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Comparing exposure assessment methods for traffic-related air pollution in an adverse pregnancy outcome study ☆

Jun Wu [a,*], Michelle Wilhelm [b], Judith Chung [c], Beate Ritz [b]

[a] Program in Public Health and Department of Epidemiology, Anteater Instruction and Research Office, Suite 2010, 2nd Floor, University of California, Irvine, CA 92697-3957, USA
[b] Department of Epidemiology, School of Public Health, University of California, Los Angeles, CA, USA
[c] Department of Obstetrics and Gynecology, School of Medicine, University of California, Irvine, CA, USA

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A B S T R A C T

Background: Previous studies reported adverse impacts of traffic-related air pollution exposure on pregnancy outcomes. Yet, little information exists on how effect estimates are impacted by the different exposure assessment methods employed in these studies.
Objectives: To compare effect estimates for traffic-related air pollution exposure and preeclampsia, preterm birth (gestational age less than 37 weeks), and very preterm birth (gestational age less than 30 weeks) based on four commonly used exposure assessment methods.
Methods: We identified 81,186 singleton births during 1997–2006 at four hospitals in Los Angeles and Orange Counties, California. Exposures were assigned to individual subjects based on residential address at delivery using the nearest ambient monitoring station data [carbon monoxide (CO), nitrogen dioxide (NO_2), nitric oxide (NO), nitrogen oxides (NO_x), ozone (O_3), and particulate matter less than 2.5 ($PM_{2.5}$) or less than 10 (PM_{10}) μm in aerodynamic diameter], both unadjusted and temporally adjusted land-use regression (LUR) model estimates (NO, NO_2, and NO_x), CALINE4 line-source air dispersion model estimates (NO_x and $PM_{2.5}$), and a simple traffic-density measure. We employed unconditional logistic regression to analyze preeclampsia in our birth cohort, while for gestational age-matched risk sets with preterm and very preterm birth we employed conditional logistic regression.
Results: We observed elevated risks for preeclampsia, preterm birth, and very preterm birth from maternal exposures to traffic air pollutants measured at ambient stations (CO, NO, NO_2, and NO_x) and modeled through CALINE4 (NO_x and $PM_{2.5}$) and LUR (NO_2 and NO_x). Increased risk of preterm birth and very preterm birth were also positively associated with PM_{10} and $PM_{2.5}$ air pollution measured at ambient stations. For LUR-modeled NO_2 and NO_x exposures, elevated risks for all the outcomes were observed in Los Angeles only—the region for which the LUR models were initially developed. Unadjusted LUR models often produced odds ratios somewhat larger in size than temporally adjusted models. The size of effect estimates was smaller for exposures based on simpler traffic density measures than the other exposure assessment methods.
Conclusion: We generally confirmed that traffic-related air pollution was associated with adverse reproductive outcomes regardless of the exposure assessment method employed, yet the size of the estimated effect depended on how both temporal and spatial variations were incorporated into exposure assessment. The LUR model was not transferable even between two contiguous areas within the same large metropolitan area in Southern California.

1. Introduction

Adverse pregnancy outcomes are an emotional and financial burden on families both in the short and long term, and are a major public health concern (Stillerman et al., 2008). More than half a million infants are born prematurely each year in the United States (CDC, 2005). Preterm birth is a primary cause of infant mortality and morbidity and is potentially associated with learning disabilities and other chronic conditions in adulthood (Cano et al., 2001; Dik et al., 2004; Stillerman et al., 2008). Preeclampsia, characterized

Abbreviations: CI, 95% confidence interval; CO, carbon monoxide; GIS, geographic information system; IQR, inter-quartile range; LUR, land-use regression; NO, nitric oxide; NO_2, nitrogen dioxide; NO_x, nitrogen oxides; O_3, ozone; PM_{10}, particulate matter less than 10 μm; $PM_{2.5}$, particulate matter less than 2.5 μm; OR, odds ratio

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* Corresponding author. Fax: +1 949 824 0529.
E-mail address: junwu@uci.edu (J. Wu).

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by elevated blood pressure, edema, and protein in the urine, is a multisystem disorder affecting 2–8% of pregnant women. Since the only cure is delivery of the fetus and placenta, preeclampsia is the most frequent primary reason for elective, non-spontaneous preterm birth, accounting for 30–35% of total preterm deliveries (Goldenberg et al., 2008; Meis et al., 1998).

Numerous epidemiologic studies have documented adverse effects of air pollution on pregnancy outcomes (Lacasana et al., 2005; Sram et al., 2005; Stillerman et al., 2008; Woodruff et al., 2009). Motor vehicle emissions are the principal source of ambient air pollution in most urban areas and are a significant contributor to the adverse effects of air pollution on health (Samet, 2007). Traffic emits a complex mixture of hundreds of toxic components including ultrafine particles and polycyclic aromatic hydrocarbons that have the potential to induce oxidative stress and other mechanisms leading to adverse impacts on the pregnancy and fetal development. Our prior studies in Southern California have linked traffic-related air pollution with preeclampsia (Wu et al., 2009a) and preterm birth (Ritz et al., 2000, 2007; Wilhelm and Ritz, 2005; Wu et al., 2009a).

In the current literature there are four major approaches to measure pregnant women's exposures to traffic-related air pollutants. The most widely used method relies on measurements from existing ambient monitoring stations, and some studies restrict the study population to those living within a specified distance to a monitoring station (Darrow et al., 2009; Ritz et al., 2000; Wilhelm and Ritz, 2005). In general, measurements of concentrations of pollutants at air monitoring stations have the highest temporal resolution, especially for certain gaseous pollutants such as carbon monoxide (CO) and nitrogen oxides (NO_x) that are usually measured on a continuous, hourly basis. However, due to the high cost of establishing and operating monitoring stations, the routine monitoring network for criteria pollutants is generally poor in spatial coverage and unlikely to adequately capture the high spatial heterogeneity of air pollutants directly emitted from traffic such as ultrafine particles (Hitchins et al., 2000; Zhu et al., 2002). In addition, CO may no longer be a good marker for traffic in Southern California because levels of this pollutant continue to decline, due to gasoline reformulation, and are reaching the minimum detection threshold of the routine monitoring system (Kirchstetter et al., 1999; South Coast Air Management District, 2007).

Recently, geographic information system (GIS)-based methods have been developed to better estimate exposures to traffic-specific pollutants. Some research has employed GIS tools to account for the high spatial heterogeneity of local traffic emissions with simple exposure surrogates such as distance-weighted traffic density (Wilhelm and Ritz, 2003). Other studies have either spatially interpolated measured concentrations from a small number of ambient monitoring stations (Leem et al., 2006) or developed more sophisticated land-use regression (LUR) models using data on pollutants collected in short-term intensive monitoring campaigns and supplemental GIS information for pollution sources and meteorology (Aguilera et al., 2009; Ballester et al., 2010; Brauer et al., 2008; Hoek et al., 2008; Slama et al., 2007). The GIS-based methods provide high spatial resolution in estimated concentrations, but have no or limited capabilities in characterizing temporal variability. For instance, most existing LUR models were developed using one to four 7- or 14-day measurement periods to characterize temporal variation in pollution over a year; temporal trends derived from measures taken at ambient monitoring stations were then applied to the modeled values based on the assumption that ambient monitoring site measures and LUR-modeled concentrations co-vary over space.

Another approach is to assign exposure based on air dispersion models that take into account the spatial relationship of sources and receptors, source emission strength, and meteorology parameters that influence dispersion (e.g. atmospheric stability and wind) (Wu et al., 2009a). These models output concentrations at high spatial but only moderate temporal variability because of a general lack of real-time inputs (e.g. hourly traffic counts), and a simplified treatment of meteorology, atmospheric chemistry, transport, and diffusion. More sophisticated air pollution models account for not only dispersion but also atmospheric chemistry and physical dynamics (Vutukuru et al., 2006; Zhang et al., 2006); however, these models are usually developed to simulate air quality at a relatively coarse spatial resolution (e.g. 5×5 km^2) and are computer-intensive, making them unsuitable for health studies that require both high spatial and temporal resolution. A combination of the above approaches has also been used in exposure assessment, such as integrating dispersion modeling results into LUR (Wilton et al., 2008) or developing two-stage geostatistical models that incorporate measured concentrations and information on temporally or spatially varying covariates (Fanshawe et al., 2008).

Reliable estimation of exposure to traffic-related air pollution is a complex and challenging issue, and different exposure assessment methods may account for differences in published findings (Woodruff et al., 2009). To date, only one Canadian study examined the implications of three different exposure assessment methods on the size of effect estimates for adverse birth outcomes and traffic-related air pollution exposure (Brauer et al., 2008). Compared to exposures derived from ambient monitoring stations, temporally adjusted LUR exposures were associated with somewhat more precise effect estimates [i.e. smaller confidence intervals (CIs)], but not necessarily larger effect estimates (Brauer et al., 2008).

In our study, we employed four commonly used exposure assessment methods: ambient monitor-based measurements, land-use regression modeling, CALINE4 line-source dispersion modeling, and traffic-density estimates to further examine whether traffic can be considered an important source of air pollution contributing to adverse pregnancy outcomes and to assess the impact of different exposure assessment methods on the size of effect estimates.

2. Methods

2.1. Study subjects

The study subjects resided in southern Los Angeles County and Orange County in the South Coast Air Basin of California. This area is heavily impacted by several major commuter freeways (e.g. I-405 and I-5) and main trucking routes (e.g. Interstate 710) for goods leading out of the Ports of Los Angeles and Long Beach. The study subjects were identified from a hospital-based birth database that included residential address at delivery, birth hospital, estimated date of conception (based on last menstrual period and ultrasound dating), prenatal care insurance, maternal age and race-ethnicity, maternal medical history (heart disease, chronic hypertension, previous preterm birth), preeclampsia and other maternal complications during pregnancy (diabetes, pyelonephritis), parity (first birth versus second or subsequent birth), gestational age, and the neonate's sex (Wu et al., 2009a). Diagnosis dates for the onset of preeclampsia were not available. Out of 105,092 neonatal records from the birth database, we obtained 81,186 singleton birth records after excluding multiple gestations, incomplete records including those without full residential address or missing covariate information, unsuccessfully geocoded residential addresses, and addresses outside the study region (Wu et al., 2009a).

2.2. Study design

We defined preeclampsia as the occurrence of preeclampsia (blood pressure $> 140/90$ and proteinuria) or hemolysis, elevated liver enzyme levels, and low platelet count (HELLP) syndrome at any time during pregnancy. As HELLP is on the continuum of preeclampsia severity and is relatively uncommon, we chose to combine this diagnosis with preeclampsia. Preterm birth was defined as births at less than 37 completed gestational weeks, and very preterm birth as births at less than 30 gestational weeks.