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Ambient Wintertime Particulate Air Pollution and Hypertensive Disorders of Pregnancy in Monroe County, New York

Vanessa Assibey-Mensah^{a,b,c}, J. Christopher Glantz^{a,d}, Philip K. Hopke^a, Todd A. Jusko^{a,e}, Kelly Thevenet-Morrison^a, David Chalupa^e, David Q. Rich^{a,e,f}

Vanessa Assibey-Mensah: assibeymensahv@mwri.magee.edu; J. Christopher Glantz: chris_glantz@urmc.rochester.edu; Philip K. Hopke: philip_hopke@urmc.rochester.edu; Todd A. Jusko: todd_jusko@urmc.rochester.edu; Kelly Thevenet-Morrison: kelly_thevenetmorrison@urmc.rochester.edu; David Chalupa: david_chalupa@urmc.rochester.edu; David Q. Rich: david_rich@urmc.rochester.edu

^aDepartment of Public Health Sciences, University of Rochester Medical Center, Rochester, NY, USA

^bDepartment of Obstetrics, Gynecology, and Reproductive Sciences, University of Pittsburgh School of Medicine, Pittsburgh, PA, USA

^cMagee-Womens Research Institute, University of Pittsburgh, Pittsburgh, PA, USA

^dDepartment of Obstetrics and Gynecology, University of Rochester Medical Center, Rochester, NY, USA

^eDepartment of Environmental Medicine, University of Rochester Medical Center, Rochester, NY, USA

^fDepartment of Medicine, University of Rochester Medical Center, Rochester, NY, USA

Abstract

Background: Previous studies have reported associations between ambient fine particle (PM_{2.5}) concentrations and hypertensive disorders of pregnancy (HDP). However, none have examined whether ultrafine particles (UFP; <100 nm), accumulation mode particles (AMP; 100–500 nm), markers of traffic pollution (black carbon; BC), or wood burning (Delta-C; (30% of ambient wintertime PM_{2.5} in Monroe County, NY is from wood burning)) are associated with an increased odds of HDP. We estimated the odds of HDP associated with increased concentrations of PM_{2.5}, UFP, AMP, BC, and Delta-C in each gestational month during winter months.

Corresponding Author: Vanessa Assibey-Mensah, PhD, MPH, Department of Obstetrics, Gynecology, and Reproductive Sciences, University of Pittsburgh School of Medicine, Magee-Womens Research Institute & Foundation/Magee-Womens Hospital of UPMC, Magee Medical Building, 3380 Boulevard of the Allies, Suite 334, Pittsburgh, PA 15213, assibeymensahv@mwri.magee.edu/ Telephone: 412.641.8979.

Competing Interests Declaration: The authors declare that they have no conflicting interests.

Ethics approval and consent: This study did not involve direct contact with study subjects. This study involved access to electronic medical records and birth certificate data. All study activities were approved by the University of Rochester Research Subjects Review Board (RSRB #00057468).

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Appendix A. Supplementary material

Methods: Electronic medical records and birth certificate data were linked with land-use regression models in Monroe County, New York in 2009–2013 to predict monthly pollutant concentrations during winter (November–April) based on maternal residential address for 16,637 births. Using multivariable logistic regression, we estimated the odds of HDP associated with each interquartile range (IQR) increase in PM_{2.5}, UFP, AMP, BC, and Delta-C concentrations during each gestational month, adjusting for maternal characteristics, birth hospital, temperature, and relative humidity.

Results: Each 0.52 µg/m³ increase in Delta-C concentration during the 7th gestational month was associated with an increased odds of HDP (odds ratio (OR)=1.21; 95% confidence interval (CI)=1.01, 1.45), with a similar sized estimate in month 8 (OR=1.18; 95%CI=0.98, 1.43). Nonstatistically significant increased odds of HDP associated with IQR increases in BC concentrations during months 3 (OR=1.12; 95%CI=0.98, 1.28) and 7 (OR=1.12; 95%CI=0.96, 1.29) were observed. Increased odds of HDP were not observed for PM_{2.5}, UFP, or AMP.

Conclusions: Our findings suggest that maternal exposure to wood smoke in Monroe County during winter is associated with an increased odds of HDP during late gestation. Additional studies are needed to evaluate the effect of wood smoke on HDP and to explore effects on other pregnancy outcomes.

Keywords

hypertensive disorders; gestational month; particulate matter; wood smoke

1. Introduction

Poor maternal adaptation to vascular, metabolic, and immune changes during pregnancy in addition to reduced placental perfusion and pre-existing risk factors can lead to hypertensive disorders of pregnancy after 20 weeks of gestation (Bramham et al. 2014; Cedergren 2004; Roberts and Hubel 2009). Hypertensive disorders of pregnancy (HDP) including gestational hypertension and preeclampsia-eclampsia, complicate up to 10% of pregnancies in the United States (Amro et al. 2016) and are responsible for a significant burden of maternal-perinatal morbidity and mortality (Roberts et al. 2013). Yet, reduced placental perfusion alone during the first trimester is insufficient to contribute to HDP, and must be accompanied by other genetic, behavioral, psychosocial, and/or environmental factors (Roberts and Gammill 2005).

Ambient particulate matter with aerodynamic diameter <2.5 µm (PM_{2.5}) has been implicated in the development of HDP in some, but not all studies (Dadvand et al. 2013; Lee et al. 2013; Mobasher et al. 2013; Rudra et al. 2011; Savitz et al. 2015; Vinikoor- Imler et al. 2012; Wu et al. 2009; Xu et al. 2014). These studies have observed both small magnitude associations or no associations, and inconsistencies in time windows during pregnancy where increased PM was associated with these complications. In recent meta-analyses, Pedersen et al. (2014) reported an increased risk of HDP (gestational hypertension, preeclampsia, or combined outcome) associated with each 5 µg/m³ increase in PM_{2.5} concentration during the entire pregnancy (OR = 1.47; 95% CI = 1.27, 1.68), whereas, Hu et al. (2014) reported substantially smaller risks of HDP associated with each 5 µg/m³ increase

in PM_{2.5} concentrations during the first trimester (OR =1.18; 95% CI = 0.98, 1.41), the second trimester (OR=1.17; 95% CI= 0.79, 1.75), and the entire pregnancy (OR=1.15; 95% CI = 0.94, 1.40). While the findings were consistent, the difference in magnitude may be due to differences in the primary studies that were included in each metaanalysis. All studies included in the meta-analyses assessed entire pregnancy pollutant effects or trimester specific pollutant effects. No studies have examined shorter critical windows of exposure, such as gestational months, which may correspond to more relevant periods of fetal development (Woodruff et al. 2009).

Moreover, previous studies have not included smaller PM size fractions or sourcespecific particles (e.g., from wood smoke or traffic pollution). Smaller size fractions of PM_{2.5} such as accumulation mode number concentration (AMP; diameters of 100–500 nm) and ultrafine particle concentrations (UFP; diameters <100 nm) have been linked to adverse vascular, inflammatory, and autonomic effects (Brook et al. 2010; Rich et al. 2012) that could contribute to HDP via oxidative stress and endothelial dysfunction in late pregnancy. The inclusion of source-specific PM_{2.5} is particularly important because the chemical composition of PM may substantially alter its toxicity. Furthermore, Wang et al. (2012a, b) estimated that on average, 30% of ambient wintertime fine PM in Monroe County, NY is from residential wood burning. Therefore, we focused our main analyses on the winter months, November–April, when wood smoke would be a major part of primary PM_{2.5} emissions. We also examined black carbon (BC) that is produced by motor vehicle exhaust, including diesel exhaust, as a marker of traffic pollution (Suglia et al. 2008). We also used Delta-C, the difference in BC measured at 370 nm and 880 nm, as a measure of wood smoke exposure (Wang et al., 2011). We linked electronic medical record data with birth certificate data and estimated the odds of HDP associated with ambient PM concentrations by using a land-use regression model (Su et al. 2015) to predict gestational month-specific pollutant concentrations (for months 1–9) for a population of pregnant women in Monroe County, New York during 2008–2012. We hypothesized that increases in ambient PM_{2.5}, UFP, AMP, BC (marker of traffic pollution), and Delta-C (marker of wood smoke) during gestational months 1–3 (i.e. early pregnancy) would be associated with increased odds of HDP.

2. Materials and Methods

2.1 Study population

Using a retrospective cohort study design and electronic medical record data linked to birth certificate data from the Finger Lakes Perinatal Database System, we retained records of 20,596 live births to female residents of Monroe County (only first births for each woman) delivering at either Strong Memorial Hospital or Highland Hospital in Rochester, NY from 2009–2013 (Figure 1). Approximately 70% of all women in Monroe county deliver at either of these hospitals. We excluded women diagnosed with pre-existing or chronic hypertension (n=572), infants with congenital anomalies (n=236), infants with a birth weight <500 g (n=63) or >5000g (n=28), out of range clinical values including gestational weeks at delivery recorded as <12 or >45 weeks and birth history/number of conceptions >25 (n=378), and those births with missing covariate information on pre-pregnancy weight, height, or education (n=1,835). Finally, to avoid the fixed cohort bias, a type of selection

bias where shorter pregnancies are missed in the beginning of the study and longer pregnancies are missed at the end (Strand et al. 2011), we excluded births ($n=761$) with an estimated date of conception before July 17, 2008 (i.e., 24 weeks before January 1, 2009) or after March 12, 2013 (i.e. 42 weeks before December 31, 2013), leaving 16,723 births available for analysis. Using the date of the last menstrual period (LMP), we calculated the start and end dates of each gestational month for each pregnancy. If the LMP date was missing ($n=778$), it was estimated using the infant date of birth and clinical estimate of gestational weeks. We then included only those births that had greater than 15 days of non-missing air pollutant concentrations during a given month (i.e., either 1st, 2nd, 3rd, . . . 9th month) in winters (November 1–April 30) of 2008–2013. We then geocoded the maternal residential address of 98% of available pregnancies using ArcGIS V.10.1 software (ESRI, Redlands, California, USA) ($n=16,637$). This study did not involve direct contact with study subjects. This study involved access to electronic medical records and birth certificate data. All study activities were approved by the University of Rochester Research Subjects Review Board (RSRB #00057468).

2.2 Air pollution and weather data

PM_{2.5}, UFP, AMP, BC, and Delta-C concentrations, temperature, and relative humidity data were obtained for the time period November 1, 2008 to April 30, 2013 from the New York State Department of Environmental Conservation (NYSDEC) site located in Rochester, New York (43°08'46" N, 77°32'54" W, Elevation = 137 m, U.S. EPA site code 36–055-1007). PM_{2.5} concentrations were measured hourly using a Tapered Element Oscillating Microbalance (TEOM; Thermo Fisher, Franklin, MA). A non-linear Julian Day based adjustment was applied to the TEOM data to remove the seasonal bias, thus providing comparability to the Federal Reference Method (FRM) values (Felton 2005; Schwab et al. 2006). A Scanning Mobility Particle Sizer (SMPS, TSI, Inc., Shoreview, MN) was used to generate counts of AMP (100–500 nm diameter) and UFP (10–100 nm diameter). Black carbon, a marker of traffic pollution (Suglia et al. 2008), was measured using a two-wavelength (370 and 880 nm) aethalometer (AE-22 aethalometer, Magee Scientific, Berkeley, CA). Delta-C, a marker of wood smoke was reported as the difference between black carbon measured at 370 nm and 880 nm (Wang et al. 2011). Delta-C has been identified as surrogate for wood smoke because it is strongly correlated with levoglucosan and potassium, two species found in residential wood combustion (Wang et al. 2011; Wang et al. 2012). Temperature and relative humidity were measured at 5-minute intervals at the NYSDC site and provided as hourly averages. Gestational month specific concentrations of BC, Delta-C, PM_{2.5}, UFP, and AMP at each mother's residential address were then estimated using the pollutant measurements described above and a previously developed LUR model for the winter (November 1 to April 30) in Monroe County, NY (Su et al. 2015). We then estimated the average pollution concentrations in addition to temperature and relative humidity for up to 9 gestational months for each pregnancy, by averaging LUR-predicted daily concentrations during the winter months.

2.3 Outcome assessment

HDP was defined as a diagnosis of either gestational hypertension, preeclampsia, and/or eclampsia in the electronic medical record for each woman, using the following

International Classification of Diseases, Ninth Revision (ICD-9) discharge diagnoses: (1) gestational hypertension (ICD-9 codes: 642.30–642.34); (2) mild or unspecified pre-eclampsia (ICD-9 codes: 642.40–642.44); (3) severe preeclampsia (ICD-9 codes: 642.50–642.54); and (4) eclampsia (ICD-9 codes: 642.60–642.64).

2.4 Statistical analyses

We used multivariable logistic regression to estimate the odds of HDP associated with each interquartile range (IQR) increase in $PM_{2.5}$, UFP, AMP, BC, and Delta-C concentrations in each month of pregnancy. Based on previously published work (Assibey-Mensah et al. 2016; Dadvand et al. 2013; Lee et al. 2013; Savitz et al. 2015; Vinikoor- Imler et al. 2012; Wu et al. 2009; Xu et al. 2014), causal diagrams, and change-in-estimate procedures, the following covariates were considered as potential confounders: parity (nulliparous or parous), multifetal gestation (yes or no), pre-pregnancy diabetes (yes or no), gestational diabetes (yes or no), maternal age (<20, 20–24, 25–29, 30–34, 35–39, or 40), maternal race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, Asian, or Other), maternal education (high school or less, high school grad/GED, some college, Associate's degree, Bachelor's degree, or Master's degree or higher), paternity acknowledgement (married or not married), pre-pregnancy body mass index (underweight, normal, overweight, class I obesity, class II obesity, or class III obesity), year of conception (2008, 2009, 2010, 2011, 2012, or 2013), season of conception (warm or cool), birth hospital (Highland or Strong), trimester prenatal care began (none, 1st, 2nd, or 3rd), prenatal care received (yes or no), Medicaid funded delivery (yes or no), smoking during pregnancy (yes or no), alcohol consumption during pregnancy (yes or no), average relative humidity, or average temperature. After inclusion of the 1st gestational month $PM_{2.5}$ concentration, we then retained only those covariates that changed the estimated odds of HDP associated with increased $PM_{2.5}$ concentration by >10% (primiparity, multifetal gestation, pre-pregnancy diabetes, gestational diabetes, age, race/ethnicity, education, pre-pregnancy body mass index, year of conception, birth hospital, average relative humidity and average temperature from the same gestational month). We then re-ran this model for concentrations of $PM_{2.5}$ and other pollutants during each gestational month, including mean temperature and relative humidity from that same gestational month.

Women with HDP who deliver preterm (gestational age <37 weeks) are typically more severely affected than those who deliver at term (gestational age ≥ 37 weeks). Therefore, we conducted a sensitivity analysis excluding all preterm births since we were unable to further distinguish between type of labor (medically-indicated or spontaneous). In an additional sensitivity analysis, we determined if our findings using measured pollutant concentrations from the NYDEC site in Rochester for the same time periods were similar to those when using the LUR estimated PM concentrations as described above. From each model described above, we report the adjusted odds ratio and 95% confidence intervals. We used SAS version 9.4 (©SAS Institute, Inc. Cary, NC) to construct all datasets and perform all statistical analyses with statistical significance defined as $p < 0.05$.

3. Results

3.1 Study population

Overall, 30% of the study population was 30–34 years of age and was predominantly non-Hispanic white (60%), with a master's degree or higher (23%), and parous (70%). Approximately 8% (1,335/16,637) of the study population had a HDP diagnosis (Table 1). Small percentages of women had pre-pregnancy diabetes (1%) or gestational diabetes (6%). Nearly half of the study population had a normal pre-pregnancy body mass index (49%). Compared with women without HDP, those with HDP were more often non-Hispanic black (31% vs 23%), primiparous (41% vs 29%), more often had a multifetal gestation (7% vs 2%) or gestational diabetes (10% vs 6%) and were more often obese (34% vs 22%) (Table 1).

3.2 Exposure assessment

Mean monthly pollutant concentrations for the 1st gestational month, estimated using the LUR and measured at the central site measurements are presented in Table 2 and Supplemental Table 1, respectively. Generally, the medians were larger for LUR modeled estimates than central site measurements during wintertime. This is possibly due to higher density housing with more emissions and less dispersion since the NYSDEC central monitoring site is an open field with good ventilation with any wind direction. The correlation coefficients between LUR modeled mean pollutant concentrations, relative humidity, and temperature during the first month of pregnancy during the winter months are presented in Table 3. PM_{2.5} was weakly correlated with BC ($r=0.31$) and Delta-C ($r=0.26$), and uncorrelated with UFP ($r=-0.02$) and AMP ($r=-0.01$). UFP and AMP were highly correlated ($r=0.80$). PM_{2.5} was weakly correlated with relative humidity ($r=0.26$) and inversely correlated with temperature ($r=-0.32$), while relative humidity and temperature were inversely moderately correlated ($r=-0.45$). Correlations between central site measured mean pollutant concentrations, relative humidity, and temperature averaged in the 1st gestational month are shown in Supplemental Table 2.

3.3 Particulate concentrations and odds of HDP

The odds of HDP associated with each interquartile range increase in concentrations of PM_{2.5}, UFP, AMP, BC, and Delta-C in each gestational month are presented in Table 4. Increased Delta-C concentrations were generally associated with increases in HDP, with the larger effect estimates occurring in late pregnancy after adjusting for maternal characteristics, birth hospital, relative humidity, and temperature. Each 0.52 $\mu\text{g}/\text{m}^3$ increase in Delta-C concentration during the 7th gestational month was associated with an increased odds of HDP (OR=1.21; 95% CI=1.01, 1.45), with a similar sized effect estimate in month 8 (OR=1.18; 95% CI=0.98, 1.43). Non-statistically significant, increased odds of HDP was associated with IQR increases in concentrations of BC during the 7th (OR=1.12; 95% CI=0.96, 1.29) and 3rd (OR=1.12; 95% CI=0.98, 1.28) gestational months. Similar patterns were not observed for PM_{2.5}, UFP, or AMP concentrations. Further, we observed no association between PM_{2.5}, UFP, or AMP concentrations during gestational months 1–3 and odds of HDP (Table 4).

After exclusion of preterm births, each $0.52 \mu\text{g}/\text{m}^3$ increase in Delta-C concentration during the 7th gestational month was associated with increased odds of HDP (OR= 1.27; 95%CI =1.04, 1.56), with a similar sized effect in month 8 (OR=1.25; 95%CI=1.02, 1.54). We also observed increased odds of a HDP associated with IQR increases in AMP concentration during the 6th gestational month (OR=1.06; 95% CI = 1.02, 1.09), and UFP during the 6th gestational month (OR=1.03; 95% CI = 1.00, 1.05). Similar to our main analyses, we observed no associations between any pollutant concentrations during gestational months 1–3 (Supplemental Table 3).

Using the NYSDEC central site measurements averaged for each gestational month, each IQR increase in Delta-C concentrations during gestational month 7 was associated with increased odds of HDP (OR=1.40; 95% CI=1.05, 1.88), with a similar effect size in the 6th month (OR= 1.31; 95% CI=0.99, 1.73). We also observed increased odds of a HDP associated with IQR increases in BC concentrations during the 7th gestational month (OR=1.25; 95% CI = 1.06, 1.48). Similar to our main analyses, we observed no associations between PM_{2.5}, UFP, or AMP concentrations during gestational months 1–3. However, we did observe non-statistically significant increased odds of a HDP associated with each $2.45 \mu\text{g}/\text{m}^3$ increase in PM_{2.5} concentrations during the 9th gestational month (OR=1.17; 95% CI=0.87, 1.58), with a smaller effect size in the 5th month (OR=1.10; 95% CI=0.87, 1.39). This pattern was not observed for UFP or AMP concentrations (Supplemental Table 4).

4. Discussion

We observed 18–21% increased odds of HDP associated with each $0.52 \mu\text{g}/\text{m}^3$ increase in Delta-C concentrations during gestational months 7 and 8, after adjusting for maternal characteristics, birth hospital, relative humidity, and temperature. However, there was no increased odds of HDP associated with increases in gestational monthly mean PM_{2.5}, UFP, or AMP concentrations. Similar patterns were generally observed after excluding preterm births, but increased odds of HDP were associated with increases in AMP concentrations during mid pregnancy. Moreover, findings were generally in the same direction, but of greater magnitude, when using air pollutant concentration measurements from the NYSDEC site in Rochester for the same pregnancies.

Similar to our finding of an increased odds of HDP associated with increased ambient Delta-C concentrations in gestational months 7 and 8, we have and others have reported associations between wood smoke, forest fires, and biomass burning and various health outcomes/biomarkers including ST-elevation myocardial infarction (Rich et al. 2018) and increased fibrinogen and C-reactive protein (Croft et al. 2017). Although it is unclear as to why the effect of residential wood smoke is greatest during late pregnancy, it is possible that exposure to Delta-C during late pregnancy leads to increased endothelial dysfunction and consequently clinical manifestation of a HDP. Yet, it is also possible that there may be less exposure misclassification during late pregnancy than early pregnancy (i.e., an ambient Delta-C concentration may be closer to a subject's true Delta-C concentration during late pregnancy than during early pregnancy). This difference may be a result of pregnant women spending more time at home or being less likely to change residence during late in pregnancy as compared with early pregnancy (Hodgson et al. 2015). The degree of exposure

misclassification and resulting downward bias, and differences in the amount of error and bias in late pregnancy versus early pregnancy, may be greater for pollutants like wood smoke that are predominantly emitted in residential neighborhoods (e.g. fireplaces, wood stoves, back yard fire pits), compared to pollutants like PM_{2.5} that are emitted by many sources, both near the home and farther away (e.g. homes, automobile emissions, industrial facilities).

Our finding of no HDP/PM_{2.5} association during any gestational month is consistent with a prior study (Savitz et al. 2015). Savitz et al. (2015) did not observe increased odds of HDP associated with each 10 µg/m³ increase in PM_{2.5} concentrations during the first trimester (OR= 1.10; 95% CI=1.00, 1.20) or second trimester (OR=1.10; 95% CI = 1.00, 1.20) after adjusting for maternal characteristics, neighborhood deprivation, and birth hospital in a retrospective cohort study of 268,601 pregnant women in New York City (Savitz et al. 2015). However, our findings are inconsistent with other previous studies that have reported increased odds of HDP associated with increases in mean PM_{2.5} concentrations during the first trimester (Mobasher et al. 2013), second trimester (Xu et al. 2014), or entire pregnancy (Pedersen et al. 2014; Vinikoor- Imler et al. 2012; Xu et al. 2014). The inconsistency of our study with previous studies may be due to heterogeneity in PM composition across geographic locations (Los Angeles County, CA; Jacksonville, FL; and North Carolina). Given that the previous studies were in warmer locations, mothers' outdoor activity levels may have also been substantially different. Additionally, in Monroe County, the median concentrations were lower than the US EPA national ambient air quality standard (12.0 µg/m³). Median ambient PM_{2.5} concentrations were also substantially lower in Monroe County compared with Jacksonville, Florida (6.5 vs 10.2 µg/m³ during 1st trimester), Los Angeles County, California (7.1 vs 17 µg/m³ during 1st trimester), and North Carolina (6.8 vs 14.7 µg/m³ during entire pregnancy). Therefore, it is possible that concentrations of PM_{2.5} may have been too low to trigger HDP in our study population.

This study is the first to estimate the odds of HDP associated with increased concentrations of ambient UFP and AMP and HDP during pregnancy. However, mean ambient UFP and AMP concentrations (UFP: mean = 14,633 p/cm³; 5th and 95th percentile = 4,647 and 60,698 p/cm³; AMP: mean = 51,258 p/cm³; 5th and 95th percentile = 5,926 and 125,669 p/cm³) may have been too low to contribute to the development of HDP. Yet, similar UFP and AMP concentrations in Monroe County have previously been associated with increased odds of cardiorespiratory outcomes (Evans et al. 2014) and cardiovascular biomarkers (Croft et al. 2017; Rich et al. 2012).

We did not find a pattern of increased odds of HDP associated with increases in BC concentrations across gestational months. Traffic pollution may not impact trophoblast invasion and subsequently placental development during early pregnancy when examining all hypertensive disorders. Future studies are needed to examine the impact of BC on individual HDP such as early-onset preeclampsia which primarily stems from poor placental perfusion. We did find non-statistically significant increases in the odds of HDP associated with increased black carbon concentrations in gestational months 3 and 7. This result is consistent with a prior study (Dadvand et al. 2014) that observed no association between preeclampsia and increases in vehicle exhaust concentration during the entire pregnancy

(OR=1.07; 95% CI = 0.75, 1.54) in a hospital cohort of 3,182 pregnant women residing in Barcelona Spain.

Systemic inflammation, oxidative stress, and endothelial dysfunction (Brook et al. 2010) have been postulated to play a role in the development of HDP during early, mid, and late pregnancy. Briefly, inhalation of particles may trigger a pulmonary inflammatory response that releases cytokines into the maternal systemic circulation (Brook et al. 2010). These cytokines could reach the placenta, resulting in placental inflammation, systemic oxidative stress (Brook et al. 2010; Risom et al. 2005), and failed remodeling of the maternal spiral arteries leading to poor placentation during months 1–3 (i.e., early pregnancy). Reduced placental perfusion secondary to abnormal placentation during gestational months 4–6 (i.e., mid pregnancy) may result in the hypoxic placenta releasing anti-angiogenic factors into maternal circulation followed by endothelial dysfunction resulting in the clinical manifestation of HDP during gestational months 7–9 (i.e., late pregnancy) (Young et al. 2010). Therefore, exposure to wood smoke during late pregnancy may contribute to the development of HDP via these mechanisms. Specifically, Brook et al. (2010) describes a pathway that PM sources or constituents may directly enter the blood stream after inhalation and result in endothelial dysfunction followed by elevations in blood pressure. Therefore, exposure to wood smoke may not impact the placenta directly, but instead results in endothelial dysfunction and the clinical manifestation of HDP during late pregnancy.

There were several strengths to this study, including use of gestational monthly mean pollutant concentrations (greater ability to identify specific mechanisms), and the use of LUR models to estimate gestational month exposure to ambient PM pollution at each mother's residential address (presumably resulting in less exposure misclassification and downward bias), and use of electronic medical records to provide more accurate information than birth certificate data on clinical diagnoses of gestational hypertension, preeclampsia, and eclampsia (resulting in less outcome misclassification and downward bias).

There are also several limitations that should be considered when making inference, including that LUR models were not developed for the entire calendar year, and thus, we were unable to examine the association between ambient pollutant concentrations during pregnancy and HDP for time periods outside of winter (November to April). However, given that wood smoke contributes on average 30% of wintertime PM_{2.5} concentrations and lower percentages in other times of the year (Wang et al. 2012), and assuming wood smoke and not total PM_{2.5} is associated with these HDP, we can expect that our risk estimates would be attenuated in analyses assessing ambient wood smoke concentrations during the entire calendar year. We did not have information on maternal mobility and assumed that each woman's residential address was the same throughout pregnancy, or if she did move, her level of exposure remained the same throughout each month of pregnancy (Chen et al. 2010) resulting in Berkson and classical error, with classical error resulting in downward bias, and underestimates of risk (Bateson et al. 2007; Zeger et al. 2000). We did not have the date of HDP diagnosis and were unable to truncate exposure prior to diagnosis (resulting in non-differential exposure misclassification and downward bias). Finally, for each pollutant we separately evaluated the association between the odds of HDP and the mean pollutant concentrations in each of 9 gestational months (9 analyses per pollutant). Given the number

of statistical tests performed (90), we would expect at least 4–5 to be statistically significant by chance. However, inference was primarily made by considering the pattern of association across these 9 gestational month mean pollutant concentrations, rather than only whether each was statistically significant.

5. Conclusion

In this retrospective cohort study in Monroe County, New York, we did not find a pattern of increased odds of hypertensive disorders of pregnancy associated with increased PM concentrations during gestational months 1–3. However, increased odds of hypertensive disorders of pregnancy were associated with increased Delta-C concentrations during late pregnancy, but not other PM pollutants. Future studies are needed to confirm this finding and explore associations between wood smoke and other pregnancy outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Wood smoke during late gestation was associated with increased odds of HDP
- Increased odds of HDP were not observed for PM_{2.5}, UFP, or AMP concentrations
- Need to further explore effects of wood smoke on HDP and pregnancy outcomes

Figure 1.

Flowchart of exclusions for analysis of PM pollutant concentration and hypertensive disorders of pregnancy, Monroe County, 2009–2013

Table 1.

Characteristics of Study Population, 2008-2013 (n=16,637)

	All Pregnancies n=16,637	No Hypertensive Disorders n=15,302	Total Hypertensive Disorders of Pregnancy n=1,335
Characteristic	n (%)	n (%)	n (%)
Maternal age (years)			
<20	1359 (8)	1219 (8)	140 (10)
20–24	3258 (20)	2975 (19)	283 (21)
25–29	4437 (27)	4048 (26)	389 (29)
30–34	5023 (30)	4689 (31)	334 (25)
35–39	2109 (13)	1949 (13)	160 (12)
40	451 (3)	422 (3)	29 (2)
Maternal race and ethnicity			
Non-Hispanic white	9905 (60)	9169 (60)	736 (55)
Non-Hispanic black	3970 (24)	3552 (23)	418 (31)
Hispanic	1433 (9)	1336 (9)	97 (7)
Asian	886 (5)	832 (5)	54 (4)
Other	443 (3)	413 (3)	30 (2)
Maternal education			
High school or less	2564 (15)	2354 (15)	210 (16)
High school grad or GED	3749 (23)	3396 (22)	353 (26)
Some college	1961 (12)	1795 (12)	166 (12)
Associate degree	1415 (9)	1271 (8)	144 (11)
Bachelor's degree	3183 (19)	2953 (19)	230 (17)
Master's degree or higher	3765 (23)	3533 (23)	232 (17)
Parity			
Nulliparous	4991 (30)	4447 (29)	544 (41)
Parous	11646 (70)	10855 (71)	791 (59)
Multifetal gestation	391 (2)	304 (2)	87 (7)
Year of conception			
2008	1515 (9)	1409 (9)	106 (8)
2009	3910 (24)	3611 (24)	299 (22)
2010	3775 (23)	3492 (23)	283 (21)
2011	3089 (19)	2850 (19)	239 (18)
2012	3671 (22)	3322 (22)	349 (26)
2013	677 (4)	618 (4)	59 (4)
Pre-pregnancy diabetes	144 (1)	116 (1)	28 (2)
Gestational diabetes	1003 (6)	871 (6)	132 (10)
Pre-pregnancy body mass index			
Underweight (< 18.5)	606 (4)	574 (4)	32 (2)
Normal (18.5–24.9)	8212 (49)	7717 (50)	495 (37)
Overweight (25.0–29.9)	4119 (25)	3769 (25)	350 (26)

	All Pregnancies	No Hypertensive Disorders	Total Hypertensive Disorders of Pregnancy
	n=16,637	n=15,302	n=1,335
Characteristic	n (%)	n (%)	n (%)
Class I obesity (30.0–34.9)	2026 (12)	1797 (12)	229 (17)
Class II obesity (35.0–39.9)	977 (6)	851 (6)	126 (9)
Class III obesity (40.0)	697 (4)	594 (4)	103 (8)
Birth hospital			
Highland	8961 (54)	8277 (54)	684 (51)
Strong	7676 (46)	7025 (46)	651 (49)

Distribution of air pollutant concentrations averaged in first gestational month during wintertime using land use regression, 2008– 2013, Rochester, NY.

Table 2.

Pollutant	N	Mean	Standard Deviation	Minimum	5 th	25 th	50 th	75 th	95 th	Maximum
AMP (p/cm ³)	4,350	51,258	103,192	1,428	5,926	16,023	28,719	47,829	125,669	1,397,190
BC (pg/m ³)	4,726	1.14	0.75	0.00	0.00	0.67	1.07	1.52	2.46	6.56
Delta-C (pg/m ³)	4,726	0.35	0.37	0.00	0.00	0.02	0.24	0.54	1.09	3.00
PM2.5 (pg/m ³)	4,361	6.9	3.5	0	2.4	4.7	6.3	8.4	13.0	47.8
UFP (p/cm ³)	4,350	14,633	28,546	4,069	4,647	6,381	8,594	10,399	60,698	198,453

Table 3.

Pearson correlation coefficients for mean pollutant concentrations, relative humidity, and temperature for first gestational month during winter, 2008-2013 (n=4,350-4,726)

	AMP	BC	Delta-C	PM _{2.5}	UFP	Relative Humidity	Temperature
AMP	1.00	--	--	--	--	--	--
BC	0.12	1.00	--	--	--	--	--
Delta-C	0.02	0.26	1.00	--	--	--	--
PM _{2.5}	-0.01	0.31	0.26	1.00	--	--	--
UFP	0.80	0.02	0.08	-0.02	1.00	--	--
Relative Humidity	-0.23	0.04	0.23	0.26	-0.31	1.00	--
Temperature	0.01	0.03	-0.26	-0.32	0.02	-0.45	1.00

Table 4.

Odds of HDP associated with each interquartile range (IQR) increase in PM concentrations in each gestational month during the winter

Pollutant	Month	N	n of HDP	OR	95% CI
AMP IQR=31,805 p/cm ³	1	4350	359	1.00	(0.96, 1.04)
	2	4634	369	1.01	(0.97, 1.05)
	3	4842	370	0.99	(0.94, 1.04)
	4	4809	371	1.01	(0.97, 1.05)
	5	4812	373	1.00	(0.97, 1.04)
	6	4620	372	1.04	(1.00, 1.08)
	7	4317	354	1.00	(0.95, 1.06)
	8	3951	310	0.98	(0.92, 1.05)
	9	3407	243	0.89	(0.76, 1.04)
Black Carbon IQR=0.86 µg/m ³	1	4726	387	1.03	(0.90, 1.17)
	2	5069	401	1.07	(0.94, 1.23)
	3	5261	402	1.12	(0.98, 1.28)
	4	5246	403	0.97	(0.85, 1.12)
	5	5224	407	1.04	(0.91, 1.19)
	6	5017	394	1.05	(0.91, 1.20)
	7	4688	375	1.12	(0.96, 1.29)
	8	4327	339	1.04	(0.89, 1.21)
	9	3777	267	0.89	(0.74, 1.06)
Delta-C IQR=0.52 µg/m ³	1	4726	387	1.03	(0.87, 1.21)
	2	5069	401	1.08	(0.93, 1.27)
	3	5261	402	1.07	(0.91, 1.26)
	4	5246	403	1.01	(0.86, 1.19)
	5	5224	407	1.10	(0.93, 1.30)
	6	5017	394	1.12	(0.95, 1.33)
	7	4688	375	1.21	(1.01, 1.45)
	8	4327	339	1.18	(0.98, 1.43)
	9	3777	267	1.14	(0.92, 1.41)
PM _{2.5} IQR=3.64 µg/m ³	1	4361	369	0.97	(0.85, 1.11)
	2	4662	364	0.99	(0.86, 1.13)
	3	4881	370	1.01	(0.89, 1.14)
	4	4873	378	0.99	(0.87, 1.12)
	5	4851	389	1.00	(0.88, 1.13)
	6	4656	371	0.95	(0.83, 1.09)
	7	4336	345	0.97	(0.85, 1.11)
	8	3960	308	1.01	(0.87, 1.18)
	9	3486	243	0.98	(0.82, 1.17)

Pollutant	Month	N	n of HDP	OR	95% CI
UFP IQR=4,018 p/cm ³	1	4350	359	1.00	(0.98, 1.02)
	2	4634	369	1.00	(0.98, 1.02)
	3	4842	370	0.99	(0.97, 1.02)
	4	4809	371	1.00	(0.98, 1.02)
	5	4812	373	1.00	(0.98, 1.02)
	6	4620	372	1.01	(1.00, 1.03)
	7	4317	354	1.00	(0.98, 1.03)
	8	3951	310	1.01	(0.98, 1.04)
	9	3450	250	0.93	(0.86, 1.02)

N=sample size; n=cases

Adjusted for age, race/ethnicity, education, parity, multifetal gestation, year of conception, pre-pregnancy diabetes, gestational diabetes, pre-pregnancy body mass index, and birth hospital