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Residential mobility during pregnancy and the potential for ambient air pollution exposure misclassification ☆

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ABSTRACT

Studies of environmental exposures and adverse birth outcomes often rely on maternal address at birth obtained from the birth certificate to classify exposure. Although the gestational age of interest is often early pregnancy, maternal addresses are not available for women who move during pregnancy when using maternal addresses abstracted from birth certificates. The aim of this study was to explore the extent of ambient air pollutant exposure misclassification due to maternal residential mobility during pregnancy among the subgroup of a New York birth cohort. The authors obtained the maternal addresses at birth from the New York Birth Certificate, and the maternal addresses by gestational age from the National Birth Defect Prevention Study for New York participants for the study period 1997–2002. Among the 1324 mothers, 172 (13.0%) moved once during pregnancy and 46 (3.5%) moved at least twice. When accounting for multiple addresses among some individuals, of the 218 mothers who moved, 38 (2.9%) moved in the 3rd to 8th weeks after conception (critical period, not exclusive from the 1st trimester), 80 (6.0%) moved in the 1st trimester, 112 (8.5%) in the 2nd trimester, and 51 (3.9%) in the 3rd trimester. Air monitoring data from the New York Department of Environmental Conservation were used as surrogates to compute the ambient ozone and PM_{10} exposures for mothers with complete residential data. This study estimates exposure using maternal address at birth obtained from birth certificates, compared to exposure estimates when using maternal addresses by gestational age obtained from maternal interview, the gold standard. Average exposures during pregnancy were similar when using interview based versus birth certificate addresses (0.035 vs. 0.035 ppm for ozone, and 20.11 vs. 20.09 $\mu g/m^3$ for PM_{10}, respectively). Kappa statistics and percent agreement were calculated to measure the degree of agreement for dichotomous exposure measurements (< median vs. > =median) and weighted kappa for quartile exposure measurements by gestational age. All the statistics indicated a high agreement between the two measurements. For mothers who moved, the majority maintained their address in the same exposure region. Given the low mobility during pregnancy and the short distance moved, the exposure assignment did not change substantially when using the more accurate interview based addresses in this study. However, the level of observed agreement may decrease for studies that require smaller geographic zones for exposure assignments or with more mobile study populations.

1. Introduction

When examining the association between residential proximity to environmental exposures and birth outcomes, maternal address at birth is often used to assign exposure status. These addresses are readily available on birth certificates (Shaw and Malcoe, 1992). The maternal address at birth is used to assign exposure with the assumption that a woman's residential address was the same throughout the pregnancy, or, if she does move, her exposure level does not change (Shaw and Malcoe, 1992). Given that the susceptibility of the fetus to environmental toxicants may vary by gestational age at the time of exposure, the use of maternal address at birth rather than maternal address at the gestational age of interest, may lead to misclassification and biased results for mothers who move during pregnancy (Canfield et al., 2006; Fell et al., 2004; Schulman et al., 1993; Khoury et al., 1988). Previous studies have found that a significant proportion of women move between the time of conception and delivery. In a case–control study of stillbirths in Canada, 12% of control mothers

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moved during pregnancy (Fell et al., 2004), while studies in California (Shaw and Malcoe, 1992) and Texas (Canfield et al., 2006) observed prevalence of moving ranging from 22% to 27% and 31% to 33%, respectively.

While previous studies examining residential proximity to exposure during pregnancy have discussed the potential bias resulting from residential mobility (Ritz et al., 2000, 2002, 2006, 2007; Maisonet et al., 2001; Maroziene and Grazuleviciene, 2002; Liu et al., 2003; Wilhelm and Ritz, 2003, 2005; Yang et al., 2003; Lin et al., 2004; Gilboa et al., 2005; Salam et al., 2005; Huynh et al., 2006; Woodruff et al., 2006; Bell et al., 2007; Hwang and Jaakkola, 2008; Rankin et al., 2009), they have not been able to assess the difference in exposure classification due to this mobility. Recently, New York State completed an analysis of air pollution and drinking water contaminants with adverse reproductive outcomes using birth certificates as the source for maternal address during pregnancy. A number of previous studies also have been using birth certificates to assess maternal exposure to ozone or PM_{10} (Ritz et al., 2000, 2002, 2006; Maisonet et al., 2001; Chen et al., 2002; Lee et al., 2003; Liu et al., 2003, 2007; Wilhelm and Ritz, 2003, 2005; Gouveia et al., 2004; Sagiv et al., 2004; Gilboa et al., 2005; Medeiros and Gouveia, 2005; Salam et al., 2005; Dugandzic et al., 2006; Hansen et al., 2006, 2007; Bell et al., 2007; Hwang and Jaakkola, 2008; Suh et al., 2008; Strickland et al., 2009). However, unlike these previous studies, we had an opportunity to examine the extent of exposure misclassification due to residential mobility during pregnancy in a small subset of the cohort.

2. Materials and methods

2.1. Study population

The study subjects are nested in the cohort used to examine air pollution and birth outcomes. The latter was a population-based cohort of all live-births (N=1 132 913) in New York State, excluding New York City, from 1995 to 2002. The maternal addresses recorded by the birth certificate were geocoded, and assigned ozone and a PM_{10} monitoring region. Regional average ozone and PM_{10} levels were calculated and assigned to each subject based on the geocoded maternal addresses recorded by the birth certificates. Risks of preterm birth, small for gestational age, and birth defects with regional ozone and PM_{10} levels were examined in this cohort.

Nested in the above cohort, infants included for this analysis are the cases and controls from the New York center of the National Birth Defects Prevention Study (NBDPS) with expected dates of delivery from October 1, 1997 to December 31, 2002. The NBDPS is an ongoing multi-center, population-based case–control study of 37 selected major structural defects. The cases and controls in the New York NBDPS were selected at birth from the Hudson Valley and Western New York. While study ascertainment was restricted to these two geographic areas, women may have moved into these two areas while pregnant but prior to giving birth and therefore have multiple addresses during pregnancy. Cases were identified from the New York State Congenital Malformations Registry and controls are a sample of live-births, without defects, selected from hospital records in the same geographic locations as the cases. Maternal residential history during pregnancy and demographic characteristics were obtained from the NBDPS maternal computer-assisted telephone interviews (CATI).

A total of 1455 of those in the original cohort for air pollution and birth outcomes study were included in the NBDPS subjects in New York. Of those, 1324 mothers had complete residential history (as obtained from the CATI) during pregnancy and reported a combined total of 1958 unique addresses on the maternal questionnaires. The maternal addresses collected from maternal questionnaire were geocoded at the street level using Map Marker Plus (Mapinfo Corp., 2005, Troy, NY) and CASS (a system used by the US Postal Service to format addresses). Of the 1958 addresses, 1321 (67.5%) were geocoded automatically at the street level and 440 (22.5%) were geocoded using CASS at the zip code level. Of the 1455 mothers with birth certificate addresses, 131 (9.0%) had insufficient information in the CATI for geocoding maternal addresses during pregnancy and were excluded from the analysis.

2.2. Exposure assessment

Both the ambient concentrations of ozone and PM_{10} were monitored by New York Department of Environmental Conservation (DEC). As of December 1998, PM_{10} is no longer monitored by DEC. Therefore, ozone monitoring data were available during the entire study period, while PM_{10} monitoring data were available for only two years (1997–1998). Thirty-two ozone monitoring stations and 41 PM_{10} monitoring stations in the state are included within the state boundaries. Ambient ozone concentration was measured daily on an hourly basis. The 8-h average (10:00 am to 6:00 pm) ozone concentration data were used for calculating the exposure, which represents peak outdoor exposure. Ambient PM_{10} was measured daily every 6 days and PM_{10} concentrations were calculated with the assumption that concentrations were constant for the 5 days following measurement.

The air pollutant cohort study examined ambient ozone and PM_{10} because the two pollutants were most widely measured among the monitoring stations across the state. While PM_{10} monitoring has been replaced by $PM_{2.5}$, there are fewer monitoring sites for $PM_{2.5}$ and, therefore, the cohort study examined the health impact of PM_{10}. In addition, pollutants easily affected by traffic, such as NO_x and CO or by industrial activity such as SO_2, were not chosen for analysis in the original cohort study, because the concentrations of these pollutants vary by distance and thus the monitoring data of those pollutants only represent the ambient concentrations in the places near the monitoring sites. Since the mothers' addresses were generally far away from the monitoring sites (minimum=0.3 miles, 1st quartile=5.9 miles, median=10.0 miles, 3rd quartile=15.5 miles, maximum=66.2 miles), the ambient monitoring data might be less relevant to mothers' actual exposure to these types of air pollutants.

Ambient air pollutant exposures were measured in a group average approach for the cohort study. It divides the state into several regions, and each region contains one or more monitoring sites. If a monitoring region contains more than one monitoring station, values from multiple sites were averaged to produce the regional air pollutant concentration. Air pollutant monitoring regions were decided based on the spatial and temporal correlations, wind direction, and traffic pattern among the monitors (Lin et al., 2008). Of the resulting 11 ozone regions and eight PM_{10} regions, seven ozone regions (see Fig. 1) and seven PM_{10} regions (see Fig. 2) overlapped with the study regions of the New York NBDPS case–control study and are included in our analysis.

The map of geocoded maternal addresses was overlaid onto the ozone and PM_{10} region maps using MapInfo (Mapinfo Corp., 2005). We assigned daily ambient air pollutant exposures to each birth certificate record with exposure regions assigned previously, and to each address recorded from the NBDPS interview. Since day was unknown, we used 15th of the month as the assigned calendar days for moving in and out of a residence following Canfield et al. (2006). For each woman, the average ambient ozone and PM_{10} concentrations were calculated for the critical period defined as the 3rd to 8th week of pregnancy (a period of susceptibility for birth defects), each trimester and the end of pregnancy. Based on the distribution of estimated exposure among controls, the exposures were categorized into both dichotomous (<median vs. >=median) and quartile categories to be comparable with previous studies of air pollutants and birth defects (Ritz et al., 2002, Gilboa et al., 2005), birthweight and/or preterm birth (Salam et al., 2005; Bell et al., 2007; Rogers and Dunlop, 2006; Ritz et al., 2007).

2.3. Demographic characteristics

Demographic factors were obtained from both the NBDPS maternal interview and the birth certificates. The information from the maternal interview included: maternal age (categorized as: <20, 20–24, 25–29, 30–34, and 35+), education (<=12 years vs. >12 years), body mass index (BMI) (<18.5, 18.5–25, 25–30, and 30+), race and ethnicity (Hispanic, non-Hispanic White, non-Hispanic Black, and other), smoking status (yes/no) and alcohol consumption during pregnancy (yes/no). Because 14.7% of all subjects had household income missing in the questionnaire, "method of payment" (Medicaid, health maintenance organization, other private health insurance, and self-pay) was abstracted from the birth certificate as a surrogate for socio-economic status. A final variable, "month prenatal care began" (month 1–3, month 4–6, and month 7+) was also abstracted from the birth certificate. We also created a dichotomous variable for distance moved, with a cut-point set at 8.7 miles (the 75th percentile of distance moved).

2.4. Statistical analysis

Following the method of Canfield et al. (2006), we compared maternal mobility during the three months before pregnancy, each trimester, and at birth. We also calculated the mobility frequency during the 3rd to 8th gestational weeks (not mutually exclusive from the 1st trimester). The count of moving was by person for each period of pregnancy. For example, if a mother moved twice during the first trimester, she was counted only once during that trimester; if a woman moved once in the first trimester and once in the second trimester, she would be counted once for each trimester. A Chi-square test was used to determine whether mobility patterns differed by case status.

We compared the exposure classification based on the maternal residential history addresses from maternal questionnaire, the gold standard, and the classification based on the maternal address at birth from the birth certificate. As controls represented the general population in case–control epidemiology studies, the distributions of the two measurements among controls were determined for the same gestational ages as described above. Based on the median and quartile cutpoints of the estimated exposures among controls, the exposure status of cases and controls was assigned.

The regular and weighted Cohen's Kappa statistics, as well as percent agreement were calculated to evaluate the agreement between the two classification methods for both case and control mothers. Both Kappa statistics and percent agreement can be used for assessment of validity, to compare the test results of a measurement to a "gold standard" (Szklo and Javier Nieto, 2006). The Kappa statistics were calculated for dichotomous exposure measurements (< median vs. > =median) and weighted Kappa for quartiles (< 25%, 25–50%, 50–75%, 75%+).

Further, stratified analyses were completed to determine whether agreement varied by certain demographic characteristics associated with maternal mobility during pregnancy (e.g. age). In addition, analyses were stratified on NBDPS study region (Western New York and Hudson Valley NYC Metro) to assess whether agreement varied by region location and size. The analyses were also stratified by the geocoding levels (zip code centroid vs. street). Finally, stratified analyses by distance moved were completed.

We excluded mothers with a geocoded birth certificate address but no geocoded addresses for the different gestational ages of pregnancy (n=131) from the maternal questionnaire. Since these women would likely be included in any study using birth certificates as a basis for assigning exposure, and given that the majority reported moving during pregnancy (n=97), we completed a sensitivity analysis to examine the range of exposure misclassification within this subset using the method described by Greenland and Rothman (Greenland and Rothman, 2008). For mothers with incomplete address information, the sensitivity analysis considered three scenarios: (1) only those who moved from foreign countries or

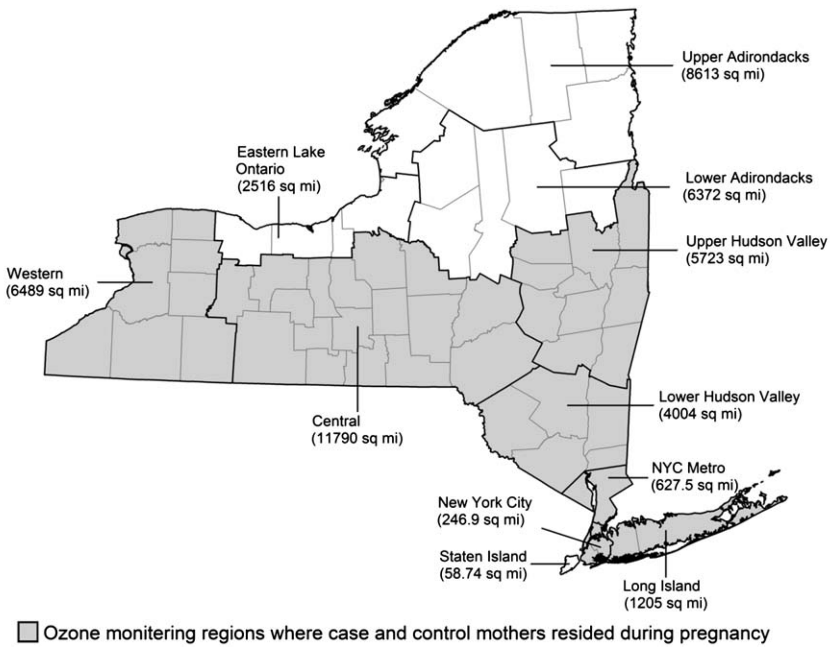

Fig. 1

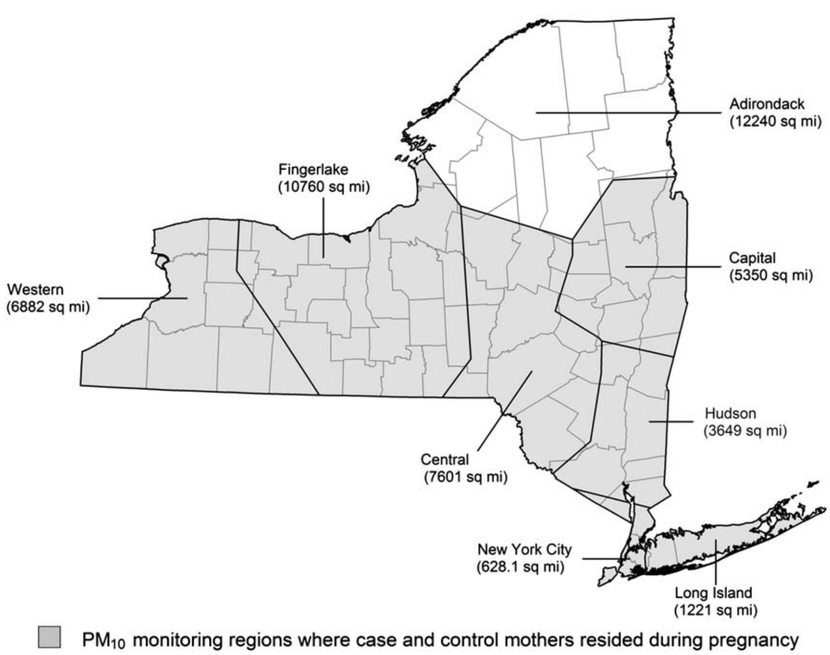

Fig. 2

from other states were misclassified; (2) only those who moved during pregnancy were misclassified; and (3) all 131 mothers were misclassified due to residential mobility. The dichotomous exposure measurements were compared for the three scenarios using Kappa statistics.

3. Results

There were 218 (16.5%) mothers moving during pregnancy. Among them 172 (13.0%) moved once and 46 (3.5%) moved at least twice. The prevalence of moving was similar between cases (8.8%) and controls (9.0%) during the three months before pregnancy (χ^2=0.02, p=0.9). During pregnancy, 17.4% case mothers and 14.3% control mothers moved. Case mothers moved more often than control mothers in each period of pregnancy (3.2% vs. 2.2% in 3rd to 8th weeks, 6.5% vs. 5.1% in the 1st trimester, 9.4% vs. 6.3% in the 2nd trimester, and 4.1% vs. 3.4% in the 3rd trimester), but not at a level of difference that was statistically significant (all chi-square tests had a p-value>0.1) (data not shown). Mobility was greatest in the second trimester. The average distance women moved during pregnancy was 10.4 miles (minimum=0.0 miles, maximum=299.3 miles, median=2.6 miles). Of those who moved, 29.7% (n=65) moved between New York State counties, but only 15.2% (n=33) moved between air pollutant monitoring regions and 18.8% (n=41) changed their closest monitoring sites.

As controls represented the general population, Table 1 describes the demographic characteristics by mobility status for control mothers by the critical period and each trimester. Women who moved were more likely to be younger, nulliparous, have low BMI, to smoke, to consume alcohol, to be non-White, be eligible for Medicaid, and to have sought prenatal care after the 3rd month of pregnancy compared to mothers who did not move during pregnancy.

The ambient ozone and PM_{10} concentrations calculated for control mothers by address source are presented in Table 2. The exposure assignments calculated for addresses by gestational age were similar to those calculated for maternal address at birth. Based on the distribution of estimated concentrations in Table 2, exposure statuses were assigned to both cases and controls. The Kappa statistics and percent agreement were presented in Table 3. The regular and weighted Kappa statistics and percent agreement were close to one for all comparisons (Table 3). All the Kappa statistics were statistically significant (p-values<0.001) for the critical period and each trimester. The agreement was highest during the critical period, and decreased slightly with increasing gestational age. The pattern remained the same for both ozone and PM_{10} exposures in spite of the different monitoring time periods of these two exposures. The correlation coefficients for continuous exposure measures were examined and the similar results were observed.

To examine if the agreement statistics differed by demographic characteristics, we stratified on these characteristics. The statistics were not different by demographic strata (data not shown). Similarly, the statistics did not vary by region of birth (Western New York and Hudson Valley region) (data not shown), or by level of geocoding results (zip code centroid vs. street). Given that the day of moving was not recorded in the NBDPS, we completed analysis using both the 1st and 15th of each month as the assigned day and results were not measurably different (data not shown). Only the results for the 15th of the month are presented here.

Finally, to assess whether misclassification differed by distance moved, we examined agreement by distance moved. As is stated above, the average distance of moving during pregnancy was 10.4 miles among our study population, with a range of 299 miles. When comparing mothers who moved more than 8.7 miles (the 75th percentile of distance moved) to mothers who moved a shorter distance, no discernible difference between the agreements was observed (data not shown).

A sensitivity analysis was completed for the 131 mothers who had incomplete maternal address history during pregnancy. Of the 131 mothers, 97 reported moving during pregnancy. Among those who moved, 15 moved to New York State from foreign countries, 44 moved from within the United State, 36 moved within New York and 2 did not provide address history. The distribution of demographic characteristics for these mothers was not different from that of the mothers with complete address information (data not shown). Kappa statistics and percent agreement for the three scenarios of sensitivity analyses are shown in Table 4. The Kappa values for the critical period and each trimester were above 0.8 (p-value <0.0001) for all comparisons. All but one percent agreement statistics were above 90%. As with our primary analysis, the degree of agreement was highest during the critical period and early pregnancy.

4. Discussion

We did not observe significant evidence of exposure misclassification by using maternal address at birth as a surrogate for the maternal addresses by gestational age. The mobility of pregnant women in our study population was much lower than those reported in California (Shaw and Malcoe, 1992) or in Texas (Fell et al., 2004). This pattern might be due to the fact that our study subjects were sampled from Hudson Valley and Western New York, where the populations are relatively stable. With a range of 299 miles, the moving distances were highly skewed, since three quarters of the pregnant women moved within 9 miles and 95% within 29 miles. Such short distance did not change most women's air pollutant region assignment or their closest monitoring stations. Therefore, the exposure misclassification due to the mobility was minimized.

As with previous studies, maternal mobility during pregnancy was associated with several demographic characteristics such as smoking, income, education and maternal age (Canfield et al., 2006; Fell et al., 2004; Shaw and Malcoe, 1992). However, unlike Khoury et al., 1988 and Canfield et al., 2006, we did not find differential mobility by ethnicity.

There was high agreement between the two exposure classification methods (address at birth versus address at specified gestational ages) for both ozone and PM_{10} using both dichotomous and categorical cutpoints. Agreement decreased slightly as gestational age increased. The level of agreement did not vary by strata of demographic characteristics or case status. Similarly, good agreement was maintained when mothers with incomplete address history during pregnancy were evaluated in a sensitivity analysis.

Misclassification may be a function of both mobility and the size of the exposure regions. In our study, about 30% of maternal mobility during pregnancy occurred between New York State counties. However, women seldom moved between monitoring regions because the regions were much larger in size compared to counties. Even the smallest exposure buffers (e.g. New York City at 246.9 sq miles) were large in size. Therefore, in studies with large exposure regions, using the birth certificate address is likely to result in little to no misclassification. Given that the average distance of moving during pregnancy was 10.4 miles and in our study population (with a range up to 299 miles), it is likely that exposure misclassification would be greater in studies of environmental exposures with smaller exposure assessment ranges (e.g. proximity to drift from applications of agricultural pesticides or estimation of disinfection by-products in drinking water). The next step of our study will be to examine the impact of maternal mobility during pregnancy when assessing these types of exposure.

The exposure measurement employed in this study is a group average approach, which drew a large exposure boundary for each maternal address. Other approaches such as using the closest monitors or inverse distance weighting of near monitors, as would be needed for SO_2 or CO, may decrease the size of the exposure region and increase the potential for bias due to mobility. However, if such an approach had been used in this study, fewer than 4% of case mothers and 1% of control mothers moved to a location during pregnancy that would change their closest monitor assignment. Therefore, the observed results are unlikely to differ. Further, given the minimal misclassification in this analysis, we would not anticipate variation in the observed estimates by analytic technique.

With such a small amount of misclassification, we would expect minimal impact on the association estimates (such as odds ratio) observed in the previous air pollution and birth outcome cohort study. For example, assuming a population of 1500 with 7% outcome prevalence, and 50% exposure prevalence among controls, 4% of residences would need to be non-differentially misclassified to change the observed odds ratio from 1.3 to 1.1, and 7% for a change from 1.3 to 1.0. As less than 1% of the pregnant women were misclassified for ozone exposure during each pregnancy period and less than 3% during the total pregnancy, the bias on the association observed by the cohort study using birth certificate for exposure assessment is expected to be minimal.

It should be noted that the exposure we have been discussing is outdoor instead of indoor or personal exposure. As the average distance from maternal addresses to the ambient air monitor sites was over 10 miles, the current monitoring data from the DEC sites are not appropriate to explore more personal exposures such as indoor or traffic-related air pollutant exposures.

Table 1
Distribution of demographic characteristics among the control mothers by moving status and gestational age, National Birth Defects Prevention Study, New York, 1997–2002.

	3rd–8th gestational weeks		Trimester 1		Trimester 2		Trimester 3		Total pregnancy	
	Moved[a,b]	Not moved[a,b]	Moved	Not moved	Moved	Not moved	Moved	Not moved	Moved	Not moved
Total number (of controls)	9 (2.2)	403 (97.8)	21 (5.1)	391 (94.9)	26 (6.3)	386 (93.7)	14 (3.4)	398 (96.6)	59 (14.3)	353 (85.7)
Parity										
0	5 (55.6)	124 (30.8)	10 (47.6)	119 (30.4)	11 (42.3)	118 (30.6)	5 (35.7)	124 (31.2)	24 (40.7)	105 (29.8)
1	1 (11.1)	178 (44.2)	5 (23.8)	174 (44.5)	11 (42.3)	168 (43.5)	4 (28.6)	175 (44.0)	20 (33.9)	159 (45.0)
2+	3 (33.3)	101 (25.1)	6 (28.6)	98 (25.1)	4 (15.4)	100 (25.9)	5 (35.7)	99 (24.9)	15 (25.4)	89 (25.2)
Race/ethnicity										
Hispanic	2 (22.2)	37 (9.2)	4 (19.1)	35 (9.0)	0 (0.0)	39 (10.1)	2 (14.3)	37 (9.3)	6 (10.2)	33 (9.4)
non-Hispanic Black	2 (22.2)	53 (13.2)	5 (23.8)	50 (12.8)	4 (15.4)	51 (13.2)	4 (28.6)	51 (12.8)	13 (22.0)	42 (11.9)
Non-Hispanic White	5 (55.6)	285 (70.7)	12 (57.1)	278 (71.1)	22 (84.6)	268 (69.4)	8 (57.1)	282 (70.9)	40 (67.8)	250 (70.8)
Other	0 (0.0)	28 (7.0)	0 (0.0)	28 (7.2)	0 (0.0)	28 (7.3)	0 (0.0)	28 (7.0)	0 (0.0)	28 (7.9)
Alcohol										
No	7 (77.8)	216 (53.6)	15 (71.4)	208 (53.2)	9 (34.6)	214 (55.4)	6 (42.9)	217 (54.5)	29 (49.2)	194 (55.0)
Yes	2 (22.2)	184 (45.7)	5 (23.8)	181 (46.3)	16 (61.5)	170 (44.0)	7 (50.0)	179 (45.0)	28 (47.5)	158 (44.8)
Smoke										
No	7 (77.8)	310 (76.9)	15 (71.4)	302 (77.2)	17 (65.4)	300 (77.7)	8 (57.1)	309 (77.6)	39 (66.1)	278 (78.8)
Yes	2 (22.2)	93 (23.1)	6 (28.6)	89 (22.8)	9 (34.6)	86 (22.3)	6 (42.9)	89 (22.4)	20 (33.9)	75 (21.3)
Education										
> High school	3 (33.3)	268 (66.5)	6 (28.6)	265 (67.8)	14 (53.9)	257 (66.6)	12 (85.7)	259 (65.1)	31 (52.5)	240 (68.0)
≤ High school	6 (66.7)	133 (33.0)	15 (71.4)	124 (31.7)	12 (46.2)	127 (32.9)	2 (14.3)	137 (34.4)	28 (47.5)	111 (31.4)
Method of payment										
Medicaid	6 (66.7)	80 (19.9)	10 (47.6)	76 (19.4)	7 (26.9)	79 (20.5)	5 (35.7)	81 (20.4)	22 (37.3)	64 (18.1)
Health Maintenance Organization	3 (33.3)	210 (52.1)	10 (47.6)	203 (51.9)	14 (53.9)	199 (51.6)	6 (42.9)	207 (52.0)	28 (47.5)	185 (52.4)
Other private health insurance	0 (0.0)	102 (25.3)	1 (4.8)	101 (25.8)	4 (15.4)	98 (25.4)	2 (14.3)	100 (25.1)	7 (11.9)	95 (26.9)
Self-pay	0 (0.0)	3 (0.7)	0 (0.0)	3 (0.8)	1 (3.9)	2 (0.5)	0 (0.0)	3 (0.8)	1 (1.7)	2 (0.6)
Maternal age at delivery										
≤ 19	3 (33.3)	18 (4.5)	16 (27.1)	49 (5.7)	11 (12.8)	54 (6.5)	6 (16.2)	58 (6.7)	24 (15.1)	41 (5.4)
20–24	3 (33.3)	68 (16.9)	23 (39.0)	133 (15.6)	22 (25.6)	134 (16.2)	10 (27.0)	144 (16.7)	47 (29.6)	109 (14.5)
25–29	2 (22.2)	111 (27.5)	7 (11.9)	209 (24.5)	25 (29.1)	191 (23.1)	10 (27.0)	201 (23.2)	40 (25.2)	176 (23.4)
30–34	1 (11.1)	126 (31.3)	9 (15.3)	276 (32.4)	18 (20.9)	267 (32.3)	5 (13.5)	279 (32.3)	30 (18.9)	255 (33.9)
35–50	0 (0.0)	80 (19.9)	4 (6.8)	186 (21.8)	10 (11.6)	180 (21.8)	6 (16.2)	183 (21.2)	18 (11.3)	172 (22.8)
BMI										
Underweight	1 (11.1)	21 (5.2)	6 (10.2)	39 (4.6)	3 (3.5)	42 (5.1)	3 (8.1)	41 (4.7)	11 (6.9)	34 (4.5)
Normal	4 (44.4)	223 (55.3)	34 (57.6)	469 (55.0)	53 (61.6)	450 (54.5)	24 (64.9)	476 (55.0)	94 (59.1)	409 (54.3)
Overweight	1 (11.1)	96 (23.8)	9 (15.3)	166 (19.5)	11 (12.8)	164 (19.9)	4 (10.8)	169 (19.5)	22 (13.8)	153 (20.3)
Obese	2 (22.2)	52 (12.9)	10 (17.0)	154 (18.1)	16 (18.6)	148 (17.9)	5 (13.5)	155 (17.9)	28 (17.6)	136 (18.1)
Month prenatal care began										
1–3	2 (22.2)	328 (81.4)	12 (57.1)	318 (81.3)	21 (80.8)	309 (80.1)	9 (64.3)	321 (80.7)	41 (69.5)	289 (81.9)
4–6	6 (66.7)	43 (10.7)	7 (33.3)	42 (10.7)	2 (7.7)	47 (12.2)	4 (28.6)	45 (11.3)	12 (20.3)	37 (10.5)
7 +	0 (0.0)	10 (2.5)	0 (0.0)	10 (2.6)	3 (11.5)	7 (1.8)	1 (7.1)	9 (2.3)	4 (6.8)	6 (1.7)

[a] Percent in parenthesis.
[b] Percent may not sum to 100% due to missing data.

Table 2
Distribution of the MI[a] ambient ozone and PM_{10} exposures and the difference between BC[b] and MI exposures for control mothers, NBDPS, New York, 1997–2002.

	3rd–8th weeks		Trimester 1		Trimester 2		Trimester 3		Total pregnancy	
	MI	Diff[c]	MI	Diff	MI	Diff	MI	Diff	MI	Diff
Ozone (ppm*100)										
N	412 (9)[d]		412 (21)		412 (26)		411 (14)		412 (59)	
Mean	3.45	–[e]	3.45	–	3.47	0.01	3.55	0.01	3.50	0.01
Std. deviation	1.05	–	0.93	–	1.00	0.01	0.99	–	0.44	–
100% Max	5.60	–	5.10	0.12	5.22	–	5.59	–	4.41	–
75% Q3	4.34	−0.01	4.29	–	4.35	0.02	4.41	–	3.85	0.01
50% Median	3.41	–	3.49	–	3.47	0.02	3.69	−0.02	3.49	0.02
25% Q1	2.59	–	2.61	–	2.52	–	2.68	–	3.17	0.01
0% Min	0.96	0.37	1.08	0.48	1.45	–	1.38	0.11	2.46	–
PM_{10} ($\mu g/m^3$)										
N	94 (2)		94 (5)		94 (9)		94 (5)		94 (18)	
Mean	20.72	−0.01	20.75	0.06	20.36	0.18	19.01	–	20.11	−0.02
Std. deviation	7.25	−0.04	5.61	–	5.48	−0.06	5.20	−0.04	2.93	−0.29
100% Max	44.13	–	36.08	–	35.12	–	30.49	–	29.47	−2.25
75% Q3	25.55	–	25.57	–	25.25	0.04	21.65	–	21.89	−0.41
50% Median	19.93	–	20.38	–	19.04	0.52	17.51	–	19.79	–
25% Q1	14.80	–	15.98	0.18	15.67	0.15	14.97	–	18.11	0.14
0% Min	9.63	–	11.06	–	10.03	1.10	11.08	–	12.99	1.80

[a] MI=Exposure calculated based on maternal addresses by gestational age from maternal interview.
[b] BC=Exposure calculated based on maternal addresses at birth from the birth certificate.
[c] Difference between the BC exposures and MI exposures (MI exposures+Diff=BC exposures).
[d] Number of control mothers who moved in parenthesis.
[e] No difference.

Table 3
The Kappa[a] and weighted[b] Kappa statistics and percent agreement[c] between the MI[d] and BC[e] ozone and PM_{10} exposures for case and control mothers, NBDPS, New York, 1997–2002.

	Ozone		PM_{10}	
	Case	Control	Case	Control
3rd–8th weeks				
N	912	412	260	94
Kappa[f]	0.99	1.00	1.00	1.00
Weighted Kappa[f]	0.98	0.99	0.99	1.00
Percent agreement (%)	99.78	100.00	100.00	100.00
Trimester 1				
N	912	412	245	94
Kappa[f]	1.00	1.00	1.00	1.00
Weighted Kappa[f]	0.99	0.99	0.97	0.97
Percent agreement (%)	99.78	100.00	100.00	100.00
Trimester 2				
N	912	412	200	94
Kappa[f]	0.98	1.00	0.89	0.98
Weighted Kappa[f]	0.98	0.98	0.93	0.93
Percent agreement (%)	99.34	100.00	94.50	99.07
Trimester 3				
N	901	411	176	94
Kappa[f]	0.99	0.99	0.96	1.00
Weighted Kappa[f]	0.99	0.98	0.97	0.98
Percent agreement (%)	99.45	99.27	98.30	100.00
Total pregnancy				
N	912	412	178	94
Kappa[f]	0.95	0.98	0.93	0.96
Weighted Kappa[f]	0.96	0.95	0.90	0.91
Percent agreement (%)	97.81	99.03	96.63	97.87

[a] Kappa for dichotomous classification (< median vs. > =median).
[b] Weighted Kappa for quartile classification (< 25%, 25–50%, 50–75%, 75%+).
[c] Percent agreement for dichotomous classification (< median vs. > =median).
[d] MI=Exposure calculated based on maternal addresses by gestational age from maternal interview.
[e] BC=Exposure calculated based on maternal addresses at birth from the birth certificate.
[f] $p < 0.0001$.

Table 4
The simulated Kappa statistics between the MI[a] and BC[b] ozone and PM_{10} exposures for case and control mothers including those whose residential history was not completely geocoded, NBDPS, New York, 1997–2002.

	Scenario I[c]		Scenario II[d]		Scenario III[e]	
	Case	Control	Case	Control	Case	Control
3rd–8th weeks						
N	1006	449	1006	449	1006	449
Kappa[f]	0.91	0.92	0.87	0.87	0.81	0.84
Percent agreement (%)	95.72	95.99	93.43	93.54	90.45	91.76
Trimester 1						
N	1006	449	1006	449	1006	449
Kappa[f]	0.91	0.92	0.87	0.87	0.81	0.84
Percent agreement (%)	95.73	95.99	93.44	93.54	90.46	91.76
Trimester 2						
N	1006	449	1006	449	1006	449
Kappa[f]	0.91	0.92	0.86	0.87	0.80	0.84
Percent agreement (%)	95.33	95.99	93.04	93.54	90.06	91.76
Trimester 3						
N	995	448	995	448	995	448
Kappa[f]	0.91	0.91	0.86	0.86	0.80	0.82
Percent agreement (%)	95.38	95.31	93.07	92.86	90.05	91.07
Total pregnancy						
N	1006	449	1006	449	1006	449
Kappa[f]	0.88	0.9	0.83	0.85	0.78	0.82
Percent agreement (%)	93.94	95.10	91.65	92.65	88.67	90.87

[a] MI=Exposure calculated based on maternal addresses by gestational age from maternal interview of the NBDPS.
[b] BC=Exposure calculated based on maternal addresses at birth from the birth certificate.
[c] Scenario I=among the mothers whose residential history not completely geocoded, those who moved from foreign countries or from other states were assumed to be misclassified.
[d] Scenario II=among the mothers whose residential history not completely geocoded, those who moved during pregnancy were misclassified.
[e] Scenario III=all the mothers whose residential history not completely geocoded were misclassified.
[f] $p < 0.0001$.

There are several other limitations regarding the ambient air pollutant exposure measurements. First, the large PM_{10} monitoring region definition could overlook the variation caused by local sources, and the PM_{10} monitoring data were only available for two of the six study years. However, results were similar for PM_{10} and ozone exposures, and ozone levels were less affected by the large region definition and were available throughout the study period. Another limitation is that the starting and stopping date of each residence only specified month and year in the NBDPS maternal interview. We arbitrarily assigned the 15th of the month for all study participants. Results did not vary when we reexamined the data using the first of the month as the moving day. A last limitation is that the study subjects were selected at birth from the two regions in upstate New York. Therefore, the results may not be generalizable to children born in New York City due to the differences in exposure levels and demographic characteristics for that region of New York State.

In conclusion, the results of our analysis show that the maternal address at birth was a good surrogate for maternal address by gestational age for studies of ambient air pollutants and birth outcomes using large exposure regions. During the early stage of pregnancy, which is the most critical time period for examining birth defects, maternal mobility was less common, and the misclassification of exposure was low compared to later stages in pregnancy. The small impact of maternal mobility on the exposure classification from address at birth may be due to the large size of the air pollutant monitoring regions. The level of observed agreement may decrease for studies that require a smaller geographic zone for exposure assignments. Future studies are needed to assess the impact of maternal mobility on exposure classification by varying exposure buffer size.

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