HHS Public Access

Author manuscript

Curr Epidemiol Rep. Author manuscript; available in PMC 2019 December 01.

Published in final edited form as:

Curr Epidemiol Rep. 2018 December ; 5(4): 370–378. doi:10.1007/s40471-018-0166-8.

Air Pollution and Cardiovascular Disease: A Focus on Vulnerable Populations Worldwide

Martin Tibuakuu, MD, MPH[1,2], **Erin D. Michos, MD, MHS**[2,3], **Ana Navas-Acien, MD, PhD**[4], and **Miranda R. Jones, PhD**[3,5]

[1]St. Luke's Hospital, Department of Medicine, Chesterfield, MO, USA

[2]Ciccarone Center for the Prevention of Cardiovascular Disease, Johns Hopkins School of Medicine, Baltimore, MD, USA

[3]Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA

[4]Department of Environmental Health Sciences, Columbia University School of Public Health, New York, NY, USA

[5]Sidney Kimmel Comprehensive Cancer Center at Johns Hopkins, Baltimore, MD, USA

Abstract

Purpose of review: Certain subgroups defined by sociodemographics (race/ethnicity, age, sex and socioeconomic status [SES]), geographic location (rural vs. urban), comorbid conditions and country economic conditions (developed vs. developing) may disproportionately suffer the adverse cardiovascular effects of exposure to ambient air pollution. Yet, previous reviews have had a broad focus on the general population without consideration of these potentially vulnerable populations.

Recent findings: Over the past decade, a wealth of epidemiologic studies have linked air pollutants including particulate matter, oxides of nitrogen, and carbon monoxide to cardiovascular disease (CVD) risk factors, subclinical CVD, clinical cardiovascular outcomes and cardiovascular mortality in certain susceptible populations. Highest risk for poor CVD outcomes from air pollution exist in racial/ethnic minorities, especially in blacks compared to whites in the U.S, those at low SES, elderly populations, women, those with certain comorbid conditions and developing countries compared to developed countries. However, findings are less consistent for urban compared to rural populations.

Summary: Vulnerable subgroups including racial/ethnic minorities, women, the elderly, smokers, diabetics and those with prior heart disease had higher risk for adverse cardiovascular outcomes from exposure to air pollution. There is limited data from developing countries where concentrations of air pollutants are more extreme and cardiovascular event rates are higher than that of developed countries. Further epidemiologic studies are needed to understand and address the marked disparities in CVD risk conferred by air pollution globally, particularly among these vulnerable subgroups.

Correspondence: Martin Tibuakuu, MD, MPH, Department of Medicine, St. Luke's Hospital, 222 S Woods Mill Road, Suite 760 North, Chesterfield, MO 63017, Telephone: 443-850-1407, tibuuakuu@gmail.com.

Keywords

Air pollution; Risk factors; Atherosclerosis; CVD; Mortality; Vulnerable populations; Global Health

Introduction

Air pollution is a major public health concern globally [1, 2]. According to the World Health Organization (WHO), approximately 7 million people die each year from exposure to fine particles in polluted air [3]. In the United States (US), the Clean Air Act requires the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for 6 common air pollutants also known as the "criteria air pollutants" [4]. These pollutants include ground-level ozone (O_3), lead, carbon monoxide (CO), sulfur dioxide, nitrogen dioxide (NO_3) and particulate matter (PM). The latter mostly results from a chemical reaction between other pollutants in the atmosphere. PM varies in size and is usually divided into those with diameters of 2.5 micrometers and smaller ($PM_{2.5}$, "fine PM") and those with diameters between 2.5 and 10 micrometers (PM_{10}, "coarse PM"). Black Carbon (BC) is a major component of PM emitted from gas and diesel engines, coal-fired power plants, and other sources that burn fossil fuel. BC, NO_2 and oxides of nitrogen (NO_x) are all measures of traffic-related air pollution. It is estimated that about 90% of the world's population is exposed to levels of air pollution above the WHO Air Quality Guidelines (AQG) for a range of air pollutants [3].

While the role of air pollution on acute and chronic respiratory diseases has been long recognized [5], the understanding of the major impact of air pollution on cardiovascular disease (CVD) has increased in recent years. Indeed, it is estimated that more than 50% of the health burden of air pollution is through CVD [6]. Epidemiologic studies have linked short- and long-term air pollution exposure to increased risk for subclinical CVD [7–14], major cardiovascular events [15–27], and cardiovascular mortality [28–45, 27, 46, 47]. The proposed mechanisms include through the promotion of CVD risk factors [48–67], as well as through increased systemic inflammation and coagulation [9••]. For example, Bell et al. recently reported a 1.68 mg/dL lower high-density lipoprotein (HDL)-cholesterol level for each 0.7×10^{-6} m^{-1} higher 3-month cumulative exposures to BC and a 0.64 μmol/L lower HDL particle number for each 5μg/m^3 higher 3-month cumulative exposures to $PM_{2.5}$ among a multi-ethnic cohort from six major US cities [59•].

Subclinical markers of CVD can provide early insight into disease processes and the identification of individuals at heightened risk for later clinical CVD events. Coronary artery calcium (CAC) is a well-established surrogate marker of total atherosclerotic burden, and CAC (and its progression) is a potent prognostic indicator of future CVD risk [68]. Other established markers of subclinical CVD include carotid intima-media thickness (IMT) and calcification of the left sided heart valves [aortic valve calcium (AVC) and mitral annular calcification (MAC)] [12•]. Perhaps the most impactful recent evidence linking air pollution to subclinical CVD, as well as systemic inflammation, among individuals without known clinical CVD emanated from the Multi-Ethnic Study of Atherosclerosis and Air Pollution

(MESA Air) cohort, a large, multiethnic, prospective, cohort study from six metropolitan cities in the US [12•, 10••, 9••, 69–75, 8, 76–79]. In MESA Air, Kaufman et al. reported a 4.1 Agatston units per year increase in CAC score for each 5 $\mu g/m^3$ increase in long-term (10-year) exposure to $PM_{2.5,}$ independent of established CVD risk factors [10••]. In a related MESA Air analysis from our group, this association with CAC remains significant even after considering a shorter follow-up period of 2.5 years [12•]. In this analysis, which also included AVC and MAC, we found evidence of increased 2.5-year progression of MAC with exposure to ambient $PM_{2.5}$ [12•]. Given that the same biological mechanisms may underlie MAC and CAC [80], the association of air pollution with CAC is most likely specific rather than with vascular calcification in general. Similarly, higher exposure to $PM_{2.5}$ has been shown to increase the progression of carotid IMT as well in the MESA Air study [69, 77••].

Many subgroups defined by sociodemographics (race/ethnicity, age, sex and SES) [81, 82, 51, 49, 83], geographic location (rural vs. urban populations) [81, 28, 84] and country economic conditions (developed vs. developing countries) [85] show striking disparities in adverse cardiovascular outcomes resulting from exposure to air pollution. Yet, all the reviews thus far have discussed this topic very broadly in the general population. The objective of this review is to provide healthcare professionals and researchers with a comprehensive summary of research within the past 5–10 years on air pollution and CVD, with a specific focus on these vulnerable populations.

Sociodemographics (age, sex, racial/ethnic minorities and low SES populations)

Race/ethnicity

In the US, exposure to air pollution is strikingly different by race/ethnicity due to racial segregation in housing [86, 87]. Racial/ethnic minorities are more likely to be of low SES and live in dense urban centers [86, 87]. Consequently, racial/ethnic minority groups, especially African Americans, have consistently shown an increased risk for CVD due to air pollution [81, 82, 51, 49, 83]. For example, Coogan et al. found that higher O_3 level was associated with a 9% increased incidence of hypertension [HR=1.09 (95% CI = 1.00, 1.18)] in a large cohort of black women after a median follow-up of 11 years (total of 348,154 person-years) [49]. In another analysis in this cohort, NO_x but not $PM_{2.5}$ was associated with increased risk of incident diabetes mellitus in black women living in Los Angeles. In a study using data from MESA Air, differences in annual $PM_{2.5}$ concentrations did not contribute to differences in carotid IMT among blacks or Hispanic participants compared to white participants in the only study that specifically examined differential impact of air pollution exposure according to racial/ethnicity in atherosclerosis [77••]. On the contrary, smaller carotid IMT measurements were noted in Chinese-Americans compared to whites after controlling for $PM_{2.5}$ concentrations which were higher among Chinese-Americans [77••].

Furthermore, evidence exists for the association of air pollution with cardiac structure and function, including among racial/ethnic minority groups in the US [70, 88, 79]. Van Hee et al. revealed that living within 50 meters of a major roadway is significantly associated with higher left ventricular (LV) mass index but not with ejection fraction (EF) in the MESA Air

cohort [70]. Susceptibility for subclinical systolic dysfunction among African Americans was confirmed in the Jackson Heart Study where living near roads was associated with LV end-systolic diameter [89]. Racial/ethnic minority groups, especially blacks, had a higher risk for adverse clinical cardiovascular outcomes due to air pollution compared to non-Hispanic whites in California [90]. Hackbarth et al. reported an excess attributable risk in cardiovascular admission rates due to exposure to O_3 and $PM_{2.5}$ among black residents compared to white residents in California [90]. Recently, Erqou et al. also reported a 45% increase in the risk of cardiovascular events among blacks compared to whites in Western Pennsylvania (greater Pittsburgh) partly because of higher chronic exposure to $PM_{2.5}$ among blacks [91••]. Interestingly, this association was no longer statistically significant after further adjustments for measures of SES, including income and education. The findings from Erqou et al. are consistent with some suggestions that air pollution may not be causal but may only be closely correlated with different markers of low SES which cause CVD [92, 93, 86]. Specifically, for subgroups defined by low SES and minority race/ethnicity, adverse dietary and lifestyle factors may be contributing to CVD risk, in addition to higher air pollution levels. Epidemiologic studies with designs targeted at accounting for all of these confounders are needed in this domain to explore whether differences in air pollution could explain disparities in CVD endpoints among subgroups defined by race/ethnicity or SES.

Age

Elderly populations are among the most vulnerable to the risk of adverse cardiovascular outcomes from air pollution [94, 95]. For subclinical CVD, Kaufman et al. found that the association of long-term exposure to $PM_{2.5}$ with increased annual CAC progression was somewhat stronger among individuals older than 65 years of age compared to younger individuals [10••]. In the ESCAPE Project, which was a meta-analysis of 11 European cohorts with a total of 100,166 participants, each 5μg/m^3 increase in long-term exposure to $PM_{2.5}$ was associated with a 13% increase in nonfatal acute coronary events [20••]. Participants 60 years of age or older were found to have the highest risk associated with $PM_{2.5}$ exposure compared to their younger counterparts [20••].

Some evidence has also linked acute exposure to CO, SO_2, NO_2, and $PM_{2.5}$ to increased heart failure exacerbations among the elderly [17]. In all, it was estimated that a 3.9μg/m^3 reduction in $PM_{2.5}$ would prevent almost 7,978 heart failure hospitalizations each year in the US alone [17]. Even at the relatively lower concentrations of air pollution in Europe, each 5μg/m^3 increase in long-term exposure to $PM_{2.5}$ was associated with a 40% (HR = 1.40, 95% CI: 1.05, 1.87) increase in the risk of stroke among adults 60 years of age and older in the ESCAPE project [21]. Results were no longer significant when the entire ESCAPE cohort, including younger adults, were analyzed. Finally, in a large cohort of 18.9 million Medicare beneficiaries from across the US, Pun et al. observed an increased risk for cardiovascular mortality with exposures to long-term $PM_{2.5}$ [95].

Sex

Evidence suggests that women may be more vulnerable than men to develop cardiovascular events upon air pollution exposure [10••, 96–99]. In MESA Air, Kaufman et al. found that women may have an increased CAC progression due to long-term exposure to $PM_{2.5}$

compared to men [10••]. Additionally, stronger associations between long-term exposure to PM with incident ischemic heart disease, stroke, heart failure and atrial fibrillation were noted among women compared to men even at relatively low levels of exposures in Gothenburg, Sweden [98]. Similarly, women were reported to have increased CVD mortality compared to men due to short-term exposure to PM_{10} and SO_2 in Hefei, China [97].

Urban vs. rural

Globally, air pollutant levels are disproportionately higher in urban centers compared to rural settings [100, 41, 40, 101–103, 86, 32, 104]. Acute exposure to both $PM_{2.5}$ and PM_{10} led to acute rises in arterial blood pressure (BP) in urban centers in the US mostly inhabited by minority groups, namely African Americans [57, 52]. In a first-ever randomized double-blind crossover study in Michigan involving 2-hour exposures to concentrated ambient PM_{10} vs. filtered air, Dvonch et al. found that both systolic (1.9 mm Hg; 95% CI: 0.96, 2.8) and diastolic (1.9 mm Hg; 95% CI: 1.1, 2.7) BP remained elevated during exposure to PM_{10} compared to filtered air [52]. In a similar trial conducted among young adults in Shanghai, higher short-term exposure to $PM_{2.5}$ caused a surge in blood levels of stress hormones including cortisol, cortisone, epinephrine, and norepinephrine [105••]. Both acute and chronic stressors are well known risk factors for CVD including myocardial infraction and sudden cardiac death.

In Europe, long-term exposure to PM_{10} was associated with atherosclerosis as measured by carotid IMT in urban centers as evidenced by an analysis of 2,348 adults who lived in Greater London [106]. For cardiovascular mortality, Crouse et al. found that long-term exposure to outdoor NO_2 was positively associated with a 4% increased mortality from all CVD (HR per 5 p.p.b.: 1.04; 95% CI: 1.01–1.06) and 5% increased mortality from ischemic heart disease (HR per 5 p.p.b.: 1.05; 95% CI: 1.02–1.08) in a cohort from 10 of the largest cities in Canada (~735,590 participants, 16 years of follow-up) [32]. Notably, it was found that these associations were determined largely by within-city contrasts in exposure, as opposed to between-city contrasts [32].

Nevertheless, rural exposure to air pollution has also been linked to increased risk for CVD in certain high-risk groups [107, 108]. In the agricultural health study cohort (which included 83,378 farmers, their spouses, and commercial pesticide applicators residing primarily in Iowa and North Carolina), long-term exposure to $PM_{2.5}$ was associated with increased cardiovascular mortality among men but not women [107]. At the other end of the spectrum, a significant association was observed between BC and higher systolic BP among women from rural China where biomass fuels are commonly used; the association was even stronger among women who lived near a highway [108]. Overall, few studies have assessed the contributions of air pollution to CVD in rural populations. More research is needed in this area, in particular because of the distinct features of air pollution in rural settings as characterized by the presence of coal fire, power plants, incineration of residual waste and other environmental challenges.

Comorbidities

Certain comorbid conditions have been noted to predispose individuals to the adverse cardiovascular effects of air pollution [30, 109–116]. For example, children with mood disorders or poor mental health were found to be more vulnerable to rises in BP resulting from exposures to air pollution [109]. Kalsch et al. reported an association of long-term exposure to $PM_{2.5}$ with subclinical atherosclerosis as measured by thoracic aortic calcium in a German cohort [110]. In this study, participants with prevalent CHD and those taking statins seemed most vulnerable to the effects of PM [110]. Additionally, exposure to $PM_{2.5}$ was associated with elevated lipoprotein associated phospholipase A_2 among participants who had a previous acute myocardial infarction in Augsburg, Germany [111]. Importantly, Kaufman et al. also reported that the association of long-term exposure to $PM_{2.5}$ with CAC progression might be greater in hypertensive individuals in MESA Air [10••].

Populations with underlying coronary heart disease had a much higher burden of acute coronary syndromes due to short-term exposure to $PM_{2.5}$ as demonstrated in an analysis of 5,679 residents of North Carolina who underwent a clinically indicated cardiac catheterization at Duke University between 2002 and 2009 [23]. In this cohort with high prevalence of coronary heart disease, each 1 $\mu g/m^3$ increase in $PM_{2.5}$ within the year prior to cardiac catheterization was associated with a 14.2% (95% CI: 3.7–25.8%) increase in the odds of having a myocardial infarction. Conceivably, acute exposure to $PM_{2.5}$ may precipitate the rupture of vulnerable atherosclerotic plaques.

Also, individuals with diabetes were reported to have the highest risk of adverse cardiovascular events from air pollution [114, 116]. In a recent analysis of patients who had undergone primary percutaneous intervention for myocardial infarction in Tehran, Iran, patients with diabetes were found to have a higher risk of myocardial infarction due to acute exposure to both $PM_{2.5}$ and PM_{10} compared to non-diabetics [116]. Similarly, Villeneuve et al. found that people with prior history of stroke (OR = 2.31; 95% CI: 1.39, 3.83), heart disease (OR = 1.99; 95% CI: 1.20, 3.28) and those on medications for diabetes (OR = 2.03; 95% CI: 1.14, 3.59) were the most susceptible to ischemic stroke from exposure to air pollution [112].

Smoking is one of the leading causes of CVD. Smokers consistently had the greatest risk for metabolic syndrome and cardiovascular mortality due to air pollution [63, 113]. It is important to note that each $10\mu g/m^3$ increment in $PM_{2.5}$ is equivalent to passively smoking 5.5 cigarettes per day [117]. Other vulnerable groups at higher risk of cardiovascular mortality risk attributed to air pollution are survivors of myocardial infarction [30]. The relation of air pollution with other strong CVD risk factors such as chronic kidney disease [118] and chronic inflammatory conditions such as lupus and rheumatoid arthritis have yet to be explored in detail.

Currently, clinical guidelines do not provide physicians with any guidance on how to manage potential air pollution exposure among patients with previous CVD. For instance, physicians do not routinely ask about living close to a road or highway. Furthermore, there exist no recommendations on what patients should do to protect themselves from air

pollution exposure, especially if they need to go back to a home environment characterized by high air pollution exposure. Developing clinical guidelines to help physicians with the management of patients who might be exposed to moderate-to-high air pollution may reduce the global burden of pollution-attributable CVD [2, 119].

Developed vs. developing countries

In a recent meta-analysis of 23 studies, short-term exposure to all major air pollutants, except for O_3, were associated with cardiac arrhythmia [19]. Short-term exposure to $PM_{2.5}$ led to a 1.5% increase in cardiac arrhythmia (per 10μg/m^3) [19]. The highest risk was noted in Asia where air pollution concentrations are exceedingly high in countries like China and India compared to other countries [19]. Additionally, urban cities in Asia like New Delhi, Hong Kong and Beijing have cardiovascular mortality rates nearly twice as high as urban cities in Europe and North America [17, 120]. These Asian megacities have air pollution levels up 10 times the US NAAQS [38, 37]. In a nationwide time-series analysis in 272 major Chinese cities, both short-term exposure to SO_2 (per 10μg/m^3 increments) and CO (per 1 μg/m^3 increments) were associated with a 0.70% increase and a 1.12% increase in overall CVD mortality, respectively [41, 42]. In a meta-analysis of 59 studies from China where mean $PM_{2.5}$ exposures were between 39 to 177 μg/m^3, each 10μg/m^3 increment was associated with a 0.63% increase in overall CVD mortality [37]. Additionally, Zhang et al. reported a 23% increase in CVD mortality [HR = 1.23 (95% CI, 1.19, 1.26)] per 10μg/m^3 increase in PM_{10} exposure in an analysis of 39,054 participants from four cities in northern China where the mean PM_{10} levels for the entire 12-year period was 144 $\mu g_{2.5}/m^3$ [38].

Conversely, in two Canadian populations with average $PM_{2.5}$ exposure levels as low as 8.7μg/m^3 and 6.3μg/m^3, each 10μg/m^3 increment was associated with a 31% increase in CHD mortality [44] and a 19% increase in cardiovascular mortality [31]. Similarly, in a multi-state analysis of 517,041 US adults with an average $PM_{2.5}$ concentration of 12 μg/m^3, each 10μg/m^3 increment was associated with a 10% increase in CVD mortality (HR = 1.10; 95% CI: 1.05, 1.15) [47]. Taken together, the results from North America suggest that there may be no “safe levels” for the effect of $PM_{2.5}$ on CVD mortality since exposures in the Canadian studies were on average below the WHO AQG of <10μg/m^3 [3]. Comparably, data are lacking on vulnerable subgroups from developing countries where concentrations of air pollutants are extreme and cardiovascular event rates are high. Research is needed to address this important gap.

Conclusion

In summary, recent epidemiologic studies have consistently shown a higher adverse CVD outcomes resulting from exposures to short- and long-term ambient air pollution among certain vulnerable subgroups including racial/ethnic minorities, the elderly, low SES individuals, smokers, diabetics and those with a history of heart disease. Some data also suggest poor air pollution-related CVD outcomes among women compared to men. Urban cities in Asia like New Delhi, Hong Kong and Beijing, with higher air pollution levels, had cardiovascular mortality rates nearly twice as high as urban cities in Europe and North America. Despite all that we have learned so far from the extensive evidence linking air

pollution to CVD, gaps in our understanding remain. To date research has mainly considered air pollutants individually, however we know that exposures to multiple pollutants occur simultaneously. Thus, integrating different types of air pollutants into a single weighted exposure may better characterize the cumulative effect of air pollution on cardiovascular outcomes. Of major concern is the paucity of data from developing countries where concentrations of air pollutants are even more extreme and cardiovascular event rates are higher than developed countries. Also, far fewer studies have assessed the contributions of air pollution to CVD in rural populations compared to urban centers. Features of air pollution in rural settings are very distinct and warrant more epidemiologic studies. Finally, given the strength of evidence implicating air pollution in CVD, especially among these vulnerable subgroups, clinical guidelines regarding the management of patients with CVD who might be exposed to moderate-to-high air pollution may help reduce the global burden of pollution-attributable CVD morbidity and mortality.

References

Papers of particular interest, published recently have been highlighted as:

• Of importance

•• Of major imprtance

1. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1659–724. [PubMed: 27733284]
2. Landrigan PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu NN et al. The Lancet Commission on pollution and health. Lancet. 2018;391(10119):462–512. [PubMed: 29056410]
3. World Health Organization. Health Topics: Air pollution. http://www.who.int/airpollution/guidelines/en/. Accessed 06/28 2018.
4. Huang YT, Brook RD. The Clean Air Act: science, policy, and politics. Chest. 2011;140(1):1–2. [PubMed: 21729884]
5. Chen H, Goldberg MS, Villeneuve PJ. A systematic review of the relation between long-term exposure to ambient air pollution and chronic diseases. Rev Environ Health. 2008;23(4):243–97. [PubMed: 19235364]
6. Brook RD, Newby DE, Rajagopalan S. Air Pollution and Cardiometabolic Disease: An Update and Call for Clinical Trials. Am J Hypertens. 2017;31(1):1–10. [PubMed: 28655143]
7. Newman JD, Thurston GD, Cromar K, Guo Y, Rockman CB, Fisher EA et al. Particulate air pollution and carotid artery stenosis. J Am Coll Cardiol. 2015;65(11):1150–1 [PubMed: 25748098]
8. Leary PJ, Kaufman JD, Barr RG, Bluemke DA, Curl CL, Hough CL et al. Traffic-related air pollution and the right ventricle. The multi-ethnic study of atherosclerosis. Am J Respir Crit Care Med. 2014;189(9):1093–100. [PubMed: 24593877]
9••. Hajat A, Allison M, Diez-Roux AV, Jenny NS, Jorgensen NW, Szpiro AA et al. Long-term exposure to air pollution and markers of inflammation, coagulation, and endothelial activation: a repeat-measures analysis in the Multi-Ethnic Study of Atherosclerosis (MESA). Epidemiology. 2015;26(3):310–20. [PubMed: 25710246] A large, multi-ethnic and prospective study of long-term exposure to air pollution and markers of inflammation, coagulation and endothelial activation. Each 5μg/m^3 increase in long-term $PM_{2.5}$ was associated with a 6% increase in IL-6. Each 40 ppb increase in long-term NO_x was associated with 7% increase in D-dimer.
10••. Kaufman JD, Adar SD, Barr RG, Budoff M, Burke GL, Curl CL et al. Association between air pollution and coronary artery calcification within six metropolitan areas in the USA (the Multi-Ethnic Study of Atherosclerosis and Air Pollution): a longitudinal cohort study. Lancet. 2016;388(10045):696–704. [PubMed: 27233746] The largest and longest study linking long-term

air pollution and traffic exposure to atherosclerosis. In this study, each 5μg/m^3 increase in long-term $PM_{2.5}$ was associated with a 4.1 Agatston units/year increase in CAC.

11. Brook RD, Rajagopalan S, Pope CA, 3rd, Brook JR, Bhatnagar A, Diez-Roux AV et al. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation. 2010;121(21):2331–78. [PubMed: 20458016]

12•. Tibuakuu M, Jones MR, Navas-Acien A, Zhao D, Guallar E, Gassett AJ et al. Exposure to ambient air pollution and calcification of the mitral annulus and aortic valve: the multi-ethnic study of atherosclerosis (MESA). Environ Health. 2017;16(1):133. [PubMed: 29268751] First longitudinal study to examine ambient air pollution with valvular calcification (AVC and MAC). There was evidence of increased 2.5-year progression of MAC with exposure to ambient $PM_{2.5}$.

13. Mehta AJ, Zanobetti A, Koutrakis P, Mittleman MA, Sparrow D, Vokonas P et al. Associations between short-term changes in air pollution and correlates of arterial stiffness: The Veterans Affairs Normative Aging Study, 2007–2011. Am J Epidemiol. 2014;179(2):192–9. [PubMed: 24227017]

14. Li W, Dorans KS, Wilker EH, Rice MB, Ljungman PL, Schwartz JD et al. Short-Term Exposure to Ambient Air Pollution and Biomarkers of Systemic Inflammation: The Framingham Heart Study. Arterioscler Thromb Vasc Biol. 2017;37(9):1793–800. [PubMed: 28751572]

15. Newby DE, Mannucci PM, Tell GS, Baccarelli AA, Brook RD, Donaldson K et al. Expert position paper on air pollution and cardiovascular disease. Eur Heart J. 2015;36(2):83–93b. [PubMed: 25492627]

16. Mustafic H, Jabre P, Caussin C, Murad MH, Escolano S, Tafflet M et al. Main air pollutants and myocardial infarction: a systematic review and meta-analysis. JAMA. 2012;307(7):713–21. [PubMed: 22337682]

17. Shah AS, Langrish JP, Nair H, McAllister DA, Hunter AL, Donaldson K et al. Global association of air pollution and heart failure: a systematic review and meta-analysis. Lancet. 2013;382(9897): 1039–48. [PubMed: 23849322]

18. Shah AS, Lee KK, McAllister DA, Hunter A, Nair H, Whiteley W et al. Short term exposure to air pollution and stroke: systematic review and meta-analysis. BMJ. 2015;350:h1295. [PubMed: 25810496]

19. Song X, Liu Y, Hu Y, Zhao X, Tian J, Ding G et al. Short-Term Exposure to Air Pollution and Cardiac Arrhythmia: A Meta-Analysis and Systematic Review. Int J Environ Res Public Health. 2016;13(7).

20••. Cesaroni G, Forastiere F, Stafoggia M, Andersen ZJ, Badaloni C, Beelen R et al. Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE Project. BMJ. 2014;348:f7412. [PubMed: 24452269] This analysis was derived from a pooling of 11 cohorts (n=100,166) from Europe. Each 5μg/m^3 increase in long-term $PM_{2.5}$ was associated with a 13% increase in nonfatal acute coronary events.

21. Stafoggia M, Cesaroni G, Peters A, Andersen ZJ, Badaloni C, Beelen R et al. Long-term exposure to ambient air pollution and incidence of cerebrovascular events: results from 11 European cohorts within the ESCAPE project. Environ Health Perspect. 2014;122(9):919–25. [PubMed: 24835336]

22. Wolf K, Stafoggia M, Cesaroni G, Andersen ZJ, Beelen R, Galassi C et al. Long-term Exposure to Particulate Matter Constituents and the Incidence of Coronary Events in 11 European Cohorts. Epidemiology. 2015;26(4):565–74. [PubMed: 25978793]

23. McGuinn LA, Ward-Caviness CK, Neas LM, Schneider A, Diaz-Sanchez D, Cascio WE et al. Association between satellite-based estimates of long-term PM2.5 exposure and coronary artery disease. Environmental research. 2016;145:9–17. [PubMed: 26613345]

24. Weichenthal S, Lavigne E, Evans G, Pollitt K, Burnett RT. Ambient PM2.5 and risk of emergency room visits for myocardial infarction: impact of regional PM2.5 oxidative potential: a case-crossover study. Environ Health. 2016;15:46. [PubMed: 27012244]

25. Wang X, Kindzierski W, Kaul P. Comparison of transient associations of air pollution and AMI hospitalisation in two cities of Alberta, Canada, using a case-crossover design. BMJ Open. 2015;5(11):e009169.

26. Wellenius GA, Burger MR, Coull BA, Schwartz J, Suh HH, Koutrakis P et al. Ambient air pollution and the risk of acute ischemic stroke. Arch Intern Med. 2012;172(3):229–34. [PubMed: 22332153]
27. Milojevic A, Wilkinson P, Armstrong B, Bhaskaran K, Smeeth L, Hajat S. Short-term effects of air pollution on a range of cardiovascular events in England and Wales: case-crossover analysis of the MINAP database, hospital admissions and mortality. Heart. 2014 7;100(14):1093–8. [PubMed: 24952943]
28. Tonne C, Halonen JI, Beevers SD, Dajnak D, Gulliver J, Kelly FJ et al. Long-term traffic air and noise pollution in relation to mortality and hospital readmission among myocardial infarction survivors. Int J Hyg Environ Health. 2016;219(1):72–8. [PubMed: 26454658]
29. Tonne C, Wilkinson P. Long-term exposure to air pollution is associated with survival following acute coronary syndrome. Eur Heart J. 2013;34(17):1306–11. [PubMed: 23423735]
30. Chen H, Burnett RT, Copes R, Kwong JC, Villeneuve PJ, Goldberg MS et al. Ambient Fine Particulate Matter and Mortality among Survivors of Myocardial Infarction: Population-Based Cohort Study. Environ Health Perspect. 2016;124(9):1421–8. [PubMed: 27152932]
31. Pinault L, Tjepkema M, Crouse DL, Weichenthal S, van Donkelaar A, Martin RV et al. Risk estimates of mortality attributed to low concentrations of ambient fine particulate matter in the Canadian community health survey cohort. Environ Health. 2016;15:18. [PubMed: 26864652]
32. Crouse DL, Peters PA, Villeneuve PJ, Proux MO, Shin HH, Goldberg MS et al. Within- and between-city contrasts in nitrogen dioxide and mortality in 10 Canadian cities; a subset of the Canadian Census Health and Environment Cohort (CanCHEC). J Expo Sci Environ Epidemiol. 2015;25(5):482–9. [PubMed: 25605445]
33. Weichenthal S, Pinault LL, Burnett RT. Impact of Oxidant Gases on the Relationship between Outdoor Fine Particulate Air Pollution and Nonaccidental, Cardiovascular, and Respiratory Mortality. Sci Rep. 2017;7(1):16401. [PubMed: 29180643]
34. Thurston GD, Burnett RT, Turner MC, Shi Y, Krewski D, Lall R et al. Ischemic Heart Disease Mortality and Long-Term Exposure to Source-Related Components of U.S. Fine Particle Air Pollution. Environ Health Perspect. 2016;124(6):785–94. [PubMed: 26629599]
35. Xie W, Li G, Zhao D, Xie X, Wei Z, Wang W et al. Relationship between fine particulate air pollution and ischaemic heart disease morbidity and mortality. Heart. 2015;101(4):257–63. [PubMed: 25341536]
36. Lu F, Zhou L, Chen X, Li C, Wang H, Xu Y et al. [Association between ambient inhalable particle pollution and mortality due to circulatory disease in Nanjing: a case-crossover study]. Zhonghua Yu Fang Yi Xue Za Zhi. 2015;49(9):817–21. [PubMed: 26733140]
37. Lu F, Xu D, Cheng Y, Dong S, Guo C, Jiang X et al. Systematic review and meta-analysis of the adverse health effects of ambient PM2.5 and PM10 pollution in the Chinese population. Environ Res. 2015;136:196–204. [PubMed: 25460637]
38. Zhang LW, Chen X, Xue XD, Sun M, Han B, Li CP et al. Long-term exposure to high particulate matter pollution and cardiovascular mortality: a 12-year cohort study in four cities in northern China. Environ Int. 2014;62:41–7. [PubMed: 24161381]
39. Beelen R, Stafoggia M, Raaschou-Nielsen O, Andersen ZJ, Xun WW, Katsouyanni K et al. Long-term exposure to air pollution and cardiovascular mortality: an analysis of 22 European cohorts. Epidemiology. 2014;25(3):368–78. [PubMed: 24589872]
40. Chen K, Wolf K, Breitner S, Gasparrini A, Stafoggia M, Samoli E et al. Two-way effect modifications of air pollution and air temperature on total natural and cardiovascular mortality in eight European urban areas. Environ Int. 2018;116:186–196. [PubMed: 29689465]
41. Liu C, Yin P, Chen R, Meng X, Wang L, Niu Y et al. Ambient carbon monoxide and cardiovascular mortality: a nationwide time-series analysis in 272 cities in China. Lancet Planet Health. 2018 1;2(1):e12–e18. [PubMed: 29615203]
42. Wang L, Liu C, Meng X, Niu Y, Lin Z, Liu Y et al. Associations between short-term exposure to ambient sulfur dioxide and increased cause-specific mortality in 272 Chinese cities. Environ Int. 2018;117:33–39. [PubMed: 29715611]

43. Newell K, Kartsonaki C, Lam KBH, Kurmi O. Cardiorespiratory health effects of gaseous ambient air pollution exposure in low and middle income countries: a systematic review and meta-analysis. Environ Health. 2018;17(1):41. [PubMed: 29669550]
44. Crouse DL, Peters PA, van Donkelaar A, Goldberg MS, Villeneuve PJ, Brion O et al. Risk of nonaccidental and cardiovascular mortality in relation to long-term exposure to low concentrations of fine particulate matter: a Canadian national-level cohort study. Environ Health Perspect. 2012;120(5):708–14. [PubMed: 22313724]
45. Luo K, Li W, Zhang R, Li R, Xu Q, Cao Y. Ambient Fine Particulate Matter Exposure and Risk of Cardiovascular Mortality: Adjustment of the Meteorological Factors. Int J Environ Res Public Health. 2016;13(11).
46. Huang C, Moran AE, Coxson PG, Yang X, Liu F, Cao J et al. Potential Cardiovascular and Total Mortality Benefits of Air Pollution Control in Urban China. Circulation. 2017;136(17):1575–84. [PubMed: 28882886]
47. Thurston GD, Ahn J, Cromar KR, Shao Y, Reynolds HR, Jerrett M et al. Ambient Particulate Matter Air Pollution Exposure and Mortality in the NIH-AARP Diet and Health Cohort. Environ Health Perspect. 2016;124(4):484–90. [PubMed: 26370657]
48. Zhao X, Sun Z, Ruan Y, Yan J, Mukherjee B, Yang F et al. Personal black carbon exposure influences ambulatory blood pressure: air pollution and cardiometabolic disease (AIRCMD-China) study. Hypertension. 2014;63(4):871–7. [PubMed: 24420543]
49. Coogan PF, White LF, Yu J, Brook RD, Burnett RT, Marshall JD et al. Long-Term Exposure to NO2 and Ozone and Hypertension Incidence in the Black Women's Health Study. Am J Hypertens. 2017;30(4):367–72. [PubMed: 28096146]
50. Giorgini P, Di Giosia P, Grassi D, Rubenfire M, Brook RD, Ferri C. Air Pollution Exposure and Blood Pressure: An Updated Review of the Literature. Curr Pharm Des. 2016;22(1):28–51. [PubMed: 26548310]
51. Coogan PF, White LF, Yu J, Burnett RT, Seto E, Brook RD et al. PM2.5 and Diabetes and Hypertension Incidence in the Black Women's Health Study. Epidemiology. 2016;27(2):202–10. [PubMed: 26595125]
52. Byrd JB, Morishita M, Bard RL, Das R, Wang L, Sun Z et al. Acute increase in blood pressure during inhalation of coarse particulate matter air pollution from an urban location. J Am Soc Hypertens. 2016;10(2):133–139.e4. [PubMed: 26750378]
53. Brook RD, Sun Z, Brook JR, Zhao X, Ruan Y, Yan J et al. Extreme Air Pollution Conditions Adversely Affect Blood Pressure and Insulin Resistance: The Air Pollution and Cardiometabolic Disease Study. Hypertension. 2016;67(1):77–85. [PubMed: 26573709]
54. Rao X, Montresor-Lopez J, Puett R, Rajagopalan S, Brook RD. Ambient air pollution: an emerging risk factor for diabetes mellitus. Curr Diab Rep. 2015;15(6):603. [PubMed: 25894943]
55. Giorgini P, Rubenfire M, Das R, Gracik T, Wang L, Morishita M et al. Higher fine particulate matter and temperature levels impair exercise capacity in cardiac patients. Heart. 2015;101(16): 1293–301. [PubMed: 26056226]
56. Coogan PF, White LF, Jerrett M, Brook RD, Su JG, Seto E et al. Air pollution and incidence of hypertension and diabetes mellitus in black women living in Los Angeles. Circulation. 2012;125(6):767–72. [PubMed: 22219348]
57. Dvonch JT, Kannan S, Schulz AJ, Keeler GJ, Mentz G, House J et al. Acute effects of ambient particulate matter on blood pressure: differential effects across urban communities. Hypertension. 2009;53(5):853–9. [PubMed: 19273743]
58. Brook RD, Rajagopalan S. Particulate matter, air pollution, and blood pressure. J Am Soc Hypertens. 2009 Sep-Oct;3(5):332–50. [PubMed: 20409976]
59•. Bell G, Mora S, Greenland P, Tsai M, Gill E, Kaufman JD. Association of Air Pollution Exposures With High-Density Lipoprotein Cholesterol and Particle Number: The Multi-Ethnic Study of Atherosclerosis. Arterioscler Thromb Vasc Biol. 2017;37(5):976–82. [PubMed: 28408373] Large, multi-ethnic study examining the cross-sectional relashionship between air pollution and both HDL cholesterol and HDL particle number. A 0.7×10^{-6} m^{-1} higher exposure to balck carbon averaged over 1 year was significantly associated with a lower HDL cholesterol.

60. Zhong J, Cayir A, Trevisi L, Sanchez-Guerra M, Lin X, Peng C et al. Traffic-Related Air Pollution, Blood Pressure, and Adaptive Response of Mitochondrial Abundance. Circulation. 2016;133(4): 378–87. [PubMed: 26660284]
61. Eze IC, Schaffner E, Fischer E, Schikowski T, Adam M, Imboden M et al. Long-term air pollution exposure and diabetes in a population-based Swiss cohort. Environ Int. 2014;70:95–105. [PubMed: 24912113]
62. Eze IC, Hemkens LG, Bucher HC, Hoffmann B, Schindler C, Kunzli N et al. Association between ambient air pollution and diabetes mellitus in Europe and North America: systematic review and meta-analysis. Environ Health Perspect. 2015;123(5):381–9. [PubMed: 25625876]
63. Eze IC, Schaffner E, Foraster M, Imboden M, von Eckardstein A, Gerbase MW et al. Long-Term Exposure to Ambient Air Pollution and Metabolic Syndrome in Adults. PLoS One. 2015;10(6):e0130337. [PubMed: 26103580]
64. Chen H, Burnett RT, Kwong JC, Villeneuve PJ, Goldberg MS, Brook RD et al. Risk of incident diabetes in relation to long-term exposure to fine particulate matter in Ontario, Canada. Environ Health Perspect. 2013;121(7):804–10. [PubMed: 23632126]
65. Mehta AJ, Kubzansky LD, Coull BA, Kloog I, Koutrakis P, Sparrow D et al. Associations between air pollution and perceived stress: the Veterans Administration Normative Aging Study. Environ Health. 2015;14:10. [PubMed: 25627872]
66. Li W, Dorans KS, Wilker EH, Rice MB, Kloog I, Schwartz JD et al. Ambient air pollution, adipokines, and glucose homeostasis: The Framingham Heart Study. Environ Int. 2018;111:14–22. [PubMed: 29161632]
67. Li W, Dorans KS, Wilker EH, Rice MB, Schwartz J, Coull BA et al. Residential proximity to major roadways, fine particulate matter, and adiposity: The framingham heart study. Obesity (Silver Spring). 2016;24(12):2593–9. [PubMed: 27804220]
68. Budoff MJ, Young R, Burke G, Jeffrey Carr J, Detrano RC, Folsom AR et al. Ten-year association of coronary artery calcium with atherosclerotic cardiovascular disease (ASCVD) events: the multi-ethnic study of atherosclerosis (MESA). European heart journal. 2018;39(25):2401–2408. [PubMed: 29688297]
69. Adar SD, Sheppard L, Vedal S, Polak JF, Sampson PD, Diez Roux AV et al. Fine particulate air pollution and the progression of carotid intima-medial thickness: a prospective cohort study from the multi-ethnic study of atherosclerosis and air pollution. PLoS Med. 2013;10(4):e1001430. [PubMed: 23637576]
70. Van Hee VC, Adar SD, Szpiro AA, Barr RG, Bluemke DA, Diez Roux AV et al. Exposure to traffic and left ventricular mass and function: the Multi-Ethnic Study of Atherosclerosis. Am J Respir Crit Care Med. 2009;179(9):827–34. [PubMed: 19164703]
71. Kaufman JD. Does air pollution accelerate progression of atherosclerosis? J Am Coll Cardiol. 2010;56(22):1809–11. [PubMed: 21087708]
72. Gill EA, Curl CL, Adar SD, Allen RW, Auchincloss AH, O'Neill MS et al. Air pollution and cardiovascular disease in the Multi-Ethnic Study of Atherosclerosis. Prog Cardiovasc Dis. 2011;53(5):353–60. [PubMed: 21414470]
73. Kaufman JD, Adar SD, Allen RW, Barr RG, Budoff MJ, Burke GL et al. Prospective study of particulate air pollution exposures, subclinical atherosclerosis, and clinical cardiovascular disease: The Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air). Am J Epidemiol. 2012;176(9):825–37. [PubMed: 23043127]
74. Krishnan RM, Adar SD, Szpiro AA, Jorgensen NW, Van Hee VC, Barr RG et al. Vascular responses to long- and short-term exposure to fine particulate matter: MESA Air (Multi-Ethnic Study of Atherosclerosis and Air Pollution). Journal of the American College of Cardiology. 2012;60(21):2158–66. [PubMed: 23103035]
75. Kim SY, Sheppard L, Kaufman JD, Bergen S, Szpiro AA, Larson TV et al. Individual-level concentrations of fine particulate matter chemical components and subclinical atherosclerosis: a cross-sectional analysis based on 2 advanced exposure prediction models in the multi-ethnic study of atherosclerosis. Am J Epidemiol. 2014;180(7):718–28. [PubMed: 25164422]

76. D'Souza JC, Kawut SM, Elkayam LR, Sheppard L, Thorne PS, Jacobs DR, Jr. et al. Ambient Coarse Particulate Matter and the Right Ventricle: The Multi-Ethnic Study of Atherosclerosis. Environ Health Perspect. 2017;125(7):077019. [PubMed: 28760719]

77••. Jones MR, Diez-Roux AV, O'Neill MS, Guallar E, Sharrett AR, Post W et al. Ambient air pollution and racial/ethnic differences in carotid intima-media thickness in the Multi-Ethnic Study of Atherosclerosis (MESA). J Epidemiol Community Health. 2015;69(12):1191–8. [PubMed: 26142402] First study examining the role of air pollution exposure in racial/ ethnic differences in atherosclerosis. The smaller carotid IMT levels in Chinese participants were even smaller after accounting for higher $PM_{2.5}$ concentrations in Chinese participants compared with Caucasian-American participants. Air pollution was not related to IMT differences in African-American and Hispanic participants compared with Caucasian-American participants

78. O'Neill MS, Diez-Roux AV, Auchincloss AH, Shen M, Lima JA, Polak JF et al. Long-term exposure to airborne particles and arterial stiffness: the Multi-Ethnic Study of Atherosclerosis (MESA). Environ Health Perspect. 2011;119(6):844–51. [PubMed: 21245016]

79. Aaron CP, Chervona Y, Kawut SM, Diez Roux AV, Shen M, Bluemke DA et al. Particulate Matter Exposure and Cardiopulmonary Differences in the Multi-Ethnic Study of Atherosclerosis. Environ Health Perspect. 2016;124(8):1166–73. [PubMed: 26859533]

80. Cosselman KE, Navas-Acien A, Kaufman JD. Environmental factors in cardiovascular disease. Nat Rev Cardiol. 2015;12(11):627–42. [PubMed: 26461967]

81. Coogan PF, White LF, Jerrett M, Brook RD, Su JG, Seto E et al. Air pollution and incidence of hypertension and diabetes mellitus in black women living in Los Angeles. Circulation. 2012;125(6):767–72. [PubMed: 22219348]

82. Coogan PF, White LF, Yu J, Burnett RT, Marshall JD, Seto E et al. Long term exposure to NO2 and diabetes incidence in the Black Women's Health Study. Environmental research. 2016;148:360–6. [PubMed: 27124624]

83. Jerrett M, Brook R, White LF, Burnett RT, Yu J, Su J et al. Ambient ozone and incident diabetes: A prospective analysis in a large cohort of African American women. Environ Int. 2017;102:42–7. [PubMed: 28153529]

84. Ramanathan G, Yin F, Speck M, Tseng CH, Brook JR, Silverman F et al. Effects of urban fine particulate matter and ozone on HDL functionality. Part Fibre Toxicol. 2016;13(1):26. [PubMed: 27221567]

85. Chen R, Zhao A, Chen H, Zhao Z, Cai J, Wang C et al. Cardiopulmonary benefits of reducing indoor particles of outdoor origin: a randomized, double-blind crossover trial of air purifiers. J Am Coll Cardiol. 2015;65(21):2279–87. [PubMed: 26022815]

86. Jones MR, Diez-Roux AV, Hajat A, Kershaw KN, O'Neill MS, Guallar E et al. Race/ethnicity, residential segregation, and exposure to ambient air pollution: the Multi-Ethnic Study of Atherosclerosis (MESA). American journal of public health. 2014;104(11):2130–7. [PubMed: 25211756]

87. Morello-Frosch R, Lopez R. The riskscape and the color line: examining the role of segregation in environmental health disparities. Environ Res. 2006 10;102(2):181–96. [PubMed: 16828737]

88. Leary PJ, Kaufman JD, Barr RG, Bluemke DA, Curl CL, Hough CL et al. Traffic-related air pollution and the right ventricle. The multi-ethnic study of atherosclerosis. Am J Respir Crit Care Med. 2014;189(9):1093–100. [PubMed: 24593877]

89. Weaver AM, Wellenius GA, Wu WC, Hickson DA, Kamalesh M, Wang Y. Residential distance to major roadways and cardiac structure in African Americans: cross-sectional results from the Jackson Heart Study. Environ Health. 2017;16(1):21. [PubMed: 28270143]

90. Hackbarth AD, Romley JA, Goldman DP. Racial and ethnic disparities in hospital care resulting from air pollution in excess of federal standards. Soc Sci Med. 2011 10;73(8):1163–8. [PubMed: 21893376]

91••. Erqou S, Clougherty JE, Olafiranye O, Magnani JW, Aiyer A, Tripathy S et al. Particulate Matter Air Pollution and Racial Differences in Cardiovascular Disease Risk. Arterioscler Thromb Vasc Biol. 2018;38(4):935–42. [PubMed: 29545240] This study reported a 45% increase in the risk of cardiovascular events among blacks compared to whites in Western Pennsylvania (greater Pittsburgh) partly because of higher chronic exposure to $PM_{2.5}$ among blacks [91]. This

association was no longer statistically significant after further adjustments for measures of SES, including income and education

92. Rooney MS, Arku RE, Dionisio KL, Paciorek C, Friedman AB, Carmichael H et al. Spatial and temporal patterns of particulate matter sources and pollution in four communities in Accra, Ghana. Sci Total Environ. 2012;435–436:107–14.
93. Hajat A, Hsia C, O'Neill MS. Socioeconomic Disparities and Air Pollution Exposure: a Global Review. Curr Environ Health Rep. 2015;2(4):440–50. [PubMed: 26381684]
94. Goldberg MS, Burnett RT, Stieb DM, Brophy JM, Daskalopoulou SS, Valois MF et al. Associations between ambient air pollution and daily mortality among elderly persons in Montreal, Quebec. Sci Total Environ. 2013;463–464:931–42.
95. Pun VC, Kazemiparkouhi F, Manjourides J, Suh HH. Long-Term PM2.5 Exposure and Respiratory, Cancer, and Cardiovascular Mortality in Older US Adults. Am J Epidemiol. 2017;186(8):961–969. [PubMed: 28541385]
96. Katsoulis M, Dimakopoulou K, Pedeli X, Trichopoulos D, Gryparis A, Trichopoulou A et al. Long-term exposure to traffic-related air pollution and cardiovascular health in a Greek cohort study. The Science of the total environment. 2014;490:934–40. [PubMed: 24908651]
97. Zhang C, Ding R, Xiao C, Xu Y, Cheng H, Zhu F et al. Association between air pollution and cardiovascular mortality in Hefei, China: A time-series analysis. Environmental pollution (Barking, Essex : 1987). 2017;229:790–7.
98. Stockfelt L, Andersson EM, Molnar P, Gidhagen L, Segersson D, Rosengren A et al. Long-term effects of total and source-specific particulate air pollution on incident cardiovascular disease in Gothenburg, Sweden. Environmental research. 2017;158:61–71. [PubMed: 28600978]
99. Green R, Broadwin R, Malig B, Basu R, Gold EB, Qi L et al. Long- and Short-term Exposure to Air Pollution and Inflammatory/Hemostatic Markers in Midlife Women. Epidemiology. 2016;27(2):211–20. [PubMed: 26600256]
100. Ho HC, Wong MS, Yang L, Chan TC, Bilal M. Influences of socioeconomic vulnerability and intra-urban air pollution exposure on short-term mortality during extreme dust events. Environ Pollut. 2018;235:155–162. [PubMed: 29288928]
101. Fan X, Lam KC, Yu Q. Differential exposure of the urban population to vehicular air pollution in Hong Kong. Sci Total Environ. 2012;426:211–9. [PubMed: 22542227]
102. Branis M, Linhartova M. Association between unemployment, income, education level, population size and air pollution in Czech cities: evidence for environmental inequality? A pilot national scale analysis. Health Place. 2012;18(5):1110–4. [PubMed: 22632903]
103. Su JG, Jerrett M, Morello-Frosch R, Jesdale BM, Kyle AD. Inequalities in cumulative environmental burdens among three urbanized counties in California. Environ Int. 2012;40:79–87. [PubMed: 22280931]
104. Bauer M, Moebus S, Mohlenkamp S, Dragano N, Nonnemacher M, Fuchsluger M et al. Urban particulate matter air pollution is associated with subclinical atherosclerosis: results from the HNR (Heinz Nixdorf Recall) study. J Am Coll Cardiol. 2010;56(22):1803–8. [PubMed: 21087707]
105••. Li H, Cai J, Chen R, Zhao Z, Ying Z, Wang L et al. Particulate Matter Exposure and Stress Hormone Levels: A Randomized, Double-Blind, Crossover Trial of Air Purification. Circulation. 2017;136(7):618–627. [PubMed: 28808144] A randomized trial testing the efficacy of air purification on levels of stress hormones. Exposure to PMs with aerodynamic diameters $\leq 2.5 \mu g/m^3$ led to significant increases in cortisol, cortisone, epinephrine, and norepinephrine.
106. Tonne C, Yanosky JD, Beevers S, Wilkinson P, Kelly FJ. PM mass concentration and PM oxidative potential in relation to carotid intima-media thickness. Epidemiology. 2012;23(3):486–94. [PubMed: 22450694]
107. Weichenthal S, Villeneuve PJ, Burnett RT, van Donkelaar A, Martin RV, Jones RR et al. Long-term exposure to fine particulate matter: association with nonaccidental and cardiovascular mortality in the agricultural health study cohort. Environ Health Perspect. 2014;122(6):609–15. [PubMed: 24633320]

108. Baumgartner J, Zhang Y, Schauer JJ, Huang W, Wang Y, Ezzati M. Highway proximity and black carbon from cookstoves as a risk factor for higher blood pressure in rural China. Proc Natl Acad Sci U S A. 2014;111(36):13229–34. [PubMed: 25157159]

109. Dales RE, Cakmak S. Does Mental Health Status Influence Susceptibility to the Physiologic Effects of Air Pollution? A Population Based Study of Canadian Children. PLoS One. 2016;11(12):e0168931. [PubMed: 28030615]

110. Kalsch H, Hennig F, Moebus S, Mohlenkamp S, Dragano N, Jakobs H et al. Are air pollution and traffic noise independently associated with atherosclerosis: the Heinz Nixdorf Recall Study. Eur Heart J. 2014;35(13):853–60. [PubMed: 24194529]

111. Bruske I, Hampel R, Baumgartner Z, Ruckerl R, Greven S, Koenig W et al. Ambient air pollution and lipoprotein-associated phospholipase A(2) in survivors of myocardial infarction. Environ Health Perspect. 2011;119(7):921–6. [PubMed: 21356620]

112. Villeneuve PJ, Johnson JY, Pasichnyk D, Lowes J, Kirkland S, Rowe BH. Short-term effects of ambient air pollution on stroke: who is most vulnerable? Sci Total Environ. 2012;430:193–201. [PubMed: 22647242]

113. Turner MC, Cohen A, Burnett RT, Jerrett M, Diver WR, Gapstur SM et al. Interactions between cigarette smoking and ambient PM2.5 for cardiovascular mortality. Environ Res. 2017;154:304–310. [PubMed: 28142053]

114. Hart JE, Puett RC, Rexrode KM, Albert CM, Laden F. Effect Modification of Long-Term Air Pollution Exposures and the Risk of Incident Cardiovascular Disease in US Women. J Am Heart Assoc. 2015;4(12).

115. Qin XD, Qian Z, Vaughn MG, Trevathan E, Emo B, Paul G et al. Gender-specific differences of interaction between obesity and air pollution on stroke and cardiovascular diseases in Chinese adults from a high pollution range area: A large population based cross sectional study. Sci Total Environ. 2015;529:243–8. [PubMed: 26022408]

116. Akbarzadeh MA, Khaheshi I, Sharifi A, Yousefi N, Naderian M, Namazi MH et al. The association between exposure to air pollutants including PM10, PM2.5, ozone, carbon monoxide, sulfur dioxide, and nitrogen dioxide concentration and the relative risk of developing STEMI: A case-crossover design. Environ Res. 2018;161:299–303. [PubMed: 29178978]

117. van der Zee SC, Fischer PH, Hoek G. Air pollution in perspective: Health risks of air pollution expressed in equivalent numbers of passively smoked cigarettes. Environ Res. 2016;148:475–483. [PubMed: 27136673]

118. Mehta AJ, Zanobetti A, Bind MA, Kloog I, Koutrakis P, Sparrow D et al. Long-Term Exposure to Ambient Fine Particulate Matter and Renal Function in Older Men: The Veterans Administration Normative Aging Study. Environ Health Perspect. 2016;124(9):1353–60. [PubMed: 26955062]

119. Hadley MB, Vedanthan R, Fuster V. Air pollution and cardiovascular disease: a window of opportunity. Nature reviews Cardiology. 2018;15(4):193–4.

120. Maji KJ, Arora M, Dikshit AK. Burden of disease attributed to ambient PM2.5 and PM10 exposure in 190 cities in China. Environ Sci Pollut Res Int. 2017;24(12):11559–11572. [PubMed: 28321701]