Birth Outcomes Among Offspring of Women Exposed to the September 11, 2001, Terrorist Attacks

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OBJECTIVE: To evaluate the effects of the September 11, 2001, World Trade Center attacks on birth outcomes.

METHODS: Live singleton births between September 11, 2001, and October 31, 2002, to women enrolled in a World Trade Center Health Registry (the Registry, n=446) were compared with births to women residing more than 5 miles from the World Trade Center (n=49,616). Birth weight, gestational age, low birth weight, and preterm delivery were evaluated using linear and logistic regression. Births before September 11, 2001, were analyzed to assess possible seasonal biases of associations with pregnancy trimester on September 11. Associations of birth outcomes with September 11–related psychologic stress and physical exposures were assessed among births to women within the Registry (n=499).

RESULTS: Birth weight and gestational age distributions were similar for births to women enrolled in the Registry and comparison births. Although mean gestational age and birth weight varied with trimester on September 11, a similar association was found among births in previous years, consistent with a seasonal effect not related to exposure. Registry-linked births to mothers with probable posttraumatic stress disorder (n=61) had a higher odds of low birth weight (adjusted odds ratio [OR] 2.49, 95% confidence interval [CI] 1.02–6.08) and preterm delivery (adjusted OR 2.48, 95% CI 1.05–5.84) compared with births to women without posttraumatic stress disorder.

CONCLUSION: Women who lived, worked, or were near the World Trade Center on or soon after September 11 had pregnancy outcomes similar to women residing more than 5 miles away. However, among exposed women, probable posttraumatic stress disorder was associated with low birth weight and preterm delivery.

LEVEL OF EVIDENCE: II

The September 11, 2001, attacks on the World Trade Center created an acute disaster of unprecedented size in New York City. Air monitoring and evaluation of settled dust indicated that persons in the vicinity of the event potentially were exposed to high levels of particulate matter and other combustion byproducts from pulverization of the buildings, jet fuel fires, and exhaust from gasoline and diesel engines used in recovery operations.1,2 Data on the possible effects of natural and man-made disasters on birth outcomes are limited. Studies have examined the relationship of air pollution to adverse pregnancy outcomes and have shown an effect on preterm delivery and on intrauterine growth restriction.3–5 Studies have also shown links between psychologic trauma and adverse pregnancy outcomes.6–13

Studies of birth outcomes after exposures from living or being near the World Trade Center at the time of the attacks have shown inconsistent re-
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MATERIALS AND METHODS

This study was conducted using data from the World Trade Center Health Registry (the Registry), a voluntary registry established by the New York City Department of Health and Mental Hygiene and the Agency for Toxic Substances and Disease Registry to monitor the physical and mental health impact of September 11. The Registry was established to prospectively monitor the physical and mental health of people with a high probability of direct exposure to September 11 and its aftermath, including rescue, recovery and volunteer workers; persons with a primary residence in lower Manhattan on September 11; office workers; and passersby present in lower Manhattan on the morning of September 11. The Centers for Disease Control and Prevention and New York City Health Department Institutional Review Boards approved the Registry protocols. A Federal Certificate of Confidentiality was obtained as was verbal informed consent. This study was approved by the Institutional Review Board at the New York City Department of Health and Mental Hygiene.

A total of 71,437 people enrolled in the Registry, making it the largest postdisaster registry in US history. Outreach and multilingual media campaigns encouraged enrollment through a toll-free number or the Registry Web site (classified as “self-identified” enrollees). Others were solicited from lists of potentially exposed persons provided by entities such as employers and governmental agencies (classified as “list-identified”). Final registry enrollment was composed of 70% self-identified and 30% list-identified enrollees. Of the 71,437 enrollees, 599 (0.84%) identified themselves as pregnant on September 11, 2001. Both active and passive recruitment methods were used over a 15-month enrollment period from September 5, 2003, through November 20, 2004, during which enrollees completed a baseline interview.

We then used data obtained from the Department of Health and Mental Hygiene’s Office of Vital Statistics. In this study, the “exposed” population of interest was all women within the Registry who gave birth to live singleton neonates in New York City with a gestation that overlapped with the period September 11, 2001, through December 1, 2001, according to the New York City birth certificate files maintained by the New York City Office of Vital Statistics. Our goal was to study live births to women who may have been exposed during or just before conception to the physical or psychologic impact of the attacks either acutely or during the time when fires continued to burn at the World Trade Center site through mid-December.

All women of reproductive age (18–49 years) on September 11 enrolled in the Registry were matched using strict criteria to data from New York City birth certificates to identify live births to women who delivered between September 11, 2001, and October 14, 2002. A pool of potential matches were identified as those records from the Registry and birth records that matched on one of the following criteria: 1) mother’s date of birth, 2) last four digits of Social Security Number, or 3) first four characters of first name and first four characters of last name and month, day, or year of birth. A score was created for each potential match by awarding points for identical or similar values in corresponding fields. Potential matches were then grouped based on which corresponding fields matched.

The comparison group included all women who were not in the Registry, who resided in a New York City census tract greater than 5 miles from the World Trade Center site, and who delivered a live singleton neonate between September 11, 2001, and October 31, 2002.

For consistency with other studies of birth outcomes related to September 11 and to minimize potential errors of vital statistics data, births were excluded from the study for the following reasons: multiple births, gestational age less than 26 weeks or greater than 42 weeks, maternal age younger than 18 or older than 49 years, birth weight less than 500 g or higher than 5,000 g, maternal smoking or pregesta-
tional diabetes noted on the birth certificate, and information on the birth outcomes missing. This excluded 45 births out of the original 544 registry births matched (9.0%) and 60,797 in the control group (35.6%). Among the remaining 499 live births linked to women in the Registry, 55 (11.0%) were to rescue and recovery workers (six of these women [1.2%] actually worked on the World Trade Center disaster site), 173 to women residing near the World Trade Center (34.7%), 244 to women who worked in lower Manhattan (including school teachers) (48.9%), and 27 to women who were passersby (5.4%).

The Registry was composed of a highly affluent population with relatively few Medicaid-covered women (53 of 499 [10.6%]) compared with women giving birth overall in New York City (60,557 of 110,173 [54.9%]). To create two comparable groups, our principal analyses excluded births to women with Medicaid as their primary coverage. The final population examined in the primary analysis was 446 women from the Registry compared with 49,616 in the control group. We also performed an analysis on subgroups of Registry-linked births to examine effects of environmental and stress-related exposures on birth outcomes. This analysis included all 499 births to mothers in the Registry regardless of health insurance coverage (Fig. 1).

Birth outcomes examined were birth weight and gestational age at delivery. Each was analyzed as both a continuous measure and classified as low birth weight (less than or equal to 2,500 g) and preterm delivery (less than 37 completed weeks of gestation), respectively. Birth weight, gestational age, and other birth characteristics are collected by the Department of Health and Mental Hygiene during the process of registering births and issuing birth certificates. The hospital or institution of birth reports birth weight in pounds and ounces or grams. Birth weights less than 1,000 g are verified with the reporting hospital. Clinical estimate of gestation was reported on the birth certificate in completed weeks and is intended to reflect the birth attendant’s best estimate of the neonate’s gestation taking into consideration all perinatal factors.

All covariates and potential confounders were based on electronic birth record data for both Registry-linked births and controls. Potential confounders included demographic and other maternal and pregnancy characteristics previously shown to be associated with the outcomes of interest. These included maternal race and ethnicity, maternal level of education (high school or less, more than high school), maternal employment, foreign born, parity (nulliparous or multiparous), neonatal sex, maternal age in years (18–34 years, 35+ years), mode of delivery (vaginal or cesarean), and maternal medical risk factors (one or more of: chronic hypertension, eclampsia, preeclampsia, pregnancy-induced hypertension, and gestational diabetes).

Using birth date and clinical estimate of gestational age to estimate the date of conception, the trimester of pregnancy on September 11, 2001, was classified based on computed days of gestation: first trimester less than 92 days, second trimester 92–181 days, third trimester 182 or more days. A fourth category included births resulting from pregnancies conceived between September 12, 2001, and December 31, 2001.

To assess associations with both exposure to September 11 and birth outcomes, we generated descriptive statistics and univariable associations for all variables. We performed t tests to examine mean gestational age

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**Fig. 1.** Study populations: World Trade Center Health Registry-linked births and control births. Includes live births between September 11, 2001, and October 31, 2002.

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and mean birth weight of neonates in the exposure and
comparison groups. A multivariable analysis was then
performed. Covariates were included in the multivari-
able model if the univariable chi-square $P$ values were
less than .05. The two outcomes, birth weight and
gestational age at birth, were analyzed as both contin-
uous variables in linear regression models and as dichot-
omous outcomes in logistic regression models. We used
backward elimination to remove covariates with incon-
sequential contribution to the model, retaining only
those that significantly contributed to final model fit
($P < .05$) using the likelihood ratio test for logistic regres-
sion and similar methods for the continuous outcomes.

One prior study found a significant association
between trimester of pregnancy on September 11 and
birth outcomes regardless of maternal place of resi-
dence or employment.15 To explore whether that
association or a similar pattern in our own data might
be the result of seasonal effects24,25 or other artifacts
and unrelated to exposure to the September 11 event,
we analyzed outcomes of live births that were con-
ceived and delivered before September 11 and thus
could not have been affected by that event. Specifi-
cally, we conducted an historical comparison analyz-
ing outcomes in a similar population of non-Medicaid
births to New York City residents ($n = 60,819$) occur-
ing between September 12, 1999, and October 14,
We developed multivariable models following the
same procedures as in our main analysis.

Within the entire group of 499 births linked to
mothers in the Registry population, we evaluated the
associations of birth outcomes with experiences and
self-reported exposures on or after September 11.
Information was obtained from all 499 women during
the baseline interview conducted between September
2003 and November 2004. We chose to examine
variables that have previously been explored within
the Registry and have been found to be associated
with higher levels of exposure.

Our primary mental health outcome focused on
September 11-related posttraumatic stress symptoms
indicative of posttraumatic stress disorder (PTSD).
These were assessed with the stressor-specific PTSD
Checklist, a 17-item self-report instrument based on
Diagnosic and Statistical Manual of Mental Disor-
ders, Fourth Edition diagnostic criteria for PTSD and
linked to a specific traumatic exposure, in this case,
“the events of September 11.” Respondents scored
each symptom on a 5-point scale; a 17-item total of 44
or greater was deemed indicative of probable PTSD.
The interview occurred 3–4 years after September 11,
but all 17 PTSD symptom questions were grounded in
the events of September 11 (eg, flashbacks to the
events of September 11) and reported for the last 30
days before interview. Therefore, we measured
probable September 11-related PTSD concurrent
with the interview. Because interviews occurred
3–4 years after September 11, the PTSD measure-
ment most likely represents individuals for which
the events of September continue to have lasting
psychologic effects.26

Witnessing horror has also been studied within
the Registry as a marker of posttraumatic stress
symptoms. Witnessing horror was coded as affirm-
ative if participants reported that they personally saw
any of the following on September 11: an airplane
hitting the World Trade Center, a building collapsing,
people running away from a cloud of dust and debris,
anyone who was injured or killed, and people falling
or jumping from the World Trade Center towers.27

We examined dust cloud exposure on September
11 because it has also been strongly associated with
both adverse physical and mental health outcomes.27
Dust cloud exposure was defined as answering “yes”
on the question in the Registry to being caught in the
dust or debris cloud on September 11.

We performed a descriptive analysis and devel-
oped multivariate models relating September 11 ex-
posures to birth outcomes as continuous or discrete
outcomes as previously described adjusting for all
covariates identified as significantly associated with
the outcome. The covariate maternal race and ethnic-
ity was defined as African American race and all other
races given the limited distribution within the Regis-
try population (largely non-Hispanic white). We used
the difference in the $-2 \log$ likelihood ratios to
determine which variables improved model fit and
used backward elimination to remove covariates with
inconsequential contribution to the model, retaining
only those which significantly contributed to final
model fit ($P < .05$). All data analysis was conducted

RESULTS

Table 1 displays the maternal demographic, medical,
and delivery characteristics of the Registry-linked
births and the control births. The former group
included 295 (66%) births to women in the Registry
who were pregnant on September 11, 2001, and 151
births (34%) to women who were in the registry and
conceived between September 12 and December 31,
2001. Compared with the control births, a signifi-
cantly higher proportion of Registry-linked births had
maternal age 35 years or older, finished high school,
were US-born, and were employed. In addition,
Registry-linked births were more likely to be to nulliparous mothers and delivered by cesarean. The distributions of trimester on September 11 and the presence of one or more medical risk factors were comparable in both groups.

There was no difference in the mean gestational age and the mean birth weight of neonates in the exposure and the comparison groups in the unadjusted analysis (3,311.8 compared with 3,325.5 g; $P = .59$). There was also no difference in gestational age of delivery (38.9 weeks in both groups, $P = .99$) (Table 2). There was no difference in the odds of low birth weight (less than 2,500 g; adjusted odds ratio [OR] 1.03, 95% confidence interval [CI] 0.7–1.55 or preterm delivery adjusted OR 1.04, 95% CI 0.72–1.50) after adjusting for trimester on September 11, race and ethnicity, education, maternal age, foreign-born, neonatal sex, parity, medical risk factors, and mode of delivery.

Although there was no difference in birth outcomes when comparing the Registry-linked births with controls, gestational age at birth and birth weights varied significantly overall by trimester on September 11; mean gestational age and birth weight were lowest in births with estimated date of conception between September 12, 2001, and December 31, 2001, and highest in those in the third trimester on September 11. The distributions of trimester on September 11 and the presence of one or more medical risk factors were comparable in both groups.
trimester on September 11, 2001. This association is almost entirely accounted for by the comparison births to mothers living more than 5 miles from the World Trade Center (more than 99% of the study population).

Among births conceived and delivered before September 11, mean gestational age and birth weight were lowest in births with estimated date of conception between September 12, 1999, and December 31, 1999, and highest in those in the third trimester on September 11, 1999 (Table 3). We also found women in their first trimester in September through December 1999 had a higher odds of preterm delivery (adjusted OR 2.27, 95% CI 2.05–2.51) and low birth weight (adjusted OR 1.56, 95% CI 1.40–1.74) compared with women in their third trimester in September 1999.

Sixty-one women (12.6%) screened positive for probable PTSD at the time of interviews. Probable PTSD was not associated with a difference in gestational age of delivery \( (P = 0.3) \) but was significantly associated with a difference in birth weight of 169.8 g \( (P = 0.03; \text{Table 4}) \) in the unadjusted analysis, although this association was borderline nonsignificant when controlling for confounding \( (152.4 \text{ g}, P = 0.06) \). There was an increased odds of preterm delivery \( (\text{adjusted OR 2.48, 95% CI 1.05–5.84}) \) and low birth weight \( (\text{adjusted OR 2.49, 95% CI 1.02–6.08}) \) after controlling for confounding in women with a high PTSD score compared with a lower score.

### Table 2. Multiple Regression Results for Outcomes of World Trade Center Health Registry-Linked Births and Control Births Between September 11, 2001, and October 31, 2002*

<table>
<thead>
<tr>
<th>Birth Weight</th>
<th>Gestational Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient</td>
<td>95% CI</td>
</tr>
<tr>
<td>WTCHR-linked compared with controls unadjusted</td>
<td>-13.7</td>
</tr>
<tr>
<td>Covariate-adjusted results</td>
<td></td>
</tr>
<tr>
<td>WTCHR-linked compared with control</td>
<td>-26.9</td>
</tr>
<tr>
<td>Trimester on 9/11</td>
<td></td>
</tr>
<tr>
<td>Pregnant after 9/1/01 and before 12/31/01</td>
<td>-82.8</td>
</tr>
<tr>
<td>First trimester</td>
<td>-53.3</td>
</tr>
<tr>
<td>Second trimester</td>
<td>-48.2</td>
</tr>
<tr>
<td>Third trimester</td>
<td>Referent</td>
</tr>
<tr>
<td>Race and ethnicity</td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>-80.1</td>
</tr>
<tr>
<td>Asian</td>
<td>-193.1</td>
</tr>
<tr>
<td>African American</td>
<td>-164.1</td>
</tr>
<tr>
<td>Other race</td>
<td>-155.8</td>
</tr>
<tr>
<td>White</td>
<td>Referent</td>
</tr>
<tr>
<td>Maternal education</td>
<td></td>
</tr>
<tr>
<td>High school graduate or less</td>
<td>38.8</td>
</tr>
<tr>
<td>More than high school graduate</td>
<td>Referent</td>
</tr>
<tr>
<td>Maternal age (y)</td>
<td></td>
</tr>
<tr>
<td>18–34</td>
<td>Referent</td>
</tr>
<tr>
<td>Older than 35</td>
<td>Referent</td>
</tr>
<tr>
<td>Mother employed</td>
<td>23.2</td>
</tr>
<tr>
<td>Foreign-born</td>
<td>Referent</td>
</tr>
<tr>
<td>Parity</td>
<td></td>
</tr>
<tr>
<td>Nulliparous</td>
<td>-91.7</td>
</tr>
<tr>
<td>Multiparous</td>
<td>Referent</td>
</tr>
<tr>
<td>Delivery mode</td>
<td></td>
</tr>
<tr>
<td>Vaginal</td>
<td>Referent</td>
</tr>
<tr>
<td>Cesarean</td>
<td>29.4</td>
</tr>
<tr>
<td>Neonatal sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>Referent</td>
</tr>
<tr>
<td>Female</td>
<td>114.0</td>
</tr>
<tr>
<td>Medical risk factors</td>
<td></td>
</tr>
<tr>
<td>-171.5</td>
<td>-190.7 to -152.3</td>
</tr>
</tbody>
</table>

CI, confidence interval; WTCHR, World Trade Center Health Registry.

* Model adjusted for all noted variables in the model, except where indicated as not included.

† Variable not included in model.

‡ Maternal medical risk factors include chronic hypertension, eclampsia, preeclampsia, pregnancy-induced hypertension, and gestational diabetes.
More than half of the women (297 [59.5%]) reported being caught in the dust cloud on September 11. There was no association between reported dust cloud exposure and either mean birth weight (P=.2) or mean gestational age of delivery (P=.1). However, births to women who reported dust cloud exposure had a trend toward a higher odds of low birth weight, but this association was not significant when controlling for confounding (adjusted OR 1.70, 95% CI 0.72–4.01).

A high percent of mothers in the Registry reported witnessing a horrific event (312 women [62.5%]). Although there was a higher odds of low birth weight (adjusted OR 2.53, 95% CI 1.08–5.93) in the unadjusted analysis, with confounder adjustment, this association was attenuated and nonsignificant (adjusted OR 1.62, 95% CI 0.67–3.96) as were associations with birth weight, gestational age, and preterm delivery (Table 4).

### Table 3. Multiple Regression Results for Historical Comparison Births Conceived and Delivered Before September 11, 2001*

<table>
<thead>
<tr>
<th>Trimester on 9/11/99</th>
<th>Birth Weight</th>
<th>Gestational Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>95% CI</td>
</tr>
<tr>
<td>Pregnant after 9/1/99 and before 12/31/00</td>
<td>-54.6</td>
<td>-66.0 to -43.0</td>
</tr>
<tr>
<td>First trimester</td>
<td>-19.6</td>
<td>-32.0 to -7.2</td>
</tr>
<tr>
<td>Second trimester</td>
<td>-38.7</td>
<td>-51.2 to -26.1</td>
</tr>
<tr>
<td>Third trimester</td>
<td>Referent</td>
<td>Referent</td>
</tr>
</tbody>
</table>

CI, confidence interval.
* Live births to New York City residents not covered by Medicaid occurring between September 11, 1999, and October 14, 2000, controlling for race and ethnicity, education, maternal employment, foreign born, parity, neonatal sex, maternal medical-related complications, and cesarean delivery.

### DISCUSSION

Our results indicate that there was no difference in birth outcomes to pregnant women enrolled in the World Trade Center Health Registry compared with the control population. Although mean gestational age and birth weight varied with trimester on September 11, a similar association was found among births in previous years, consistent with a seasonal effect not related to exposure. Among singleton live births to Registry enrollees, those whose mothers had probable PTSD had higher odds of preterm delivery and low birth weight.

Births to women who were in the Registry and either lived or worked near the World Trade Center site on September 11 or in the subsequent months had a similar distribution of birth weight and gestational age at birth compared with births among women residing more than 5 miles from the World Trade Center.
Center during the same time period. Our finding differs from prior studies that have shown associations with one or more related outcomes. The samples of exposed and comparison births in one of these studies were identified from very different populations and methods and may have had differential selection biases. A second study showed a significant but small effect size, which was not replicated in our study.

Previously, Lederman and colleagues found that mothers who were in their first trimester of pregnancy on September 11, 2001, delivered 3.6 days earlier than mothers who were past the first trimester on that date regardless of location of work or residence in New York City. Our analysis found a similar pattern, but we also showed that this same association exists among births conceived and delivered before September 11, 2001, in relation to pregnancy trimester on September 11, 1999, suggesting the association is not causally related to the World Trade Center attacks that occurred in 2001. One possible explanation of this association is confounding by an association of season and birth weight, possibly mediated by ambient temperature or other environmental variables. Because season and trimester on a specific date are perfectly confounded, a seasonal bias on our result and those of Lederman et al cannot be excluded.

Women within the Registry varied in their experiences related to the World Trade Center attacks and in associated psychologic stress and physical exposures. Although the number of births linked to women reporting symptoms compatible with PTSD was limited (61, approximately 13% of the total), those births were significantly more likely to be preterm or to be low birth weight. Mean birth weight was also lower in this subgroup, although this effect was marginally nonsignificant in the adjusted analysis. More than half of Registry-linked births were to mothers who reported either being caught in the dust cloud from the World Trade Center attacks or witnessing one or more specified horrific events. Crude associations of these experiences with low birth weight and were substantially attenuated and nonsignificant with adjustment for confounders. These inconclusive results are limited by wide CIs indicating limited power to detect an effect as well as some overlap of these experiences with probable PTSD.

Previous data on possible connections of psychologic stress from the events of September 11 and adverse pregnancy outcomes are limited. Engel et al assessed outcomes of a small cohort of pregnant women (n=52) who completed at least one prenatal psychologic assessment and observed a marginal association among symptoms of probable posttraumatic stress symptomatology, increased gestational duration, and decreased head circumference. Of this cohort, only four women had probable PTSD.

Although there are numerous studies evaluating stress and trauma in pregnancy, less than a handful of studies have evaluated PTSD as a risk factor for adverse perinatal outcomes although PTSD is the third most common psychiatric illness among pregnant women. The stress response involves coordination of several systems, but particularly the hypothalamic–pituitary–adrenal axis, which may lead to an increase in cortisol production and cortisol-releasing hormone, which are involved with the cascade that leads to delivery.

Our study was limited, because births outside of New York City to pregnant women enrolled in the World Trade Center Health Registry were not captured. Additionally, the validity of some covariate data from the birth certificates such as maternal health conditions is questionable, thereby limiting the ability to control for potential confounders. Some mothers in comparison neighborhoods may have been present near the World Trade Center on September 11 and eligible for enrollment but did not enroll, which may have introduced some exposure misclassification into our data. However, essentially all women in the Registry would be considered “exposed” to the September 11 attacks using more stringent proximity criteria than used in prior studies, whereas the proportion exposed among controls is almost certainly much lower. Enrollment in the registry raises questions about the representativeness of the study population. It seems most likely that Registry mothers would be more likely to enroll had they had problems with a pregnancy outcome. This would tend to bias the Registry population toward a finding with a higher risk of adverse pregnancy outcomes than a less exposed population, which we did not find. Finally, the interview collecting the PTSD measure occurred 3–4 years after the event and may have not fully captured the complete stress response for the women between the time of September 11 and the birth of their children.

Despite these limitations, the analysis within the Registry showed that there is a higher odds of preterm delivery and low birth weight in women who had the highest level of exposure to stress associated with September 11. Our findings contribute to the growing body of evidence that extreme levels of psychologic stress and PTSD affect pregnancy outcomes.
REFERENCES


