Auctus: The Journal of Undergraduate Research and Creative Scholarship

2013

Examining the Relationship between Particulate Matter, Nitrogen Oxide, Carbon Oxides, Sulfur Dioxide and Hypertension in Urban Areas in India: A Review

Hiren Kolli
Virginia Commonwealth University

Examining the Relationship between Particulate Matter, Nitrogen Oxide, Carbon Oxides, Sulfur Dioxide and Hypertension in Urban Areas in India: A Review

by Hiren Kolli

Introduction

While blood pressure may be decreasing around the world, it has been on the rise in India (Kounteya, 2012). According to the World Health Organization, the average blood pressure went down by 2.7mm Hg among women globally, while increasing by 2.4mm Hg in India. In men, blood pressure decreased by 2.3mm Hg globally in the past three decades but increased by 2.2mm Hg in India (Kounteya, 2012). Almost three-quarters of people with hypertension live in developing countries with limited health resources where there is very low awareness of hypertension, and India is one of these countries. Hypertension is the leading risk factor for cardiovascular disease mortality, causing more than seven million deaths every year worldwide. Hypertension is a chronic condition of concern due to its role in the causation of coronary heart disease, stroke and other vascular complications. It is the most common cardiovascular disorder, posing a major public health challenge to populations in socioeconomic and epidemiological transition. It is one of the major risk factors for cardiovascular mortality, which accounts for 20 – 50% of all deaths (Gupta, 2004). Age, ethnicity, family history, exercise, and diet are some of the most common risk factors for hypertension but more area-specific factors must be examined in developing countries such as India.

Developing countries are notorious for their poor air quality, but India is reported to have the worst air pollution in the entire world, beating China, Pakistan, Nepal, and Bangladesh (Timmons, 2012). According to the Environmental Protection Agency (2012), three of the six most common air pollutants are particulate matter, nitrogen dioxide, and carbon monoxide. These fine particles can settle into the furthest reaches of the lungs and may even be able to enter the bloodstream directly. Particulate matter and other airborne pollutants are byproducts of fuel-burning machines from factories and car engines (Langrish et al., 2012). The primary goal of this research is to identify potential air pollutants that can be linked with the rising trend in hypertension in order to establish a basis for future research.

The Increase in Hypertension

Recent studies have shown an increase in the prevalence of hypertension in both urban and rural communities in India (Gupta, 2004). In Study of urban community survey in India: Growing trend of high prevalence of hypertension in a developing dountry, Das, Sanyal, and Basu (2005), state that in the last three decades, the prevalence of hypertension has increased by about 30 times among urban dwellers. Das, Sanyal, and Basu examined the growing trend of hypertension and found that an age and sex specific increase in prevalence of systolic and diastolic hypertension in both men and women indicated a significant role of environmental factors. However, the researchers in this study did not specifically identify what factors would have an effect on blood pressure, instead suggesting methods of regulating blood pressure.

Gupta (2004) reports in Recent trends in hypertension epidemiology in India that "Hypertension is directly responsible for 57% of all stroke deaths and 24% of all coronary heart disease deaths in India" (p.73). This gives researchers reason to believe that hypertension is the underlying cause for the elevated number of cardiovascular deaths in India. The prevalence of hypertension among urban men in Mumbai is between 44% and 45% (p. 73). The exact reasons for the increase in high blood pressure amongst Indians have not been established. Some studies have shown that age does not have an influence on blood pressure levels. Hypertension seems to be more so related to environmental and lifestyle factors rather than to genetically defined racial differences (Langrish et al., 2012).

Factors such as exposure to stress and industrialization in urban populations have led to increases in hypertension prevalence. Gupta (2004) states that there is a strong correlation between urbanization and the increase in hypertension prevalence. Wealth, as measured by evaluation of per capita, net domestic product, growth of production, and human development index has also increased sharply in India in recent years and correlates positively with the hypertension increase.

India's Air Pollution

India is reported to have the most polluted air in the world. According to Jebaraj (2012), India placed last among 132 nations in terms of air quality with regard to human health. India scored a minute 3.73 out of a possible 100 points in the analysis, lagging far behind the next worst performer, Bangladesh, which scored a 13.66. Heather Timmons and Malavika Vyawahare (February 1st, 2012), report on the World Health Organization's ranking of India as dead-last in air quality. The report attributes this rank to high levels of particulate matter as levels in India are "nearly five times the threshold where they become unsafe for human beings" (p. 1). Acute respiratory infections were one of the most common causes of deaths in children under five in India and also contributed to "13% of in-patient deaths in pediatric wards in India" (p. 2). These figures support that India has a profound problem with air quality and distinguishes it as a viable place of study.

Harmful Effects of Air Pollutants on Hypertension

Air pollutants are known to be harmful to one's health because they are easily respired and can be toxic in heavy concentrations. Kathleen Bush (2011) discusses the effects of air pollution on respiratory disease and found that emergency department visits increased by approximately 20% because of high levels of pollutants in Delhi. Bush notes that another study concluded that "short-term exposure to particulate matter ≤ 10 µm in aerodynamic diameter (PM10) resulted in an estimated risk ratio of 1.0044 per a 10 µg/m3 increase in daily average concentrations (p. 767). This information presents a clear connection between air pollution and cardiovascular problems. In order to distinguish more nuanced relationships between blood pressure and pollution, consistent monitoring of particulate matter and nitric oxides over a wide geographical area is needed. Jie Cao, et al. (2010) analyzed the China National Hypertension Follow-up Survey, a study of 158,666 adults, and conducted their own study using the given information. Jie Cao et al. found that "Among adults from 31 Chinese cities followed prospectively, higher residential exposure to ambient air pollution was associated with an increased risk of cardiopulmonary and lung cancer mortality." The authors' evidence supports previous findings from cross-sectional studies examining the association between long-term air pollution exposure and cardiopulmonary mortality. This finding points out that air pollution does not only trigger life-threatening events like heart attacks and strokes, but that it may also influence the underlying processes, which can lead to chronic cardiovascular diseases.

Zhang et al. (2000) conducted an ecological analysis to assess the relationship between long-term exposures to sulfate, an indication of air pollution, and mortality in Beijing. Significant correlations between sulfate concentration and cardiopulmonary mortality were found. The health effects of sulfate were independent of total suspended particles, meaning that besides contributing to particle formation, sulfates can be related to adverse health effects and thus need to be regulated. These studies broadly suggest that cardiovascular mortality is associated with the pollutants examined but the studies fail to determine the effects of the pollutants on specific functions in the body.

In Opposing effects of particle pollution, ozone, and ambient temperature on arterial blood pressure," Hoffman (2012) found that "BP tended to increase with elevations in levels of fine particle mass (245)." This would mean that people with a higher baseline blood pressure are more susceptible to a larger increase in blood pressure after particulate matter exposure. The particles studied by Hoffman included PM2.5 (Particulate Matter 2.5), sulfate (SO42−), black carbon (BC), elemental carbon (EC), organic carbon (OC), and particle number concentration (PNC). An interesting finding from this research is that ozone was found to lead to a decrease in systolic blood pressure, diastolic blood pressure, and central mean arterial blood pressure (243). Thus, decreases in blood pressure, after high ozone exposure, would be noticeably stronger in those with lower baseline blood pressure. Future studies may need to identify where ozone pollution is prominent and determine whether its affects have significance when compared to the other types of pollutants.

Hoffman et al.'s claim that air pollution has a direct effect on blood pressure is supplemented by Urch et al.'s claim that particulate matter exposure lead to increases in blood pressure. In "Acute Blood Pressure Responses in Healthy Adults During Controlled Air Pollution Exposures," Urch et al. studied the responses during two hour exposures to concentrated ambient fine particles plus ozone and compared the results to those exposed to particle-free air in 23 non-smoking healthy adults. They observed a significant 6mm Hg increase for those exposed to concentrated ambient particles. These particles included nitrogen oxides, sulfur dioxide, and carbon monoxide. The levels of pollutants in this study were environmentally relevant concentrations, meaning that people who are exposed to air pollutants during the course of their everyday routines are at higher risk of developing hypertension. Urch et al. also contend that the organic carbon content of particulate matter is an important factor in blood pressure effects. If this is true, then the carbon fractions warrant further study to assess the danger of particulate matter.

Fine particles of size 2.5 micrometers and less, PM2.5, are signifcantly more harmful to human health than larger particles. These smaller particles are small enough to be inhaled and absorbed so they act as carriers of toxic substances in a way that particles over 10 micrometers do not.

Levels of particulate matter in India were found to be much higher than the set World Health Organization guidelines (Goyal et al., 2005). In Acute effects of ambient particulate matter on blood pressure, Dvonch et al. (2009) state that "In this study of 347 adults in 3 Detroit communities, short-term increases in exposure to PM2.5 levels less than the current daily US Environmental Protection Agency National Ambient Air Quality Standard (65 g/m3) were significantly associated with an increase in systolic and pulse pressures (p. 855). Zanobetti et al. (2004) confirm this association by investigating the connection between fine particulate pollution and blood pressure during repeated visits for cardiac rehabilitation in 62 Boston residents with cardiovascular disease. They found a 2.7mm Hg increase in blood pressure and a 2.7mm Hg increase in mean arterial blood pressure. Zanobetti et al. claim that "The longer cumulative particle effects, occurring over 48 to 120 hours, suggest that the mechanism of action of pollution on BP may involve systemic inflammation and subsequent endothelial dysfunction rather than more immediate effects of autonomic dysfunction (p. 2187). The autonomic nervous system regulates unconscious body functions including heart rate and blood pressure. The authors' claims illustrate that the mechanism of air pollution's direct effect on blood pressure cannot be identified because blood pressure changes can be prompted by a plethora of faults in body functions.

Dvonch et al. (2009) found that "Results of the community location analysis in this study suggest that increased levels of PM2.5 and possibly differences in chemical composition of the PM emitted from nearby emission sources may be responsible for the adverse effect observed on BP outcomes (p.858). India in that is a developing country with huge amounts of dust, smoke and dirt from factories, farming and roads. These sources can emit particulate matter of varying chemical compositions because the surrounding environment and the pollutants emitted could combine in different ways to either be of significant or unnoticeable in terms of health effects. The smaller particulates stay in the air longer and travel further. Because the PM2.5 travels deeper into the lungs and because the PM2.5 is made up of substances that are more toxic like heavy metals and cancer-causing organic compounds, severe health effects can result. Examining cardiovascular deaths could establish a connection between the air pollutants and blood pressure; this data could be used to single out blood pressure as a primary factor of these problems.

Vehicles: The Main Source of Pollution

While there are many sources of air pollution in India, including factory emissions and household biomass fuels, the largest source of pollution seems to be from vehicles. According to Roychowdhury, executive director of India's Centre for Science and Environment, the main culprit of air pollution is the growing number of vehicles in India. While the country still has far fewer vehicles per capita than developed nations, India's cars are more polluting. Roychowdhury states that emission standards are nearly "10 years behind European standards" (as cited in Timmons, 2012).

One of the most obvious problems regarding vehicles in India is unchecked growth. Madhav Badami (2005) uses the city of Delhi as an example, stating that "while Delhi's population has grown at around 5% per annum over the last three decades, motor vehicles grew 20% per annum in the 1970s and 1980s and 10% per annum during the 1990s" (p.195). This disproportionate ratio has led to an overabundance of vehicles on the roads and in turn a plethora of traffic problems. Badami also reports a study that showed 24-hour average suspended particle levels, exceeding guideline limits set by the World Health Organization. Sulfur dioxide and nitrogen dioxide exceeded WHO limits at several sites. Both of these particles are known to be emitted in relatively high concentrations from vehicles.

In Jie Cao et al.'s (2010) Association between long-term exposure to outdoor air pollution and mortality in China: A cohort study, the authors state that the reason some of their findings differed from those experiments conducted in other countries is because "the motor vehicle fleet may differ from that in Europe and North America" (p.1597). While Badami (2005) distinguishes India's increasing number of vehicles, Jie Cao et al. put vehicular air pollution into perspective by singling it out as the big difference in findings between countries. This implies that while there are other variables that can have affect on blood pressure, motor vehicle pollution is an important factor in determining blood pressure elevations in areas where pollution is highly concentrated.

Devi, Gupta, Tripathi & Ujinwal's (2009) study in Kanpur, India called "Assessment of personal exposure to inhalable indoor and outdoor particulate matter for student residents of an academic campus (IIT-Kanpur), measured pollution levels in different areas and then analyzed the effect each area had on "integrated personal exposure" (p.1210). The authors studied particulate matter exposure among students going outside their campus on the most common mode of transportation in India called rickshaws. Devi, Gupta, Tripathi & Ujinwal found that "with an increase in the vehicular traffic, both the fine and coarse particle concentration increase[d]" (p.1217).

The peaks in fine particle mass concentration can be attributed primarily to vehicle exhaust due to the absence of other combustion sources. The same results on a trip to a shopping mall in a diesel-powered bus instead of a six-seater auto rickshaw showed that the higher presence of coarse particles compared to fine particles. Particulate matter is one of the leading causes of acute lower respiratory infections and cancer. Vehicles are a major source of these and other pollutants, therefore vehicular emissions must be studied further and identified accurately. In addition, exposures near roadways include products of vehicle and tire wear, re-suspended particles that arise from road dust, and ambient background pollutants. Moreover, many of the traffic-related air pollution components are physically and chemically reactive, resulting in complex pollutants that can change rapidly over short distances near roadways (Martuzevicius, 2010).

In Understanding urban vehicular pollution problem vis-a-vis ambient air quality: Case study of a megacity (Delhi, India), Goyal, Ghatge, Nema, & Tamhane (2005) found that the number of two wheelers is about 67 percent of the entire vehicle fleet in India. In terms of percentage of the total pollution from different category of vehicles, "two wheelers contribute about 40% CO, 3.5% NOx, 60.4% HC and 38.6% PM" (p.558). While the other studies discussed only mentioned particulate matter and fine/

coarse particles, this study built upon the idea and identified the specific pollutants that come from two-wheelers, which is significant because with the rising population of India, especially that of Delhi where the population increased double to that of the nation, two-wheelers will become more popular because of their affordability and ease of maneuverability in traffic. Because motorized two-wheeled vehicles are used intensively, and are, for the most part, powered by highly polluting two-stroke engines, these vehicles play an important role in transport air pollution, particularly on a passenger per mile basis.

Further an "increase in population plus industrialization and an increase in motorized transport have resulted in an increased concentration of sulfur dioxide, nitrogen oxides, suspended particulate matter, respire-able suspended particulate matter, carbon monoxide, lead, ozone, benzene and hydrocarbons" (p. 558). As Goyal et al. show, vehicles in India are emitting harmful substances into the air and it is evident that these vehicles are specific to India.

Reasons to Study Hydrocarbons

Hydrocarbons, though abundant in high traffic areas, have not been studied for links to blood pressure. Polycyclic aromatic hydrocarbons or PAH's come from incomplete combustion, are ubiquitous in the global environment, and are typically more concentrated near urban centers. Srogi (2007) supports Goyal et al. in that PAHs in the air come from sources such as automobiles, re-suspended soils, refineries and power plants. Hydrocarbons from fuel emissions tend to be quickly absorbed into particles and to accumulate into sediments, which makes them dangerous when released into an environment full of other pollutants such as nitric oxides, carbon and sulfate. Srogi puts these pollutants into perspective, stating "PAHs have received increased attention in recent years in air pollution studies because some of these compounds are highly carcinogenic or mutagenic" (p. 170). In addition, Srogi supports Goyal et al. (2005) and the implication that "PAHs are present in gasoline and diesel engine exhaust, thus making, motor vehicle emissions in urban areas a major source of exposure to these compounds" (p.566).

Martuzevicius, Kliucininkas, Prasauskas, Krugly, Kauneliene, & Strandberg (2012) also claim that the incomplete combustion of fuels leads to production of hydrocarbons, but assert that street dust acts as a source of particle-bound hydrocarbons. Street dust is directly exposed to vehicle exhaust emissions and thus may adsorb emitted particles and PAHs. The results of their study showed that street dust not only emits fugitive dust, but may also be a substantial source of PAHs bound to particulate mass fractions. The ratio of concentrations of hydrocarbons to particulate matter showed similar differences between "dust from the city center street and dust from the connecting streets" (p. 314). It is evident that exposure to hydrocarbons can occur on a high level when traveling on major roadways where vehicles, as well as people, are abundant and also when the roads are not properly maintained and have a considerable amount of dust.

Xu, Cook, Llacqua, Haidong, Talbott, & Kearney (2010) investigated the associations between PAHs and cardiovascular disease. Xu et al. recognized that hydrocarbons are prevalent in ambient air and that humans can be exposed to these chemicals through inhalation. This cross-sectional study "suggested that exposure to some PAHs was positively associated with the prevalence of self-reported CVD in the U.S. general population aged 20 years and older" (p. 4946). Additionally, the study found that some PAHs, independent of cigarette smoking and other covariates, were significantly associated with cardiovascular disease, suggesting different sources of PAHs may contribute to these associations.

Discussion

Future research must consider isolating hydrocarbons and determining their underlying effects. If these hydrocarbons can lead to cardiovascular disease, they may also lead to blood pressure changes or even build up in the arteries. A mechanism by which hydrocarbons can have an effect on blood pressure is through membrane proteins or G-protein-coupled receptors. Blood pressure is regulated by blood vessel radius, which is established by chemicals binding to GCPRs. Once hydrocarbons enter a body, they have the potential to block or inhibit the receptors, thereby causing an alteration in the highly regulated signaling flow. By inhibiting the mechanisms in the cells, the overall function of many cells will be also be inhibited. A decrease in GCPR signaling can lead to an increase in blood pressure as a result of a decrease in regulation and dilation (Brinks, 2010).

An application of this research would help doctors and other health advisors, who have patients with hypertension problems, to better assess the nature of their blood pressure problems and direct patients by recommending more appropriate treatments and care accordingly--including the filtration of particulate matter.

Langrish et al. (2012) found that reducing personal exposure to air pollution using a highly efficient facemask appeared to reduce symptoms and improve a range of cardiovascular health measures in patients with coronary heart disease. Langrish et al. reported that "use of a facemask that decreased personal PM air pollution exposure reduced systolic blood pressure in healthy volunteers during a 2-hr walk by 7 mmHg" (p.370). Air pollution, when tested in isolation, can have an effect on health. In addition to regulating diet, changing drug prescriptions, or mandating exercise, environmental factors need to be considered for people who live in highly urbanized areas and are constantly in direct contact with respire-able air pollutants.

Brook et al. (2004) state that during the past 15 years, the magnitude of evidence and number of studies linking air pollution to cardiovascular diseases has grown substantially. However, the links between blood pressure and air pollution have not been studied as extensively. One of the studies referenced in the article mentions that of 1401 deaths, 646 were due to cardiovascular causes and that, among air pollutants, elevations of particulate matter of size 2.5 and smaller and sulfates showed the strongest associations with disease. All of these studies tend to link air pollution with cardiopulmonary diseases and not specifically blood pressure. Future research needs to examine specific chemical and biological constituents of particulate matter such as metals, carbon and hydrocarbons. The role of hydrocarbons in blood pressure regulation is not well studied, but should be since vehicles in India are known to emit significant amounts of hydrocarbons (Badami, 2005). The idea of various constituents of air pollutants and would logically lead us to identify the effects of "gaseous co pollutants alone and in combination with particulate matter" (p.201). This along with an improvement in exposure estimates and metrics can assist individuals by informing them of the air quality on certain days and can help them to keep their blood pressure levels controlled.

Smoking, an extraneous factor that contributes to high blood pressure, was accounted for in this review. Smoking accounts for a large percentage of deaths, especially those of males, among Indians between the ages of 30 and 69. Tobacco use is highly prevalent in India, particularly because much of the surveyed population is illiterate and unaware of the adverse health outcomes of smoking. Hypertension as a result of smoking could be a potentially confounding variable in the studies conducted on the effects of pollution on blood pressure. However, most, if not all, of the studies, conducted surveys prior to their experiments and ruled out smokers to make sure to minimize any potential confounding variables. What they may not have accounted for was presence of smoking around the test subjects. The particles from the smoke could have combined with vehicle pollution to spike blood pressure.

A factor that wasn't considered in most of these studies was diet. Consumption of salty foods, lack of fruit and vegetable intake, and high alcohol consumption are major risk factors for high blood pressure. Dieting habits of people in India could be reason enough for the recent spike in blood pressure, but diet patterns have not been studied to determine whether or not there has been a significant change to correlate to the increase in hypertension. The base blood pressure data collected could reflect diet habits, but then the increases would be due to environmental changes such as vehicle pollution.

Conclusion

As research continues regarding air pollution in relation to increased blood pressure, there is accumulating evidence that air pollution has a definitive association with elevated blood pressure levels. Research on vehicle emissions in India associated high levels of pollutants, particularly hydrocarbons, with the number of vehicles in an area, thus leading to the conclusion that traffic-related pollution may have a direct effect on blood pressure. Based on previous and ongoing research on the role of air pollutants in blood pressure, it must be concluded that in order to best treat a hypertensive individual, the air quality of where said individual lives must be taken into account when determining the appropriate treatment. Air pollution is a ubiquitous exposure; therefore, small increases in risk may carry large public health implications.

An example of one of the most common methods of blood pressure control is exercise, as it has been proven to lower blood pressure and combat the corrosive effects of plaque buildup. Studies have shown that exercise is effective because it stimulates a substance within our bodies called nitric oxide, which helps to keep blood vessels open. However, if an individual were to live in a highly polluted area such as an urban city in India, exercising outdoors would prove to be more detrimental than beneficial. The inhaled pollutants, specifically particulate matter, could enter the blood stream and combine with the nitric oxides to make a substance that may block the arteries or inhibit the proteins involved in the pathway, thereby causing a spike in blood pressure. If physicians were aware of the air quality in their area they could advise their patients to perform exercises indoors or to wear facemasks when performing activities outdoors to reduce the amount of pollution uptake (Langrish et al., 2012). While these prevention methods may be effective, it is not currently known which prevention strategies would be the most effective.

In the future, new studies are necessary to further provide evidence for the claim stated in this review. Most of the pre-existing studies on the topic have attributed the effects of air pollution to cardiopulmonary syndromes. Instead of identifying the effects as a combination, studies should attempt to delve deeper and recognize what is specifically being affected by air pollution. In doing so, it can be recognized that there are significant effects on the cardiovascular and pulmonary systems, respectively. More specifically, research needs to be conducted to support the association between hypertension and ambient air pollution as their combination have the potential to lead to an increased risk of heart attack, stroke, and atherosclerosis. Such studies can help India to identify air pollution problems as specific public health risks and allow the country address these risks by placing more stringent vehicle regulations in place. This research can lead to identification and confirmation of air pollution as an underlying factor of the vast amount of hypertension and cardiovascular disease cases in India.

References

Badami, M. (2005, August). Transport and urban air pollution in India. Environmental Management, 36(2), 195-204. doi:10.1007/s000267.004.0106x

Brinks, H. (2010, December). Regulation of GPCR signaling in hypertension. Molecular Basis of Disease, 1802(12), 1268-1275. doi: 10.1016/j.bbadis.2010.01.005

Brook, R., Franklin, B., Cascio, W., Hong, Y., Howard, G., Lipsett, M., Luepker, R., Mittleman, M., Samet, J., Smith, S.C., & Tager, I. (2004, April 5). AHA scientific statement air pollution and cardiovascular disease: A statement for healthcare professionals from the expert panel on population and prevention science of the American Heart Association. doi: 10.1161/ 01.CIR.0000128587.30041.C8

Bush, K., Luber, G., Kotha, R., Dhaliwal, R.S., Kapil, V., Pascual, M., & Brown, D. G. (2011, June 01). Impacts of climate change on public health in India: Future research directions. Environmental Health Perspectives, 119(6), 765-770. doi: 10.1289/ehp.1003000

Cao, J., Yang, C., Li, J., Chen, R., Chen, B., Gu, D., & Kan, H. (2010, December 15). Association between long-term exposure to outdoor air pollution and mortality in china: A cohort study. Journal of Hazardous Materials, 186(2), 1594-1600. doi:10.1016/j.jhazmat.2010.12.036

Das, S. K., Sanyal, K., & Basu, A. (2005, April). Study of urban community survey in India: Growing trend of high prevalence of hypertension in a developing country. International Journal of Medical Sciences, 2(2), 70-78. Retrieved from http://www.ncbi.nlm.nih.gov/

Devi, J. J., Gupta, T., Tripathi, S. N., & Ujinwal, K. K. (2009). Assessment of personal exposure to inhalable indoor and outdoor particulate matter for student residents of an academic campus (IIT-Kanpur). Inhalation Toxicology, 21(14), 1208-1222. doi: 10.3109/08958370902822875

Dvonch, T. J., Kannan, S., Schulz, A. J., Gerald K.J., Graciela M., House J., Benjamin, A., Paul M., Bard R. L., & Brook R. D. (2009, March). Acute effects of ambient particulate matter on blood pressure. American Heart Association. 853-859. doi: 10.1161/HYPERTENSIONAHA.108.123877

Environmental Protection Agency. (2012). Six common air pollutants. Retrieved from http://www.epa.gov/airquality/urbanair/

Goyal S. K., Ghatge S. V., Nema P., & Tamhane S. M. (2005). Understanding urban vehicular pollution problem vis-a-vis ambient air quality – Case study of a megacity (Delhi, India). Environmental Monitoring and Assessment, 119(1-3). 557-569. doi:10.1007/s10661-005-9043-2

Gupta, R. (2004). Trends in hypertension epidemiology in India. South Asian Journal of Preventative Cardiology. 73-78. doi:10.1038/sj.jhh.1001633

Hoffmann B., Luttmann-Gibson, H., Cohen, A., Zanobetti, A., de Souza, C., Foley, C., Suh, H. H., Coull, B. A., Schwartz, J., Mittleman, M., Stone, P., Horton, E., & Gold, D. R. (2012, February). Opposing effects of particle pollution, ozone, and ambient temperature on arterial blood pressure. Environmental Health Perspectives. 241-246. doi:10.1289/ehp.1103647

Jebaraj, P. (2012, January). India has the most toxic air: A study. The Hindu. Retrieved from http://www.thehindu.com/

Kounteya, S. (2012, April). Average bp falls across the world, rises in India. The Times of India. Retrieved from http://articles.timesofindia.indiatimes.com/

Langrish, J. P., Li, X., Wang, S., Lee, M., Barnes, G. D., Miller, M. R., Cassee, F. R., Boon, N. A., Donaldson, K., Li, J., Li, L., Mills, N. L., Newby, D. E., & Jiang, L. (2012). Reducing personal exposure to particulate air pollution improves cardiovascular health in patients with coronary heart disease. Environmental Health Perspectives, 120(3), 367-372. doi:10.1289/ehp.1103898

Martuzevicius, D., L. Kliucininkas, T. Prasauskas, E. Krugly, V. Kauneliene, B. & Strandberg. (2010). Resuspension of particulate matter and PAHs from street dust. Atmospheric Environment, 45(2), 310-317. Retrieved from http://dx.doi.org/10.1016/j.atmosenv.2010.10.026

Srogi, K. (2007, November). Monitoring of environmental exposure to polycyclic aromatic hydrocarbons: A review. Environmental Chemistry Letters, 5(4), 169-195. doi:10.1007/s10311-007-0095-0

Timmons, H., & Malavika, V. (2012, Feb. 1). India's air the world's unhealthiest, study says. The New York Times. Retrieved from http://india.blogs.nytimes.com

Urch, B., Silverman, F., Paul, C., Brook, J. R., Lukic, K. Z., Rajagopalan, S., & Brook R.D. (2005). Acute blood pressure responses in healthy adults during controlled air pollution exposures. Environmental Health Perspectives, 113(8), 1052-1055. doi:10.1289/ehp.7785

Xu, X., Cook, R. L., Llacqua, V. A., Haidong, K., Talbott, E. O., & Kearney, G. (2010). Studying associations between urinary metabolites of polycyclic aromatic hydrocarbons (PAHs) and cardiovascular diseases in the United States. Science of the Total Environment, 408, 4943-4948. doi: 10.1016/j.scitotenv.2010.07.034.

Zanobetti, A., Jacobson Canner, M., Stone, P. H., Schwartz, J., Sher, D., Eagen-Bengston, E., Gates, K. A., Hartley, H., Suh, H., & Gold, D. R. (2004). Ambient pollution and blood pressure in cardiac rehabilitation patients. Circulation, 110(5), 2184-2189. Retrieved from http://circ.ahajournals.org/

Zhang, J. (2000). Ambient sulfate concentration and chronic disease mortality in Beijing. Science of the Total Environment, 262(1), 63-71. doi:10.1016/S0048-9697(00)00573-8