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Low-level Prenatal Toxin Exposures and Breastfeeding Duration: a Prospective Cohort Study

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Abstract

Introduction—Maternal exposure to tobacco smoke is associated with shortened breastfeeding duration, but few studies have examined the effects on breastfeeding outcomes of low level exposures to other toxic chemicals. Moreover, it is unclear if passive smoking is associated with duration of breastfeeding. Our objective was therefore to examine the effect of low-level prenatal exposures to common environmental toxins (tobacco smoke, lead, and phthalates) on breastfeeding exclusivity and duration.

Methods—We conducted an analysis of data from the HOME (Health Outcomes and Measures of the Environment) Study. Serum and urine samples were collected at approximately 16 and 26 weeks gestation and at delivery from 373 women; 302 breastfed their infants. Maternal infant feeding interviews were conducted a maximum of 8 times through 30 months postpartum. The main predictor variables for this study were gestational exposures to tobacco smoke (measured by serum cotinine), lead, and phthalates. Passive smoke exposure was defined as cotinine levels of 0.015–3.0 µg/mL. Primary outcomes were duration of any and exclusive breastfeeding.

Results—Serum cotinine concentrations were negatively associated with the duration of any breastfeeding (29.9 weeks unexposed vs. 24.9 weeks with passive exposure, $p=0.04$; and 22.4 weeks with active exposure, $p=0.12$; $p=0.03$ for linear trend), but not duration of exclusive

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Declarations:

Dr. Lanphear has served as an expert witness and a consultant to the California Attorney General's Office for the plaintiffs in a public nuisance case related to childhood lead poisoning, but he has not personally received any compensation for these services. Dr. Lanphear has also served as a paid consultant on a US Environmental Protection Agency research study related to childhood lead poisoning. None of these activities are directly related to the present study.

breastfeeding. Prenatal levels of blood lead and urinary phthalate metabolites were not significantly associated with duration of any or exclusive breastfeeding.

Conclusions—Passive exposure to tobacco smoke during pregnancy was associated with shortened duration of any breastfeeding.

Keywords

breastfeeding; duration; prenatal; exposures; secondhand smoke; environmental tobacco smoke; cotinine; phthalates; lead

Introduction

Environmental contaminants, such as tobacco smoke, lead and phthalates, are transferred from mothers to infants transplacentally and via breast milk (Green and Marsit 2015; Dzwilewski and Schantz 2015; Shah-Kulkarni et al. 2016; LaKind et al. 2008; Kim et al. 2014). Research on the impact of environmental toxins on breastfeeding has focused on breast milk as a vehicle of infant exposure. (LaKind et al. 2004; LaKind et al. 2008; LaKind et al. 2015; Kim et al. 2015). Few studies have examined the effects on breastfeeding outcomes of low-level exposures to toxins during pregnancy. The Health Outcomes and Measures of the Environment (HOME) Study is a prospective cohort study of pregnant women and their infants to examine the impact of common environmental toxins on children's health (Werner et al. 2015). Data were collected on breastfeeding, and toxins were evaluated for associations with breastfeeding outcomes. One recent report from this cohort found a shortened duration of breastfeeding at higher levels of serum perfluoroalkyl concentrations in pregnancy (Romano et al. 2016), raising the concern that other environmental contaminants may have a similar impact. Therefore, we sought to determine whether an association exists between breastfeeding outcomes and prenatal exposures to tobacco smoke, lead and phthalates, as they represent some of the most common household toxins (Jurewicz et al. 2013).

Breastfeeding initiation and duration appear to be negatively affected by both active and passive maternal smoking (Chou et al. 2008; Donath and Amir 2004; Kehler et al. 2009; Liu et al. 2006; Weiser et al. 2009; Amir and Donath 2002). Some studies have shown a dose-response relationship (Amir and Donath 2002), and stopping smoking in pregnancy may improve duration (Liu et al. 2006). The impact of prenatal passive exposure to tobacco smoke has been less widely studied, but has been associated with shortened breastfeeding duration. In the Krakow inner city prospective cohort study, 441 healthy 18–35 year old non-smoking women had blood cotinine levels measured at delivery. Women in high-exposure groups had higher risk of early cessation of any and exclusive breastfeeding (Jedrychowski et al. 2008a). Another group of 6747 Chinese infants were recruited in 1997–8 and followed for 9 months (Leung et al. 2002). Passive exposure to tobacco smoke in utero and postpartum were related to lower breastfeeding initiation but not duration in this sample. The impact of prenatal passive exposure on breastfeeding duration may be mediated by hormonal disruption or by toxic impacts on the developing mammary gland, which undergoes rapid hyperplasia and differentiation in pregnancy. Cotinine, a metabolite of nicotine, can be used

as a reliable biomarker of tobacco smoke exposure and can be measured in the urine or serum (Jedrychowski et al. 2008a; CDC 2008).

Though there are studies on the transfer of lead to children via breastmilk, there are no studies of its effect on breastfeeding duration. Lead is well-known heavy metal toxin that has many sources, though it is predominantly found in areas highly exposed to lead-based paint and gasoline. Its effects on neurodevelopment are well-described, and are attributed to the interruption of varied cellular processes and therefore on neurological cellular organization (Garza et al. 2006). As lead freely passes the placenta, it is not surprising that that low-level prenatal exposures to lead may also affect children's neurodevelopment (Shah-Kulkarni et al. 2016). Other heavy metals and metalloids, such as arsenic, mercury and cadmium, have been implicated as endocrine disruptors, though lead is not described in this way and the Endocrine Society calls for more research in this area. (Gore et al. 2015). It is therefore conceivable that lead could also play a role in endocrine pathways, thereby affecting breastfeeding and breastfeeding outcomes. Its effect on breastfeeding outcomes is therefore of interest because of its known toxic effects and high prevalence in the environment.

Phthalates are endocrine disruptors widely used in consumer and personal care products, and can enter the body by inhalation, ingestion, or skin absorption (Johns et al. 2015a Boas et al. 2012; Ye et al. 2014; Johns et al. 2015b). Higher exposures to phthalates have been associated with decreased anogenital distance (Braun et al. 2013), diminished oocyte yield for in-vitro fertilization (Hauser 2015), decreased maternal thyroid levels (Boas et al. 2012) and increased prenatal blood pressure and pregnancy-induced hypertensive diseases (Werner et al. 2015). Phthalates are metabolized and excreted in the urine. They have a short half-life, therefore urinary metabolites can be used as reasonable estimates of exposure in the past days or weeks (Braun et al. 2013).

Given the high prevalence of maternal exposure to tobacco smoke, lead, and phthalates, the biological plausibility of their impact on breastfeeding, and the lack of evidence about their effects on breastfeeding outcomes, this study aimed to test the effect of low-level prenatal exposures to these toxins on breastfeeding duration and exclusivity. A prospective birth cohort design was used to minimize reverse causality and thus strengthen the possibility that associations found may be causal.

Methods

Study sample

We conducted an analysis of data from the HOME Study, a prospective cohort study of pregnant women and their infants who were enrolled in Cincinnati, OH from 2003 to 2006 to examine the impact of common environmental toxins on children's health (Werner et al. 2015). Pregnant women were enrolled from 9 prenatal clinics associated with 3 hospitals. Inclusion criteria included maternal age over 18 years old, pregnancy gestational age of 16 +/- 3 weeks, and living in a home built in 1978 or before (due to the widespread use of lead-based paint in houses built in this time period). Women were excluded if they had HIV or were taking medicines for seizure or thyroid disorders, all known to affect infant neurodevelopment. The study was approved by the Institutional Review Board of the

Cincinnati Children's Hospital Medical Center, participating hospitals and the Centers for Disease Control and Prevention (CDC).

Measurement of exposure

The main predictor variables for this study were gestational exposures to tobacco smoke (active or passive), lead, and phthalates. Maternal whole blood, serum and urine samples were collected at about 16 (range: 10–23) and 26 (range: 19–35) weeks gestation and at delivery, with less than 1% of the 16 week samples collected after 20 weeks gestation (Werner et al. 2015). Samples were stored at or below -20°C until analysis and measured at the CDC Division of Laboratory Sciences using previously described methods (Werner et al. 2015). Figure 1 shows a study flow diagram of the collection timeline of samples and surveys. Mean values of toxin exposures over the three time points were analyzed to ensure stability of exposure over time. "Gestational exposure" was defined as the mean level of exposure at 16 and 26 weeks gestation, and at delivery.

Serum Cotinine—Cotinine was used as a biomarker of tobacco smoke exposure because of its long half-life (15–20 hours) and high serum concentrations (10-fold higher than nicotine) (Lambers and Clark 1996). Serum samples were analyzed for cotinine using high performance liquid chromatography-tandem mass spectrometry (HPLC-MS/MS). The limit of detection for this assay was $0.015\mu\text{g/mL}$ with a coefficient of variation ranging from 0.1–1 $\mu\text{g/mL}$ (Braun et al. 2010). Passive tobacco smoke exposure was defined as cotinine levels of $0.015\text{--}3.0\mu\text{g/mL}$; active tobacco exposure (active smokers) was defined as serum cotinine concentrations $>3.0\mu\text{g/mL}$. (Jedrychowski et al. 2008a; CDC 2008)

Whole Blood Lead—Whole blood samples were measured for lead by inductively coupled plasma mass spectrometry (Nixon et al. 1999) with a limit of detection of $0.3\mu\text{g/dL}$. (Nixon et al. 1999; Jones et al. 2009) Though blood lead is not a good biomarker for long-term exposures, this was mitigated by the serial measurements during gestation (Barbosa et al. 2005).

Urinary Phthalate Metabolites—We measured 9 phthalate metabolites in urine ($\mu\text{g/L}$), including mono(2-ethyl-5-carboxypentyl phthalate (MECPP), mono-(2-ethylhexyl) phthalate (MEHP), mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP), mono-2-ethyl-5-hydroxyhexyl phthalate (MEHHP), monobenzyl phthalate (MBzP), mono-3-carboxypropyl phthalate (MCP), monoethyl phthalate (MEP), mono-butyl phthalate (MBP), and monoisobutyl phthalate (MiBP), using online solid phase extraction coupled to high performance liquid chromatography-isotope dilution tandem mass spectrometry (SPE HPLC-MS/MS) (Silva et al. 2007).

Measurement of outcome

The primary outcomes for this analysis were duration of any and exclusive breastfeeding. As measures of breastfeeding initiation reflect the choice to breastfeed, rather than function of the mammary gland, we focused instead on duration, which is a closer behavioral measure of milk supply. We surveyed mothers about breastfeeding 8 times, beginning at 4 weeks postpartum and continuing until children were 30 months of age (4 weeks and 3, 6, 9, 12,

18, 24 and 30 months). Duration of any breastfeeding was determined by response to the question “What was the total length of time (in weeks) since birth that {child participant} was fed at least some breast milk?” We asked this question after the mother reported having stopped feeding breast milk during an infant feeding interview. We treated the provision of mother’s milk by expression or direct breastfeeding equally. Exclusive breastfeeding duration was defined as the number of weeks before the start of any water, juice, formula, or food. We also asked mothers about breastfeeding behaviors, including previous breastfeeding experience, current breastfeeding duration, and whether they met their breastfeeding goals. Mothers of preterm and low birth weight infants were included.

Statistical analysis

We considered various potential confounders for inclusion in our statistical models, including the socio-demographic variables of maternal race, age at delivery, mode of delivery, previous live births, previous breastfeeding experience, whether breastfeeding goals had been attained, smokers in household, income, employment, plans to return to work, marital status, biological father/grandmother in the home and parental education. Neonatal Intensive Care Unit (NICU) stay, gestational age and intra-uterine growth were also measured. Covariates were collected during the baseline prenatal survey, based on factors known to be associated with breastfeeding (Sriraman and Kellams 2016; Dagher et al 2016; McLeod et al 2002; Cernadas et al. 2003). Chi square tests were used to determine statistically significant associations between these characteristics and rates of any breastfeeding. We used linear regression analyses to identify predictors of any and exclusive breastfeeding duration. Those who reported never feeding their infant breast milk were excluded from the regression analyses. We selected covariates on the basis of their association with breastfeeding in previous studies and included maternal race (white vs non-white), household income (under \$25,000, \$25,000–\$50,000, \$50,000–\$80,000, and over \$80,000), maternal plans to return to work after delivery, previous live births and breastfeeding experience (none, > 1 birth with previous breastfeeding, >1 birth without previous breastfeeding), biological father in the home, maternal education (high school, some college, college degree and above), delivery type (vaginal vs cesarean), breastfed for as long as intended, and maternal age at delivery. These variables were tested for each outcome in stepwise linear regression models, with a significance level at entry of 0.10 and a significance level to remain in the model of 0.10.

We grouped cotinine results by exposure level as described above (passive exposure 0.015–3.0 µg/mL; active exposure >3.0 µg/mL). (Jedrychowski et al. 2008a; CDC 2008). Associations of cotinine with duration of any breastfeeding were modeled with adjustment for race and attainment of breastfeeding goals, while associations with exclusive breastfeeding duration were adjusted for race, breastfeeding goal, biological father in the home, and mode of delivery. We grouped blood lead concentrations and urinary phthalate concentrations by terciles to account for skewness of the distributions, and verified by log-transformation. Associations of lead with any breastfeeding duration were adjusted for race, attainment of breastfeeding goals, and maternal age, while associations with exclusive breastfeeding duration were adjusted for race, breastfeeding goals, biological father in the home and mode of delivery. For the models with urinary phthalates, we also included non-

transformed creatinine concentrations in the models to account for urine dilution (Barr et al. 2005). Associations of phthalates with breastfeeding duration were adjusted for race, attained breastfeeding goals, maternal age and prenatal creatinine. Associations of phthalates with exclusive breastfeeding duration were adjusted for race, attained breastfeeding goals, biological father in the home, mode of delivery and prenatal creatinine.

Because the effect of toxins on breastfeeding may be mediated by impacts on mammary gland development, these analyses were also completed for a primiparous subgroup. Correlation analyses confirmed lack of collinearity among variables included in the regression models. To further understand the effects of exposure levels on breastfeeding outcomes, we report on the correlation with both adjusted p-values and linear trend analysis p-values. Analyses were performed using SAS version 9.3.

Results

Demographics and Breastfeeding Rates

Of the 468 women enrolled, 373 delivered live singleton babies and had complete outcome data (Table 1). Among this group of 373, 302 (81%) initiated breastfeeding, 190 (51%) were breastfeeding at 3 months, 138 (37%) were breastfeeding at 6 months. Exclusive breastfeeding rates were lower: 41 (11%) of women were exclusively breastfeeding at 3 months and 11 (0.3%) at 6 months. The average age of women who breastfed was 29.5 (SD 5.8).. About a quarter (25.7%) of households had an income below \$25,000 per year, while another quarter (27.4%) had an income above \$80,000 per year. A high percentage of women (76.7%) had more than a high school diploma, were employed during pregnancy (81.2%), and had plans to return to work after delivery (61.7%). The biologic father was present in 76.6% of households and 65.7% were married. About half of the sample (46.9%) was primiparous, and more than half (56%) had no prior breastfeeding experience.

Of the total sample, 302 (80.9%) women initiated breastfeeding, but only 42.4% breastfed as long as they had intended. The mean duration of any breastfeeding was 27.8 weeks (range 0.14–144; SD 22.68); the mean duration of exclusive breastfeeding was 3.9 weeks (range 0.14–28; SD 6.82). All socio-demographic indicators measured were associated with breastfeeding initiation ($p < 0.05$), except mode of delivery, intrauterine growth and having a grandmother in the home. (Table 1)

Toxic Exposures and Breastfeeding

Cotinine, lead and the phthalate metabolite concentrations were not correlated ($r < 0.4$). Each is addressed independently in the following paragraphs due to public health impact and precedent.

Serum cotinine—Based on self-report, 46 (12.3%) women reported smoking cigarettes at baseline; 92 (24.7%) were passively exposed to tobacco smoke. Prenatal serum cotinine concentration ranged from 0.001 to 355.5 $\mu\text{g/mL}$. On regression analysis, mothers who were unexposed to tobacco (cotinine $< 0.015 \mu\text{g/mL}$, $n = 126$), any breastfeeding duration averaged 29.9 weeks compared with 24.9 weeks among women who were passively exposed ($0.015\text{--}3.0 \mu\text{g/mL}$, $n = 194$) ($p = 0.04$). (Table 2 and Figure 2) The duration of any breastfeeding for

women who were actively exposed ($>3.0 \mu\text{g/mL}$, $n=25$) was lower, at 22.4 weeks. Duration for active exposure was not significantly different than unexposed groups ($p=0.12$), but there was a significant linear trend for cotinine exposure and duration of any breastfeeding ($p=0.03$). Duration of exclusive breastfeeding was 2.7 weeks for women unexposed to tobacco, 2.1 weeks for women with passive exposure, and 3.2 weeks in women with active exposure (linear trend $p=0.80$).

We observed similar associations for primiparous women. The average breastfeeding duration for the unexposed group was 30.5 weeks, compared with the passively exposed (23.8 weeks) and actively exposed groups (18.1 weeks, linear trend $p=0.02$). There were no significant differences in the duration of exclusive breastfeeding by cotinine exposure in the primiparous group.

We also examined whether women who were exposed to different cotinine levels reported meeting their breastfeeding goals. Sixty seven percent of women who were unexposed to tobacco stated they had breastfed as long as they wanted to, compared with 50% for those passively exposed and 52.6% of women who had active exposure ($p=0.02$).

Whole blood lead—Gestational whole blood lead levels ranged from 0.17 to $3.45 \mu\text{g/dL}$. On regression analysis, the associated breastfeeding duration ranged from 24.2 – 30.5 weeks (linear trend $p=0.38$) and exclusive breastfeeding duration ranged from 2.4 – 2.7 weeks (linear trend $p=0.69$) (Table 2). In the primiparous sample, average breastfeeding duration for the lowest tercile of exposure was 24.3 weeks, and for the highest tercile was 31.6 (linear trend $p=0.07$). There were no significant differences in the primiparous group for duration of exclusive breastfeeding.

Urinary Phthalate Metabolites—Only 3 urinary phthalate metabolites, MECPP, MEHP and MEOHP, showed a significant relation to breastfeeding outcomes at the level of $p<0.10$. On regression analysis, we modeled breastfeeding duration for these 3 phthalate metabolites, comparing the middle (2nd) and highest (3rd) terciles with the lowest (1st) tercile (Table 2). Urinary levels ranged from 3.0 – $1677.9 \mu\text{g/mL}$ for MECPP, 0.85 – $532.3 \mu\text{g/mL}$ for MEHP, and 1.76 – $704.0 \mu\text{g/mL}$ for MEOHP. For MECPP, associated duration of any breastfeeding was 28.4 weeks for those women in the lowest tercile of exposure to MECPP and 23.9 weeks for the highest tercile of exposure to MECPP (linear trend $p=0.11$), while exclusive breastfeeding ranged from 1.5 – 3.0 weeks (linear trend $p=0.97$). For MEHP, women in the lowest tercile of exposure had a duration of any breastfeeding of 28 weeks, while those in the highest tercile breastfed 22.9 weeks (linear trend $p=0.07$). Exclusive breastfeeding for MEHP ranged from 2.3 to 2.9 weeks (linear trend $p=0.93$). For MEOHP, women in the lowest tercile of exposure breastfed for 29.3 weeks, while those in the highest tercile breastfed 24.5 weeks (linear trend $p=0.09$). Exclusive breastfeeding ranged from 2.0 to 2.8 weeks (linear trend $p=0.98$). None of the phthalates showed a significant association with any or exclusive breastfeeding duration in the primiparous sample.

Discussion

We found that passive gestational exposure to tobacco smoke was associated with breastfeeding duration, even after controlling for confounders. A strength of this study was in its prospective design, mitigating the impact of reverse causality and recall bias and thereby strengthening the possibility of a causal relationship between exposure and shortened breastfeeding duration. Women who had passive tobacco smoke exposure breastfed about 5 fewer weeks than those not exposed. Given the beneficial dose-response relationship of breastfeeding on infant and maternal health (Horta and Victora 2013; Ip et al. 2007), a reduction in breastfeeding by five weeks could adversely impact maternal and child health. Our primary result is reinforced by our parallel finding that more women in passively and actively exposed groups stated that they hadn't breastfed as long as they had intended compared with unexposed women. Though it is possible that maternal return to work negatively affected duration, only 21% of women reported not meeting their goal because of back to work or school, whereas 49% reported not having enough milk or growth failure for their infants. This suggests that attainment of breastfeeding goals may be impacted by tobacco smoke exposure. Other investigators have concluded that the impact of active smoke exposure on breastfeeding duration might be related to parenting and breastfeeding choices rather than biologic mechanisms (Donath and Amir 2004; Logan et al. 2016). In contrast, our findings and other studies indicate that a biological mechanism may be involved (Vio et al. 1991; Jedrychowski 2008a). Our data do not address the nature of this mechanism, but Lawrence and Lawrence have suggested that passive smoke exposure may have a toxic impact on the ongoing development of the mammary gland during pregnancy, or disrupt hormonal signaling (Lawrence and Lawrence 2015). These hypothesized effects would presumably reduce the mother's milk supply, thus making the breastfeeding experience less adequate for infant nutrition. Though few animal studies have investigated the effect of cigarette exposure on lactation, one study may support this biological claim in which rat offspring had slower growth after maternal exposure to cigarette smoke during pregnancy and lactation (Gaworski et al. 2004).

If a biological mechanism is at play, one might expect that duration of exclusive breastfeeding would be similarly abbreviated, and that women with cotinine exposures >3.0 $\mu\text{g/mL}$ (i.e., active smokers) would also show significantly shortened breastfeeding durations. We did not see this in our study, though there was a significant trend toward further declines in duration and only 12% of women were active smokers. Of note, exclusive breastfeeding rates in our sample were much lower than National and Ohio state figures from the same time period, and thus are not representative of a statewide or national cohort (CDC 2003; CDC 2004). It is possible that an association between passive tobacco smoke exposure and exclusive breastfeeding would be observed in a larger, more representative sample. Alternatively, it is possible that women who were especially motivated to breastfeed, as indicated by the choice to exclusively breastfeed, were able to overcome the potential diminished production of breastmilk linked to tobacco exposure.

Lead exposure was not associated with shortened breastfeeding duration. Indeed, primiparous women in the highest tercile of exposure breastfed longer in our sample, though this finding wasn't significant. Similarly, we found no association between levels of urinary

phthalate metabolite excretion and shortened breastfeeding duration. We saw marginally significant associations for MEHP and MEOHP which deserves further investigation. Though most animal studies on phthalates have focused on lactation as a means of exposure, one study in rats found lower weight gain in offspring during lactation after parental exposure to di-isononyl phthalate (Waterman et al 2000). Another study found decreased milk production, mammary gland weight and offspring growth after dam exposure to di(2-ethylhexyl) phthalate (DEHP) and mono(2-ethylhexyl) phthalate (MEHP) (Dostal et al 1987). In addition, it is possible that the clinical effect of phthalates may be additive, particularly within high molecular weight and low molecular weight groups, which deserves further consideration (Kay, et al. 2013).

Breastfeeding is both the physiologically normal infant feeding method and promotes optimal infant and maternal health (Eidelman and Schanler 2012). Many women face barriers to reaching their breastfeeding goals, and the role of ubiquitous environmental toxins in this process deserves additional attention. Our analysis of the potential impact of these ubiquitous toxins on breastfeeding may therefore help us to improve the experiences of breastfeeding women. Further research is needed to clarify these associations and expand our understanding of the potential impact these, and other, toxins may have on breastfeeding experiences.

This study had several limitations. First, our sample may not be representative. Mothers in the HOME Study had lower rates of exclusive breastfeeding and briefer breastfeeding duration than women in Ohio and national samples during this time period (CDC 2003; CDC 2004), and high educational levels. They also had lower rates of smoking. Given that socio-cultural factors related to breastfeeding may also be associated with the extent of exposures to environmental chemicals, this suggests that our positive results may represent potential unmeasured confounding. Using significance tests to identify confounders allowed us to find associations but not etiologies. Also, we did not examine the impact of postnatal exposures to toxins on breastfeeding duration, or use data on when women returned to work, as breastfeeding durations were short. Though provision of mother's milk by expression or direct breastfeeding were treated equally, sociodemographics between these two groups may have differed, thus creating unforeseen confounding. Finally, given the stability of exposure over the three time periods, and our resultant use of an average level of toxin exposure through pregnancy, we were unable to determine if there are more sensitive periods in gestation associated with decreased breastfeeding duration.

Conclusions for Practice

Maternal prenatal serum cotinine, at levels consistent with passive tobacco smoke exposure, were associated with shortened duration of any breastfeeding and marginally associated with cigarette smoking. Our findings add to prior research showing decreased breastfeeding duration in mothers who were exposed to tobacco during pregnancy, and provide further reason for pregnant women to avoid passive and active exposure. If indeed such causal relationships exist, then breastfeeding counseling should include discussion of potential impacts of passive exposure. Additionally, if further research elaborates a link between

phthalates and breastfeeding duration, impact on manufacturing policy and population exposures could be extensive.

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Significance

What is already known on the subject?

Maternal exposure to tobacco smoke has been associated with shortened breastfeeding duration, though less is known about prenatal exposure. Few studies have examined the effects on breastfeeding outcomes of low level exposures to other toxic chemicals.

What this study adds?

This study showed that low-level passive exposure to tobacco smoke in the prenatal period has potentially deleterious effects on breastfeeding duration. However, this was not seen with phthalates and lead.

Figure 1.
Study Flow Diagram: timing of collection of samples and survey data

Figure 2.
Breastfeeding duration and standard error by prenatal serum cotinine concentrations with linear trend significance reported

Table 1

Socio-demographic and biologic descriptors with relationship to breastfeeding initiation

	Sample size	% Overall	% BF	p-value for breastfeeding
All Mothers	373	100	81	
Maternal Race				0.001
White	239	64.1	86.2	
Non-white	134	35.9	71.6	
Maternal age at delivery, y	373	29.5 (5.8) ^a		
Mode of delivery				0.77
Vaginal	268	71.9	81.3	
Cesarean	105	28.1	80	
Infant gestational age				
by LMP	362	39.0 (1.8) ^a		
by ultrasound	33	37.8 (3.9) ^a		
by Ballard	292	38.7 (1.9) ^a		
Infant birth weight, g	373	3382.5 (620.8) ^a		
Intra-uterine growth				0.58
AGA	283	75.9	79.9	
SGA	5	1.3	80	
LGA	80	21.5	85	
Unknown	5	1.3	--	
Length of stay, d (NICU admission)	17	8.8 (8.7) ^a		
Previous live births				<0.001
None	175	46.9	88	
1	114	30.6	81.6	
>1	83	22.2	65.1	
Unknown	1	0.3	--	
Previous maternal breastfeeding				0.001
Yes	157	42.1	89.8	
No	209	56	75.6	
Unknown	7	1.9	--	
Breastfed for as long as intended				--
Yes	158	42.4	100	
No	118	31.6	100	
Did not breastfeed or unknown	97	26	--	
Mother smokes				0.01

	Sample size	% Overall	% BF	p-value for breastfeeding
Yes	46	12.3	67.4	
No	327	87.7	82.9	
No. smokers in household				0.01
None	280	75	84.3	
1	63	16.9	71.4	
>1	29	7.8	69	
Unknown	1	0.3	--	
Household income				<0.001
Under \$25,000	96	25.7	62.5	
Between \$25,000 and \$50,000	78	20.9	82.1	
Between \$50,000 and \$80,000	90	24.1	87.8	
Over \$80,000	102	27.4	91.2	
Unknown	7	1.9	--	
Maternal employment during pregnancy				<0.001
Yes	303	81.2	84.5	
No	70	18.8	65.7	
Maternal plans to return to work after delivery				0.001
Yes	230	61.7	86.1	
No	132	35.4	71.2	
Unknown	11	2.9	--	
Maternal marital status				<0.001
Married	245	65.7	89.8	
Not married, but living with someone	50	13.4	70	
Not married, living alone	78	20.9	60.3	
Biological father in home				<0.001
Yes	286	76.7	87.4	
No	87	23.2	59.8	
Grandmother in home				0.32
Yes	31	8.3	74.2	
No	342	91.7	81.6	
Number of extended family members in home				0.001
None	134	35.9	90.3	
1	120	32.2	81.7	
2	65	17.4	67.7	
>2	54	14.5	72.2	
Maternal education				<0.001
< High school graduate	38	10.2	47.4	
High school diploma/GED	49	13.1	65.3	

	Sample size	% Overall	% BF	p-value for breastfeeding
Some college/technical/trade school	96	25.7	82.3	
Bachelor's degree	110	29.5	88.2	
Graduate or professional school	80	21.5	95	
Paternal education				<0.001
< High school graduate	39	10.4	56.4	
High school diploma/GED	67	18	67.2	
Some college/technical/trade school	92	24.7	84.8	
Bachelor's degree	89	23.9	89.9	
Graduate or professional school	75	20.1	93.3	
Unknown	11	2.9	-- ^b	

^a arithmetic mean (standard deviation)

^b -- %BF for unknown category not included in chi-square test

Table 2

Adjusted mean^a breastfeeding duration by categorical maternal prenatal toxin exposures

	LSMean ^a (SE)	Any BF (wk) p-value ^b	Linear trend p-value	LSMean ^a (SE)	Exclusive BF (wk) p-value ^b	Linear trend p-value
Serum cotinine (µg/mL)^{c,e}			0.03 [*]			0.8
Unexposed (<0.015)	29.9 (1.8)	--		2.7 (0.9)	--	
Passive (0.015–3.0)	24.9 (1.6)	0.04 [*]		2.1 (0.7)	0.51	
Active (>3.0)	22.4 (4.3)	0.12		3.2 (1.6)	0.81	
Blood lead (µg/dL)^{d,e}			0.38			0.69
1st tercile (0.17–0.590)	27.1 (1.9)	--		2.3 (0.9)	--	
2nd tercile (0.591–0.820)	24.2 (2.0)	0.3		2.4 (0.9)	0.85	
3rd tercile (0.821–3.45)	30.5 (2.3)	0.27		2.7 (0.9)	0.69	
Urinary MECPP (µg/mL)^{d,e,f}			0.11			0.97
1st tercile (3.0–40.9)	28.4 (1.9)	--		2.9 (0.8)	--	
2nd tercile (41.0–97.5)	28.0 (2.0)	0.89		1.5 (0.9)	0.13	
3rd tercile (97.6–1677.9)	23.9 (2.0)	0.11		3.0 (0.9)	0.94	
Urinary MEHP (µg/mL)^{d,e,f}			0.07			0.93
1st tercile (0.85–5.34)	28.0 (1.9)	--		2.3 (0.9)	--	
2nd tercile (5.35–15.8)	29.4 (1.9)	0.62		2.9 (0.8)	0.49	
3rd tercile (15.9–532.3)	22.9 (2.0)	0.07		2.3 (0.9)	0.95	
Urinary MEOHP (µg/mL)^{d,e,f}			0.09			0.98
1st tercile (1.76–22.7)	29.3 (2.0)	--		2.7 (0.8)	--	
2nd tercile (22.8–54.32)	26.6 (2.0)	0.32		2.0 (0.9)	0.46	
3rd tercile (54.33–704)	24.5 (2.0)	0.09		2.8 (0.9)	0.97	

Maternal prenatal toxin exposure is average of 16w, 26w, and birth measures.

^a Adjusted means here are least squares means, controlling for identified covariates^b p-value compared to lowest level of exposure^c Any BF adjusted for maternal race and breastfeeding goal

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^dAny BF adjusted for maternal race, breastfeeding goal, and maternal age

^eExclusive BF adjusted for maternal race, biological father in the home, mode of delivery, breastfeeding goal.

^fModels further adjusted for maternal prenatal creatinine.

* Statistically significant