

## Effects of the September 11, 2001 disaster on pregnancy outcomes: a systematic review

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## Introduction

The terrorist explosions of the World Trade Center (WTC) in New York City as well as the other events on the Pentagon and in Pennsylvania on 11 September 2001 were stressful events that affected people around the world. Pregnant women and their offspring are especially vulnerable during and after such a terrorist attack (1, 2). Terrorist attacks and natural disasters are difficult to predict and effects are complicated to measure. Adverse pregnancy outcomes have been noted after earthquakes with an increase in preterm births (PTB)

## Abstract

**Background.** The terrorist explosions of the World Trade Center in New York City and the other events on the Pentagon and in Pennsylvania on 11 September 2001 were stressful events that affected people around the world. Pregnant women and their offspring are especially vulnerable during and after such a terrorist attack. The objective was to systematically review the risks of adverse pregnancy outcomes after the terrorist attacks on Sept 11, 2001. **Methods.** The Meta-analysis of Observational Studies in Epidemiology (MOOSE) criteria were used for reporting of this review. Statistical analyses were performed using RevMan 5.0. **Results.** Ten reports of low-to-moderate risk of methodological bias were included. There was increased risks of infants with birthweight of 1,500 g–1,999 g (adjusted odds ratio [AOR] 1.67 [95%CI 1.11–2.52]) and small-for-gestational age births (AOR 1.90; 95%CI 1.05–3.46) in New York. There was increased risks of low birthweight (relative risk 2.25; 95%CI 1.29–3.90) and preterm births (relative risk 1.50; 95%CI 1.06–2.14) among ethnically Arabic women living in California. There was a reduction in birthweight by 276 g and in head circumference by 1 cm when DNA adducts, a marker for environmental toxin exposure, were doubled in maternal blood. In Holland, a 48-g reduction in birthweight was reported. **Conclusions.** The World Trade Center disaster influenced pregnancy outcomes in New York, among ethnically Arab women living in California and among Dutch women. The adverse outcomes are likely due to environmental pollution and stress in New York, ethnic harassment in California and communal bereavement and stress in Holland.

during the 48 hours following an earth quake (3) and low birthweight (LBW) possibly due to spousal casualty (4). The possible mechanisms for the effects on pregnancy outcomes of the WTC disaster include; effects of stress on local and distant populations possibly modified by ethnicity; effects of chemicals released on the local population; and effects of climate changes.

As no systematic review has been done to date, our objective was to systematically review the studies of the effects of the 11 September 2001 attacks on pregnancy outcomes, including the effects on the rates of LBW, PTB, gestational

age (GA), fetal growth (birthweight [BW], head circumference and length at birth and small-for-gestational age [SGA] births).

## Material and methods

We followed the Meta-analysis of Observational Studies in Epidemiology (MOOSE) criteria (5) for reporting of this systematic review. The method for a determinants' review by our group has been published (6). No research ethics board approval was obtained as data were extracted from published manuscripts.

### *Criteria for considering studies for the review*

Observational studies that explored the association of the WTC attack and pregnancy outcomes (LBW, PTB, fetal growth [weight, length and head circumference at birth] and SGA) were included in this review. No language or geographical restrictions were applied. Studies published only as abstracts were not included. The types of studies included observational cohort studies with matched, unmatched, or historical controls; longitudinal studies; and case-control studies, which have assessed the impact of the WTC attack on pregnancy outcomes.

Included participants were women, who were pregnant on 11 September 2001, regardless of the post-menstrual age of the fetus on that date and regardless of the woman's place of work or residence. The study could be reporting on women affected directly (living in the area – New York City) or indirectly (women living further away).

Following the WTC attack different types of exposure were plausible; a direct effect of chemicals and physical injury in the immediate surroundings of the WTC site; communal bereavement in local and distant populations as a result of the news; change in environmental temperature due to lack of plane contrails; and discrimination of certain ethnic populations after the WTC disaster.

*Primary outcomes* were LBW (categorical data), defined as birthweight <2,500 g, and PTB (categorical data), defined as a birth occurring at <37 weeks GA. *Secondary outcomes* were GA in weeks (continuous data), fetal growth assessed by one of the following: Birthweight (grams, continuous data), length at birth (centimeters, continuous data), head circumference at birth (centimeters, continuous data) and SGA (categorical data) defined as birthweight <10th percentile for GA according to an appropriate growth standard either at birth or by an antenatal ultrasound examination.

### *Search strategy for identification of studies and data extraction*

Electronic databases (Medline, EMBASE and CINAHL) were searched from the year 2000 (before the event of 11 September 2001) to January 2010 for studies published in any lan-

guage. The general search terms used were similar to what was used in one previous systematic review on the topic of mental health of workers and volunteers responding to events of 11 September 2001 (7). The reference lists of the identified articles were reviewed to locate further eligible studies. In addition the website (<http://www.cdc.gov/niosh/>) for the National Institute for Occupational Safety was searched under the health topic 'World Trade Center Response.' The website includes an updated bibliography of studies related to the WTC disasters. The articles were scanned initially based on titles and abstracts by two authors (AO and PS). This resulted in 234 references to studies for potential inclusion (for final study inclusions see Figure 1). For PubMed, the search terms were; (September 11th) OR (9/11) OR (WTC) OR (World Trade Center) AND (pregnancy OR PTB OR low birth weight). The search terms were modified according to database requirements.

Data from each eligible study were extracted to custom-made data-collection forms by two authors (AO, PS). No modification of original data was performed. Covariates that were adjusted for in the analyses in the individual studies were abstracted.

### *Assessment of quality of included studies and data synthesis*

Methodological quality of studies was assessed using a pre-defined checklist (6) based on criteria for sample selection, exposure assessment, confounder, analytical, outcome assessment and attrition biases. The classification in each category was no bias, low risk, moderate risk and high risk of bias. Studies with high likelihood of bias in three or more domains were to be excluded. At any stage of the review, discrepancies (which were rare) between the two reviewers (AO, PS) were resolved by discussion.

Adjustment for confounders in observational studies of this nature varies between studies. A priori a decision was made to include both unadjusted and adjusted data. Knowing the heterogeneity of the studies on the subject, we reviewed studies using systematic review techniques and meta-analyses were not planned.

When possible the statistical software RevMan 5.023 from the Cochrane Collaboration was used to calculate relative risk (RR), odds ratio (OR) and mean difference with 95% CI from original data reported in the individual publications (8).

## Results

Eight primary studies (9–16), and two subgroup reports (17, 18) qualified for inclusion in this review and the characteristics of the included studies are summarized in Table 1.

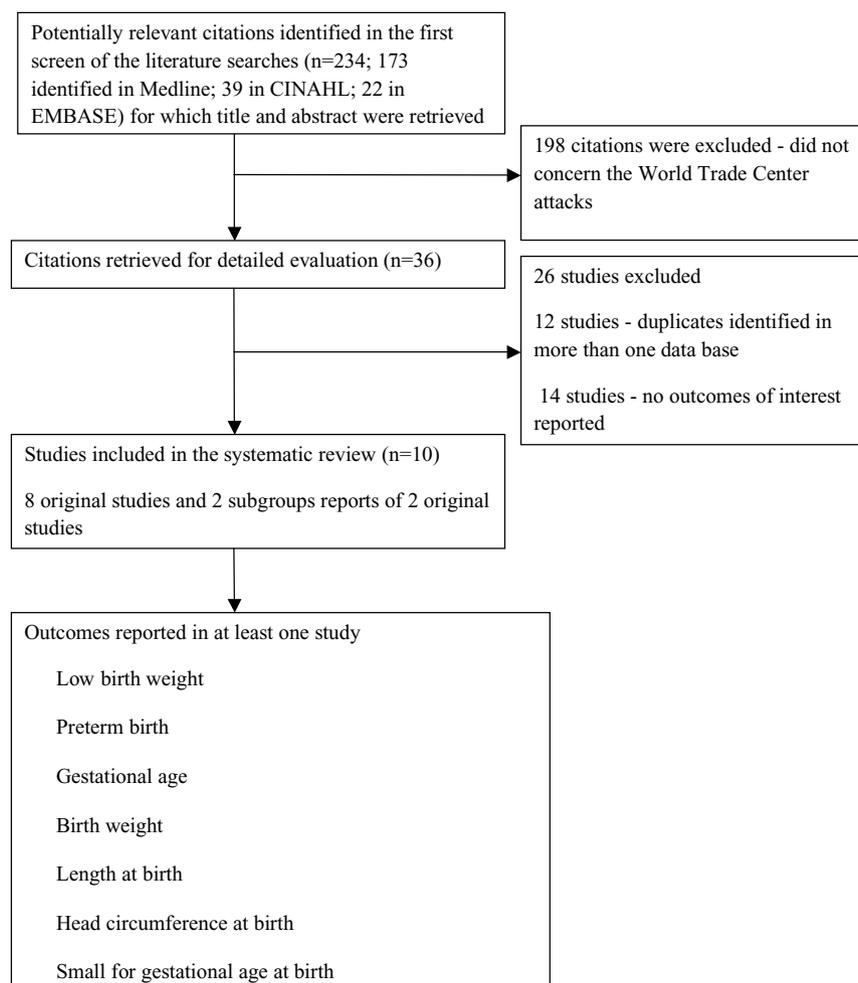


Figure 1. Flow diagram of included studies.

All studies were of good quality with low-to-moderate risk of bias (Table 2). The results of the studies were grouped and summarized by our primary and secondary outcomes and for each outcome according to the distance from the WTC; New York (9–11); Boston (12); California (13) and Michigan (14); US and overseas (15); and Holland (16) (Table 3). Publication bias is not likely to have played a major role in this systematic review, as three published studies reported no significant increase in adverse pregnancy outcomes (12, 14, 15).

### Primary outcome: LBW

Four studies were reported on this outcome. In New York City (Table 3). Eskenazi et al. (11) reported a statistically increased adjusted OR (AOR) of 1.67 (95% CI 1.11, 2.52) for LBW births between 1,500 g to 1,999 g compared to births >2,500 g, but not for lower or higher LBW groups. In upstate New York, none of the AORs for these weight group comparisons were significantly different. Berkowitz

(9) reported a non-significant increase in LBW births in their study of women exposed close to the WTC.

The results from the two studies (13, 14) that assessed the effects of possible increased harassment, violence and work place discrimination of persons perceived to be Arabs in the United States immediately after the disaster, differed in their results. In California (13), there were significantly increased risks for LBW among Arabic named infants and Arabic ethnically distinctive named infants, whereas in Michigan (14) there was no significant difference in the LBW rates among infants born to mothers with an Arabic name or ancestry. There was a reduction in the incidence of very LBW (VLBW, <1,500 g) infants for mothers with Arabic ancestry.

### Primary outcome: PTB

In New York, two studies (9, 11) reported no statistically significant differences in the risks of PTBs among women exposed close to the WTC or in Upstate New York (Table 4).

**Table 1.** Characteristics of included studies.

First author	Year of study	Place of study/setting	Population	Exposure assessment	Outcomes assessed	Control variables (covariates)
Berkowitz et al. (9)	2001–2002	Five exposure zones near the WTC site in New York, New York, US	A total of 187 pregnant women present in one of five exposure zones near the WTC at the time of attack or within the succeeding three weeks. A total of 2,367 pregnant women under private care who delivered at Mount Sinai Medical center during the same period but were not near attack site	Maternal history	LBW, PTB, BW, IUGR, GA	Race/ethnicity, infant's sex, maternal age, parity, cigarette smoking
Engel et al. (17) Secondary study to Berkowitz (9)	2001–2002	As above	A total of 52 women with singleton pregnancies derived from the population described by Berkowitz et al. 9 and who completed at least one psychological assessment for post-traumatic stress symptoms (PTSS)	Maternal history	LBW, PTB, BW, GA, head circumference at birth	Maternal age
Lederman et al. (10)	2001–2002	Three hospitals close to the WTC site in lower Manhattan, New York City, US	300 nonsmoking women who were pregnant at the time of the WTC event. Recruited while in labor for delivery between December 2001 and June 2002. Most participants were in their first or second trimester at the time of disaster.	Residential and work address for all participants along with maternal history of time spent in each location based on this classification: Group 1 resided, Group 2 worked and Group 3 neither resided nor worked within 2 miles of the WTC	BW, length and head circumference at birth, SGA, GA, for term infants	Race/ethnicity, medical status, infant's sex, maternal height, pre-pregnancy weight, parity, maternal age, C/S, medical complications
Perera et al. (18) Secondary study to Lederman et al. 2004 (10)	2001–2002	Same as described by Ledermann et al. (10)	A subgroup of the above population – see exposure assessment	Benzol[a]pyrene-DNA adducts in maternal ( $n = 170$ ) and umbilical cord blood ( $n = 203$ ) obtained at delivery from non-smoking women who were pregnant on 11 September 2001. Exposure to environmental tobacco smoke was recorded	BW, head circumference (no effect on GA or SGA; numbers not provided)	Maternal age, parity, pre-pregnancy weight, height, ethnicity, Medicaid status, medical complications, trimester of pregnancy on 11 September 2001, GA, C/S, sex of newborns
Eskenazi et al. (11)	1996–2002	New York City and upstate New York, US	Births in New York City and New York state one week after 11 September 2001 vs. three weeks before, and for 10 four-week intervals post-disaster vs. births in similar intervals in the two previous years.	A total of 8,465 births to residents within New York City (6,304 births before and 2,161 after 11 September 2001). A total of 9,573 births from upstate New York (7,259 before and 2,494 after 11 September 2001)	LBW, VLBW, PTB (32 weeks GA, 32–37 weeks GA)	Infant's sex, maternal race/ethnicity, age, education, nationality, smoking, parity, insurance, initiation of prenatal care in the first trimester and hypertensive disorder

Table 1. continued

First author	Year of study	Place of study/setting	Population	Exposure assessment	Outcomes assessed	Control variables (covariates)
Rich-Edwards et al. (12)	1999–2002	A total of eight Boston-area obstetric offices, Massachusetts, US	A total of 1,354 women who gave birth before 11 September 2001 and 606 women who were pregnant on 11 September 2001	Charts, history	PTB, GA	Trimester at exposure, household poverty level
El Sayed et al. (14)	2000–2002	Michigan, US	Women with Arab surname = 3,133; Women of Arab ancestry = 3,501	Maternal history and a name algorithm was used to determine Arab American ancestry	LBW, VLBW, PTB	Infant's sex, number of previous children born to the mother, mother's age, education and marital status
Lauderdale (13)	2000–2002	California, US	Arabic named singleton infants	History	LBW, and preterm LBW births	None
Endara et al. (15)	2000–2002	USA and 20 foreign countries	A total of 164,743 infants born to active duty military families included in the Department of Defense (DoD) Birth and Infant Health Registries	History	PTB, growth deficiency at birth	Maternal age, military status, education, race/ethnicity, service branch, pay grade, occupation
Smits et al. (16)	2001–2003	Southeastern part of the Netherlands	Exposed group: 1,885 women pregnant on 11 September 2001 and did not deliver before 24 weeks GA. Non-exposed group: 1,258 women pregnant on 11 September 2002, and who did not deliver before 24 weeks GA	History/charts	BW, GA	Maternal age, height, pre-pregnancy weight, education, parity, pregnancy-induced hypertension, use of tobacco

BW = birth weight, CS = cesarean section, IUGR = intra uterine growth restriction, LBW = low birth weight (< 2,500 g), GA = gestational age, PTB = preterm birth, SGA = small for gestational age, VLBW = very low birth weight (< 1,500 g), WTC = World Trade Center.

**Table 2.** Quality assessments of included studies\*.

First author	Type of study	Selection bias	Exposure assessment bias	Outcome assessment bias	Confounding factors bias	Analytical bias	Attrition bias	Overall bias
Berkowitz et al. (9) Engel et al. (17)	Cohort study	None	None	None	Low	Low	None	Low
Lederman et al. (10) Perera et al. (18)	Cohort study with unmatched concurrent controls	Moderate	None	None	Moderate	Low	None	Moderate
Eskenazi et al. (11)	Cohort study with historic controls	None	None	None	Low	Low	None	Low
Rich-Edwards et al. (12)	Matched cohort study	None	None	None	Low	Low	None	Low
El-Sayed et al. (14)	Cohort study with historic controls	None	Low	None	None	None	None	Low
Lauderdale (13)	Cohort study with historic controls	Low	Low	None	Low	Low	None	Low
Endara (15)	Cohort study with controls one year before and one year after	None	Low	None	None	Low	None	Low
Smits et al. (16)	Cohort study with controls one year later	Low	Low	None	None	Low	None	Low

Note: This table includes risk of bias assessment of eight studies as two studies by Engel et al. and Ferrera et al. are secondary studies of Bekowitz et al. and Lederman et al., respectively.

**Table 3.** Low birth weight births.

First author	Exposed group number of LBW births/total number in exposed group	Unexposed group number of LBW births/total number in exposed group	Univariate assessment RR or unadjusted OR (95% CI)	Multivariate assessment adjusted OR (95% CI) or $\beta$ and <i>p</i> -value
Berkowitz et al. (9) Eskenazi 2007 (11)	15/182 Mothers who gave birth in the week beginning 11 September 2001	161/2,367 Mothers who gave birth in the three weeks preceding 11 September 2001	RR 1.21 (0.73, 2.01) New York city OR 1.41 for births <1,500 g vs. $\geq$ 2,500 g, OR 1.67 for births 1,500 g–1,999 g vs. $\geq$ 2,500 g, OR 0.81 for births <2,000 g–2,499 g vs. $\geq$ 2,500 g	New York city AOR 1.44 (0.97, 2.15) for births <1,500 g vs. $\geq$ 2,500 g, AOR 1.67 (1.11, 2.52) for births 1,500 g–1,999 g vs. births $\geq$ 2,500 g, AOR 0.83 (0.63, 1.07) for births 2,000 g–2,499 g vs. births $\geq$ 2,500 g Upstate New York AOR 0.89 (0.54, 1.46) for births <1,500 g vs. $\geq$ 2,500 g AOR 1.42 (0.88, 2.29) for births 1,500 g–1,999 g vs. births $\geq$ 2,500 g, AOR 0.87 (0.66, 1.16) for births 2,000 g–2,499 g vs. births $\geq$ 2,500 g
Lauerdale (13)	N/A	N/A	Pre/post 11 September 2001 Arabic named infant RR 1.34 (1.04, 1.73) Arabic ethnically distinctive name RR 2.25 (1.29, 3.90) Arabic ethnically not distinctive name RR 1.16 (0.87, 1.54) N/A	Pre/post 11 September 2001 Arab name $\beta = -0.26; p = 0.09$ (LBW) $\beta = -0.56; p = 0.22$ (VLBW) $\beta = -0.21; p = 0.09$ (LBW) $\beta = -0.90; p = 0.02$ (VLBW)
El-Sayed et al. (14)	N/A	N/A	N/A	Arab ancestry $\beta = -0.26; p = 0.09$ (LBW) $\beta = -0.56; p = 0.22$ (VLBW) $\beta = -0.21; p = 0.09$ (LBW) $\beta = -0.90; p = 0.02$ (VLBW)

Note: AOR, adjusted odds ratio; LBW, low birth weight (< 2,500 g); N/A, not available; OR, odds ratio; RR, relative risk; VLBW, very low birth weight (<1,500 g).

**Table 4.** Preterm births.

First author	Exposed group Number of preterm births/ total number of births	Unexposed group Number of preterm births/ total number of births	Univariate assessment Unadjusted RR/OR (95% CI)	Multivariate assessment adjusted OR (95% CI)
Berkowitz et al. (9)	18/182	218/2,367	RR 1.07 (0.68, 1.69)	
Eskenazi et al. (11)	Mothers who gave birth in the week beginning 11 September 2001	Mothers who gave birth in the three weeks preceding 11 September 2001	New York City OR 1.29; for births <32 weeks vs. $\geq 37$ weeks, OR 0.92; for births 32 to <37 weeks vs. $\geq 37$ weeks Upstate New York OR 1.12; for births < 32 weeks vs. $\geq 37$ weeks, OR 0.98; for births 32 to <37 weeks vs. $\geq 37$ weeks N/A	New York City AOR 1.30 (0.89, 1.91) for births <32 weeks vs. $\geq 37$ weeks AOR 0.91 (0.75, 1.09) for births 32 to <37 weeks vs. $\geq 37$ weeks Upstate New York AOR 1.09 (0.75, 1.60) for births <32 weeks vs. $\geq 37$ weeks AOR 0.98 (0.82, 1.17) for births 32 to <37 weeks vs. $\geq 37$ weeks
Ei-Sayed et al. (14)	N/A	N/A	N/A	Arab name Beta -0.01, $p = 0.93$ Arab ancestry Beta -0.17; $p = 0.12$
Lauerdale (13)	N/A	N/A	The RR for preterm LBW was 1.50 (1.06, 2.14) for Arabic named women and 0.98 (0.92, 1.04) for non-Hispanic white women in the post-versus pre 11 September 2001 period	
Rich-Edwards et al. (12)	29/606	82/1,184	OR 0.68 (0.44, 1.04)	AOR 0.60 (0.36, 0.98)
Endara et al. (15)	3,761/53,330	7,692/111,413	OR 1.02 (0.98, 1.07)	AOR 1.02 (0.98, 1.06)

Note: AOR, adjusted odds ratio; LBW, low birth weight (<2,500 g); N/A, not available; OR, odds ratio; RR, relative risk.

In Boston (12), there was a significant reduction in the AOR for PTB associated with the WTC disaster. In an Arabic population in California (13), there was an increased risk for PTB among Arabic named women compared to non-Hispanic white women after the WTC disaster period. No increased risk for PTB among women with Arabic name or with Arabic ancestry was reported in Michigan (14). Among infants born to active duty military families in the USA and around the world, no significant difference was reported in the incidence of PTB before and after the WTC disaster (15).

### Secondary outcomes

GA at birth is shown in Table 5 (web-based version). Berkowitz et al. (9) in their main study reported no significant difference in GA at birth whereas in a subgroup of women a one-unit increase in the Post-traumatic Stress Symptomatology score was associated with an increase in GA (17). A significant reduction in GA was reported among women who resided or worked close to the WTC compared to women who neither resided nor worked in the same area (10). In Boston (12) and Holland (16), no significant differences in GA were reported.

One study from New York city reported no significant difference in birthweight (9) whereas another study reported lower BW (10) among full-term neonates (Table 6, see web-based version). In a sub-group analysis of the same study, Perera et al. (18) reported that a doubling of adducts in environmental tobacco smoke exposed mothers resulted in an estimated average of 276-g reduction in BW. In the Dutch study, there was a significant 48 g (95% CI; -83 g, -14 g) mean reduction in BW (16).

Length at birth (Table 7, see web-based version) was reported in one study that reports lower (by 1 cm) length at birth among infants born at term to women who resided within two miles of the WTC (10).

Head circumference at birth is shown in Table 7 (see web-based version). Perera et al. (18) in a sub-study to Lederman et al. (10) reported that a doubling of benzo(a)pyrene-DNA adducts in environmental tobacco smoke exposed mothers resulted in an estimated average reduction of 1 cm in head circumference. In a secondary study to Berkowitz et al. (9), Engel et al. (17) reported that a one-unit increase in the Post-traumatic Stress Disorder score was associated with a significant mean decrease in head circumference of 0.07 cm.

Data on SGA and intrauterine growth-restricted births (Table 8, see web based version) were reported in three studies (9, 10, 15). Berkowitz et al. (9) reported on a significantly increased risk of SGA births in their study close to the WTC. Lederman et al. (10) reported on a similar odds ratio for SGA births in their study in three hospitals close to the WTC, but the finding was not significant. Among active duty military families in the USA and abroad there was no significant

difference in the risk for an SGA birth following the WTC disaster (15).

## Discussion

In this systematic review of eight primary studies (9–16) and two sub-group analyses (17, 18) with low-to-moderate overall risk of bias, the authors identified that the WTC disaster affected pregnancy and birth outcomes adversely in and around the disaster area in New York, among Arabic women in California and in a cohort of women in Holland. The most consistent finding was a significant reduction in fetal growth as measured by BW, length at birth and/or head circumference and an increase in SGA births (see results section and Tables 6–8). In the Dutch study, the mean reduction in BW of 48 g is not likely to be of clinical importance but a reduction of 83 g (the lower 95% CI) may be of importance. In Boston, a decrease in the risk of PTB was reported (12) and there were no adverse effects noted among women of Arabic origin living in Michigan (14). The differences in the findings between the study from California and the study from Michigan are difficult to reconcile. Both research teams assumed that ethnic Arab women could have been exposed to abuse following the WTC disaster. We speculate that differences in the population characteristics of the neighborhoods in the two states may explain some of this variation.

All studies used controls born either before or after the WTC disaster. The studies conducted in Boston (12) and Holland (16) took advantage of cohorts that had been recruited for other research purposes. Two studies were population based (13, 14). Three studies were based on information collected through state (13, 14) or military birth registries (15). The studies were conducted in a wide variety of settings in the USA and internationally. No study followed all pregnancies from the time of onset to their termination whether by spontaneous or by induced abortion, still birth or live birth. These are competitive outcomes and one may be influenced by alteration of the other. Additionally, the sample sizes for the studies conducted in New York City were small and perhaps lacked power. In a recent study of all fetal deaths at or greater than the 20th week of gestation in the USA between 1996 and 2002, Bruckner et al. (19) reported that the odds of a male fetal death increased above its expected value in September 2001. It is possible that the terrorist attacks may have threatened the gestation of male fetuses more than female fetuses. The findings support their “communal bereavement” hypothesis that pregnant women were affected even if they did not know those directly affected by the attacks. Fukada et al. (20) reported a decline in the sex ratio among live-born infants nine months after the Kobe earthquake in 1995 and proposed that the acute stress was responsible.

Acute stress secondary to bereavement leads to increased production of corticosteroids and may compromise immune

**Table 5.** Gestational age at birth.

First author	Exposed group mean GA (weeks or days), (SD)/n = total number of births	Unexposed group mean GA (weeks or days) (SD)/n = total number of births	Univariate assessment Mean difference (weeks or days) ( <i>p</i> -value or 95% CI)	Multivariate assessment Adjusted mean difference (95% CI)
Berkowitz et al. (9)	39.1 (weeks)	39.0 (weeks)	<i>p</i> = 0.55	
Engel et al. (17)	A total of 50 women who completed at least one prenatal psychological assessment (a sample from the study by Berkowitz et al. [9])			A one-unit increase in the post-traumatic stress symptomatology score was associated with a mean increase in GA of 0.04 weeks (SD 0.02); <i>p</i> = 0.03
Lederman et al. (10)	Group 1; 277.7 days /n = 80 Group 2; 275.5 days/n = 51	Group 3; 279.0 days/n = 169	<i>p</i> = 0.026	
Rich-Edwards et al. (12)	39.6 (SD 1.71) weeks/n = 606	39.5 (SD 1.8) weeks/n = 1,184	0.10 weeks (-0.07, 0.27)	0.13 weeks (-0.05, 0.30)
Smits et al. (16)	278.2 (SD 11.4) days/n = 1,885	278.9 (SD 11.1) days/n = 1,258	-0.7 days (-1.5, 0.1)	-0.7 days, <i>p</i> = 0.07

Note: GA, gestational age; SD, standard deviation.

**Table 6.** Birthweight.

First author	Exposed group Mean BW (g) (SD)/total number of births	Unexposed group Mean BW (g) (SD)/total number of births	Univariate assessment Mean difference in BW (g) ( <i>p</i> -value or 95% CI)	Multivariate assessment Adjusted mean difference (95% CI)
Berkowitz et al. (9)	3,203 g /n = 182	3,267 g/n = 2,367	<i>p</i> = 0.14	
Engel et al. (17)	50 women who completed at least one prenatal psychological assessment (a sample from the study by Berkowitz et al. [9])			A one unit increase in the post-traumatic stress symptomatology score was associated with a mean reduction in BW of 2.62 g (SD 6.43); <i>p</i> = 0.69
Lederman et al. (10)	Group 1; 3,339.6 g/n = 80 Group 2; 3,442.7 g/n = 51	Group 3; 3,511.8 g/n = 169	<i>p</i> = 0.019	
Perera et al. (18) Secondary study to Lederman et al. (10)				A doubling of adducts in environmental tobacco smoke exposed mothers resulted in an estimated average 276 g (8%) (95% CI 31, 480 g) reduction in BW ( <i>p</i> = 0.03)
Smits et al. (16)	3,489 (SD 474) g/n = 1,885	3,537 (SD 478) g/n = 1,258	-48.0 g (95% CI; -82.0-14.0)	-48 (95% CI; -83, -14) g

BW = birthweight; SD = standard deviation.

function (21, 22). Maternal stress during pregnancy has been associated with PTB (23). The murder of prime minister Olof Palme in Stockholm in 1986 and the sinking of the ferry Estonia in the Baltic Sea in 1994 were stressful events for many Swedes. Following each of these events, there were increases in VLBW rates (21 and 15%, respectively) over the quarterly average, which was thought to be related to communal bereavement (24). Catalano and Hartig defined communal bereavement as 'the widespread experience of distress among persons who never met the deceased' (24). The authors re-

ported that both events affected fetuses in the third trimester of gestation. They used data from the Medical Birth Registries in Sweden and Norway and controlled for changes in the climate.

At the WTC site and its surroundings, a toxic atmospheric plume was released that contained soot, benzene, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls, polychlorinated furans, dioxins, heavy metals, pulverized glass, cement, asbestos, lead, and alkaline particulates (25). Particulate levels in the air were very high immediately after

**Table 7.** Length and head circumference at birth.

First author	Exposed group Measurement (cm), mean (SD)/n = total number of births	Unexposed group Measurement (cm), mean (SD)/n = total number of births	Univariate assessment	Multivariate assessment
Length				
Lederman et al. (10)	Group 1; 50.06 cm/n = 78 Group 2; 51.44 cm/n = 48	Group 3; 51.15 cm/n = 165	$p = 0.008$	
Head circumference				
Lederman et al. (10)	Group 1; 34.10 cm/n = 78 Group 2; 34.18 cm/n = 49	Group 3; 34.51 cm/n = 164	$p = 0.097$	
Perera et al. (18) Secondary study to Lederman et al. (10)				A doubling of Benzo[a]pyrene-DNA adducts in environmental tobacco smoke exposed mothers resulted in an estimated average 1.0 (95% CI 0.2, 2.0) cm reduction in head circumference ( $p = 0.04$ )
Engel et al. (17) Secondary study to Berkowitz et al. (9)	A total of 50 women who completed at least one prenatal psychological exam			A one-unit increase in the post-traumatic stress symptomatology score was associated with a mean decrease in head circumference of 0.07 cm (SD 0.03); $p = 0.01$

Note: SD, standard deviation.

**Table 8.** Results for small-for-gestational age births/growth restricted births.

First author	Exposed group Number of SGA births/total number of births	Unexposed group Number of SGA births/total number of births	Univariate assessment RR or unadjusted OR (95% CI)	Multivariate assessment adjusted OR (95% CI)
Berkowitz et al. (9)	15/182	89/2,367	RR 2.19 (1.30, 3.71)	AOR 1.90 (1.05, 3.46)
Lederman et al. (10)	7/80	9/169	OR 1.70 (0.61, 4.75)	
Endara et al. (15)	828/53,330	1,723/111,413	1.00 (0.92, 1.09)	AOR 1.00 (0.92, 1.09)

Note: AOR, adjusted odds ratio; OR, odds ratio; RR, relative risk; SGA, small-for-gestational age.

the disaster and decreased sharply with increasing distance from the WTC. The pH of the dust was alkaline (pH 9.0 to 11.0) (25). This increased pollution may have affected birth outcomes among pregnant women who were directly exposed.

In the aftermath of the WTC disaster, all commercial aircrafts in the United States were grounded for three days. Condensation trails from jet aircrafts (contrails) can reduce the transfer of both incoming and outgoing infrared radiation and thus reduce the daily temperature range. It has been proposed that the absence of contrails during this time period was responsible for the increase in the average diurnal temperature range for the period 11–14 September 2001. (26). This may have affected birth outcomes as change in air temperature and season is known to influence birth outcomes (27).

In the vicinity of the WTC, it is likely that the effect on fetal growth was due both to toxins in the environ-

ment and psychological trauma. It is possible that the decrease in BW noted in the study from Holland (16) was due to communal bereavement and/or to change in the temperature range secondary to decrease in contrails as air traffic was reduced.

Long-term developmental effects on the fetus following man-made or natural disasters are possible. Toddlers born to mothers experiencing stress during pregnancy following an ice storm and extended power outage in Quebec, Canada, in 1998, were found to have lower general intellectual and language skill abilities (28). Perera et al. (29) found a significant interaction between cord blood adducts and in utero exposure to environmental tobacco smoke and mental developmental index (Bayley-II Scales of Child Development) score at three years of age. Neither adducts nor in utero exposure to environmental tobacco smoke alone were significant predictors of mental developmental index (29).

## Conclusions

This systematic review identified studies that documented statistically significant adverse pregnancy outcomes following the WTC disaster among women in New York (increase in LBW or SGA births, reduced GA, BW, length and head circumference), among ethnically Arab women living in California (LBW births and PTB) and among Dutch women (decreased BW). Other reports could not confirm these findings in similar populations studied. The adverse pregnancy outcomes are likely due to stress combined with environmental pollution in New York, ethnic harassment in California and communal bereavement in Holland. Whether a change in the diurnal temperature range could play a role or not remains to be studied. The recently documented increase in male fetal loss in the USA following the WTC disaster supports the notion of impact of the WTC disaster on birth outcomes.

### Implications for research

Examination of markers related to stress and/or toxins in maternal and cord blood, and using validated assessment tools following natural or man-made disaster should be further explored. Population-based registries such as the Nordic Medical Birth Registration databases may provide excellent sources for research related to the WTC disaster and other man-made or natural disasters (30).

### Implications for practice

Following a man-made or natural disaster, it is important to identify and support pregnant women, reduce/avoid known risk factors such as exposure to environmentally toxic pollution, provide shelter, improve access and utilization of prenatal care including counseling and psychosocial support. Medical birth registration and ongoing surveillance in real time from the onset of a known pregnancy allows for easy accounting and follow-up of all pregnant women within an exposed jurisdiction following any such event and should be actively encouraged.

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