 (– 60.4, 40.3)
NO_x	FEV_1	9.86 (– 14.6, 34.3)	-
$PM_{2.5}$	FEV_1	– 4.9 (– 26.1, 16.3)	– 5.4 (– 28.2, 17.4)
$PM_{2.5\text{-}10}$	FEV_1	– 3.4 (– 39.6, 32.8)	– 2.6 (– 39.9, 34.7)

[a] $p \leq 0.1$.
[b] $p \leq 0.05$.
* All models include covariate adjustment for age at time of lung function test, sex, height, BMI, race, ethnicity, parental education, tobacco smoke, and a random intercept for community.
** Effect estimates with freeway NOx included in the model.

SUMMARY

- Limited number of studies examining non-tailpipe emissions, mostly mortality, some morbidity and birth outcomes.
- Inconsistency as to species examined (i.e. Cu, Fe not always included so these results are heterogeneous).
- Of non-tailpipe, Zn appears to be most consistently associated with detrimental health effects. From meta-analyses:
  - Acute exposures indicate associations with Zn for morbidity and mortality, some evidence of Fe associations
  - Long-term exposures indicate associations with Zn, evidence of cardiovascular mortality with Cu, Zn, Fe
  - Significant associations between Zn exposure and birth weight

MOVING FORWARD

<u>Epidemiological studies are limited by exposure assessment</u>

- Exposure assessment challenges to tackle:
  - Limited routine measurements
  - Inconsistencies in methods for modeling exposures (LUR, CTM, ML, dispersion)
  - Measurements and subsequent exposure model estimates may not capture small enough near-road spatial gradients
  - Are exposures capturing near roadway emissions or just background?
  - Correlation among components
  - Should we focus on source factors rather than tracers?
  - Separation of non-tailpipe from tailpipe

MOVING FORWARD

- Epidemiological challenges to tackle:
  - Discrepancies in the effect sizes depending on different exposure time frames
    - Generally, acute effects smaller than long-term effects
    - May be related measurement error
  - Acute studies examining specific morbidities are needed but are difficult due to lack of exposures at fine enough temporal (and spatial) resolution
    - Need for examining different exposure lags
  - Long-term (cohort) studies are needed that examine morbidities, birth outcomes
  - Need for consistency in adjusting for tailpipe ($PM_{2.5}$, EC, NO_2) in assessing health effects

Thank you!