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Adverse reproductive outcomes associated with exposure to a municipal solid waste incinerator

Michele Santoro[1], Fabrizio Minichilli[1], Nunzia Linzalone[1], Alessio Coi[1], Maria Teresa Maurello[2], Domenico Sallese[2] and Fabrizio Bianchi[1]

[1]*Unità di Epidemiologia Ambientale e Registri di Patologia, Istituto di Fisiologia Clinica, Consiglio Nazionale delle Ricerche, Pisa, Italy*
[2]*Dipartimento di Prevenzione, AUSL 8, Arezzo, Italy*

Abstract
Introduction. The association between reproductive health outcomes and exposure to municipal solid waste incinerators (MSWIs) is inconclusive. This study investigates the association between exposure to a MSWI and various reproductive outcomes (preterm birth, low birth weight, small for gestational age, and sex ratio), taking into account other sources of pollution (industrial plants, highway, major roads with high traffic flows) and maternal factors, including the socioeconomic status.
Methods. PM_{10} concentration maps were used for the exposure assessment to the MSWI and to other sources of pollution in the study area. Information on resident births and maternal covariates were selected from the delivery certificates referred to the period 2001-2010. Mothers' addresses were geocoded in order to attribute the individual level of exposure. Odds ratios (ORs) with a 95% confidence interval (CI) adjusted for maternal covariates and exposure to other pollution sources were calculated.
Results. A total of 3153 newborns to 2401 mothers residing in area during the study period were analyzed. A risk of preterm birth associated with increased exposure was detected (OR = 1.61; 95% CI: 0.88-2.94; p test for trend 0.098). When newborns to primiparous women were considered an OR of 2.18 (95% CI: 1.05-4.53) and a significant trend were observed (p = 0.033). No significant results for the other investigated outcomes were observed.
Conclusions. The study detected a slight association between exposure at MSWI and preterm births. The results are in agreement with those of a previous multi-site study with similar design, and they strengthen the recommendation to consider gestational age in studies and surveillance in areas with MSWIs and similar sources of pollution.

Key words
- reproductive outcomes
- preterm birth
- waste incinerators
- cohort
- dispersion models

INTRODUCTION

Adverse reproductive outcomes are an important field of investigation in environmental epidemiology due to their short-term latency. The association between reproductive health and air pollution is studied worldwide [1]. A limited number of studies have investigated the relationship of reproductive outcomes with exposure to municipal solid waste incinerators (MSWIs). Two systematic reviews highlighted that the results of the few epidemiological studies on this topic are not fully consistent [2, 3]. These studies investigated several types of pregnancy outcomes (*i.e.* sex ratio, low birth weight, preterm birth, small for gestational age, multiple births, congenital anomalies, neonatal and infant mortality) and reported associations only for specific outcomes, sometimes not confirmed by other studies. Furthermore, Ashworth *et al.* [2] highlighted that the methods of the studies are very heterogeneous and that the results could be affected by low statistical power, inadequate control of confounders, and limited exposure assessment. Dispersion models are considered useful tools for exposure assessments in environmental epidemiology studies, and have been recommended for a more accurate exposure assessment of MSWI compared to proxy measures, such as the distance from the source [4-6]. Recent epidemiological studies have investigated cohorts of residents, using dispersion models and geocoding of residential addresses for the exposure assessment. This approach has been used to study the association between exposure to MSWIs and

Address for correspondence: Michele Santoro, Istituto di Fisiologia Clinica, Consiglio Nazionale delle Ricerche, Via Moruzzi 1, 56124 Pisa, Italy. E-mail: michele.santoro@ifc.cnr.it.

long-term outcomes [7-11]. The same study design was also adopted to investigate the association of adverse reproductive outcomes in a multisite-cohort of 21000 newborns [12]. A clear evidence of association between exposure to MSWIs and preterm birth was reported, which strengthened the weaker evidence of a previous similar study conducted in Taiwan [13].

Our study investigated the association between air pollution exposure from an MSWI and the occurrence of various adverse reproductive outcomes (preterm birth, low birth weight, small for gestational age, sex ratio) in newborns to mothers residing in the area. In risk estimation, other pollution sources located in the area, and some maternal factors, including socioeconomic status, were taken into account.

The study was carried within the framework of the project LIFE+2010 ENV/IT/331 "Participatory evaluation of health, environmental and socio-economic impacts resulting from urban waste treatment" aimed at applying a health impact assessment of urban waste cycle policies [14].

METHODS

We focused on an incinerator plant located in an area named "San Zeno", in the neighbourhood of the municipality of Arezzo, Tuscany Region, Italy. The plant uses the "Best Available Techniques" for waste incineration, has been active since 2000, and burns about 40 000 tons/year of urban solid waste [15-17]. The MSWI is located close to various industrial plants, namely "San Zeno plants", involved in the refining of gold. Other industrial plants located in a neighbouring area deal with precious metal recycling, road paving maintenance, furniture production, recovery of recyclable materials and waste disposal including hazardous wastes. There is an infrastructure of highway and major roads with high traffic flows in the area. The study area *(Figure 1)* is a square of 12 km^2 including the major sources of pollution and for which environmental data produced by the University of Siena and the Regional Agency for Environmental Protection are available. Atmospheric dispersion models relating to MSWI and other pollution sources in the area were applied using the ADMS-Urban model. The simulation models used environmental and meteorological data of the year 2007 and considered the orography of the area. The models generated annual average concentration maps. In our study, concentration maps of PM_{10}, considered as tracer of air pollution, were used to estimate exposure to each of the following sources: the MSWI, the San Zeno plants, other industrial plants, and the highway. For the other industrial plants, an overall concentration map, defined as the sum of the concentrations of the individual maps, was used.

The study population is constituted by the newborns to the cohort of mothers residing in the area in the period 2001-2010. The Department of Prevention of the Local Health Authority provided the delivery certificates of all the births from 2001 to 2010 to mothers residing in the municipalities of Arezzo and Civitella Val di Chiana. All the mothers were linked to the municipal General Registry Offices to obtain the residential addresses. All the addresses were geocoded and only the mothers living in the study area were selected. Subjects who were not residents in the area during the pregnancy were excluded. Residential address at the time of the pregnancy was attributed to the mothers. For mothers who changed the residence during pregnancy but still within the study area (overall 6 cases), we considered the first residential address. The exposure to each mother was attributed on the basis of the corresponding PM_{10} concentration map related to: the MSWI, the San Zeno plants, other industrial plants, and the highway. For the MSWI and for each other pollution source, three exposure classes, labelled as *low*, *medium* and *high* exposure, were defined using the 50^{th} and 80^{th} percentiles of the distribution of the PM_{10} concentrations estimated through the dispersion models. Cut-off levels were chosen accordingly to a recent Italian epidemiological study on population living close to urban waste incinerator plants in Lazio Region [9]. As no concentration maps were available for the major roads, a buffer distance from the residential addresses was used to define the exposure. The roads with high traffic flows considered in the study were the ones rated from 1 to 5 by the Functional Road Class (FRC). Exposure to the major roads was defined using the distance of 150 meters as critical threshold.

We used the information obtained from the delivery certificates to define maternal characteristics potentially associated with reproductive outcomes [18-21]. We considered the following information collected in the birth certificates: maternal age, mother's educational level, pregnancy order, country of origin, and sex of the newborn. Socioeconomic status was assessed through a deprivation index calculated by census tract [22], attributed to each mother on the basis of her residence, and categorized in quartiles.

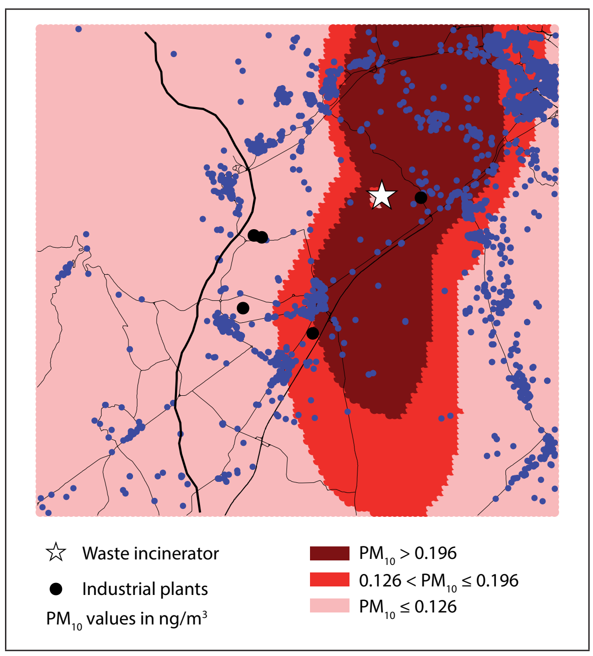

Figure 1
Study area. Incinerator dispersion map of PM_{10} with geocoded mothers' addresses.

The outcomes considered and the corresponding criteria of exclusion are:

- preterm birth (PTB): gestational age less than 37 weeks, excluding multiple births;
- low birth weight (LBW) among term pregnancies: birth weight less than 2500 grams excluding preterm births and multiple births;
- small for gestational age (SGA): infants whose birth weight is <10th percentile for the corresponding gestational age and sex, using Canadian growth curves by sex [23] and excluding multiple births and infants born to Indian mothers;
- sex ratio (SR): ratio between the number of males and females born.

We estimated the association between each outcome and the exposure classes to the MSWI by the odds ratio (OR) with a 95% confidence interval (CI) and p-value, adjusted for: maternal covariates, exposure classes to the other pollution sources, and socioeconomic status. The class with the lowest exposure was used as a reference. An adjusted trend of ORs along the classes of exposure with the relative p-value was also estimated. Data analysis was performed by multivariate logistic regression models using STATA 13 (StataCorp LP, College station, TX) and SAS version 9.2 (SAS Institute, Inc, Cary, NC).

RESULTS

In the study area, the mean of the estimated concentrations of PM_{10} from the MSWI was 0.155 ng/m^3 (SD 0.131 ng/m^3), with a maximum value of 1.380 ng/m^3. The exposure levels in the three classes were: *low exposure*: PM_{10} (ng/m^3) ≤ 0.126; *medium exposure*: 0.126 < PM_{10} (ng/m^3) ≤ 0.196; *high exposure*: PM_{10} (ng/m^3) > 0.196.

A total of 3069 newborns to 2401 mothers residing in the study area during the study period were analyzed. The characteristics of the study population are reported in *Table 1*. A total of 495 newborns (16.1%) were included in the class with the highest exposure. Newborns included in the two highest classes of exposure to the MSWI were more represented among those exposed to the San Zeno plants and less to the other industrial plants. Newborns in the highest class of exposure to the MSWI were not represented among the highly exposed subjects to the highway. No significant differences in maternal characteristics were found among the exposure classes. Newborns in the highest class of exposure were more present in the least deprived classes.

A total of 164 cases of PTB, 5.3% of the total newborns, were detected in the area during the study period. Increased ORs with increasing levels of exposure to the MSWI were observed (p for trend = 0.098), up to an OR of 1.61 (95% CI: 0.88-2.94) in the highest class of exposure *(Table 2)*.

A total of 456 SGA cases were observed (14.9% of total newborns); the trend was not significant with increasing exposure (p = 0.155); OR of 1.30 (95% CI: 0.90-1.88) in the higher class was observed.

A limited number (n = 74, 2.4%) of LBW cases from full-term pregnancies were observed. ORs slightly decreased along the classes of exposure (OR = 0.85; 95% CI: 0.53-1.81) with no evidence of trend (p = 0.751).

No evidence for SR alteration was observed (p for trend = 0.250).

As seen in *Table 2*, the results of the multivariate analysis showed a thin association between increasing exposure to MSWI and PTB. This association increases among newborns to primiparous women (n = 1749, 57.0% of the births). 103 cases of PTB (6.1%) were detected among the births to mothers at the first pregnancy. Increased ORs with increasing exposure (p for trend = 0.033) up to an OR of 2.18 (95% CI: 1.05-4.53) in the highest class were observed *(Table 3)*.

DISCUSSION AND CONCLUSIONS

The aim of this study was to estimate the association between exposure to a MSWI and adverse reproductive outcomes. One of the key features of the study was the use of dispersion models for assigning exposure to the MSWI and to other sources of pollution located in the area. In addition, the study design enabled the exposure to be attributed to the different sources at an individual level. Finally, individual maternal characteristics were also considered. The adopted methodology is consistent with the recent suggestions about the epidemiological investigation on health effects associated to MSWI exposure, including the use of atmospheric dispersion modelling for a more accurate exposure assessment, the adequate control for confounding related to other pollution sources and individual characteristics [2, 5, 6].

In our model, mother's educational level and a census tract-based deprivation index were included, which allowed us to partially adjust for unavailable individual variables such as occupational exposure and smoking, and reasonably reduce a possible bias. Single-site studies, as the one here presented, are commonly characterized by a small population size often leading to models endowed of a low statistical power. Considering that the adverse reproductive outcomes are quite rare events, the risks estimated in our study can be affected by low precision. The study area presents an overall complex environmental framework and the overlap of the different sources of air pollution could lead to a misclassification of the individual exposure. Modeled PM_{10} concentrations from the MSWI of San Zeno were quantitatively low and have been considered as a tracer for evaluating the level of environmental exposure in relative terms, consistently with other recent epidemiological studies on MSWIs [9-12]. The simulation models used in our study for the exposure assessment were based on data available only for the year 2007. The assumption of lack of temporal variability of exposure is likely supportable by the fact that major changes of operating conditions of the MSWI plant in 2001-2010 are not documented by its monitoring systems.

In our study we observed a risk of preterm birth with an increased exposure to the MSWI. The strength of the association increases if births to primiparous mothers are selected. The association between preterm birth and exposure to waste incinerators is investigated by the scientific community in a limited way. In the systematic review by Ashworth *et al.* [2] only one study

Table 1
Maternal characteristics and other sources of environmental exposures by class of exposure to the waste incinerator, 2001-2010

Exposure to waste incinerator	Low $PM_{10} \leq 0.126$		Medium $0.126 < PM_{10} \leq 0.196$		High $PM_{10} > 0.196$		Total	
	N.	(%)	N.	(%)	N.	(%)	N.	(%)
Newborns	1405	(45.8)	1169	(38.1)	495	(16.1)	3069	(100.0)
Exposure to San Zeno plants								
Low	840	(59.8)	227	(19.4)	119	(24.0)	1186	(38.6)
Medium	527	(37.5)	577	(49.4)	221	(44.7)	1325	(43.2)
High	38	(2.7)	365	(31.2)	155	(31.3)	558	(18.2)
Exposure to other industrial plants								
Low	742	(52.8)	925	(79.1)	191	(38.6)	1858	(60.5)
Medium	366	(26.1)	88	(7.5)	239	(48.3)	693	(22.6)
High	297	(21.1)	156	(13.3)	65	(13.1)	518	(16.9)
Exposure to highway								
Low	736	(52.4)	843	(72.1)	248	(50.1)	1827	(59.5)
Medium	192	(13.7)	293	(25.1)	247	(49.9)	732	(23.9)
High	477	(34.0)	33	(2.8)	0	(0.0)	510	(16.6)
Vicinity to major roads (within 150 meters)	852	(60.6)	827	(70.7)	277	(56.0)	1956	(63.7)
Maternal age								
<35	1013	(72.1)	825	(70.6)	347	(70.1)	2185	(71.2)
35-40	350	(24.9)	316	(27.0)	140	(28.3)	806	(26.3)
>40	42	(3.0)	28	(2.4)	8	(1.6)	78	(2.5)
Primiparous	800	(56.9)	663	(56.7)	286	(57.8)	1749	(57.0)
Missing	3	(0.2)	3	(0.2)	3	(0.6)	9	(0.3)
Educational level								
Low	436	(31.0)	303	(25.9)	138	(27.9)	877	(28.6)
Medium	714	(50.8)	626	(53.6)	255	(51.5)	1595	(52.0)
High	255	(15.2)	240	(20.5)	102	(20.6)	597	(19.5)
Foreign mothers	232	(16.5)	208	(17.8)	77	(15.6)	517	(16.8)
Deprivation index								
Low	447	(31.8)	298	(25.5)	168	(33.9)	913	(29.7)
Medium-low	313	(22.3)	261	(22.3)	153	(30.9)	727	(23.7)
Medium-high	395	(28.1)	260	(22.2)	52	(10.5)	707	(23.0)
High	250	(17.8)	350	(29.9)	122	(24.7)	722	(23.5)

PM_{10} values in ng/m^3.

about this birth outcome was reported. The study was conducted in Taiwan in 2006 by Lin *et al.* [13] and detected a slight increase of preterm birth. A more recent Italian multisite study by Candela *et al.* [12] detected a strong evidence of an association between exposure to MSWIs and preterm birth. Furthermore, an association between exposure with incinerator emissions and the occurrence of miscarriages has recently been reported by the same Authors, who suggested interpreting this finding together with previous results on the risks of preterm birth [24]. Although we detected a slight evidence of risk of preterm birth, the result is consistent with results previously found in the multisite study by Candela *et al.* [12] characterized by an analogous study design.

Preterm birth is an outcome poorly investigated on specific association with exposure to MSWIs but some suggestive associations with sources of air pollution are also reported in recent studies [25, 26]. Premature birth is an important public health issue. The World Health Organization includes complications related to preterm birth among the main indirect causes of neonatal mortality, mortality in children under 5 years old, and long-term disability [27]. Spontaneous preterm delivery is recognized as a multi-factorial process, caused by the interaction of several factors [18]. This includes the role of environmental causes, and the potential role of genetic-environment interactions in increasing the risk of preterm birth is considered as a research priority in this field [27]. It is our belief that the results of this present study reinforce the recommendation to consider age of

Table 2
Associations between class of exposure to waste incinerator and adverse reproductive outcomes

Outcome	Exposure	N.	OR	95% CI	p
Preterm birth	Low	70	1		
	Medium	65	1.35	0.88-2.07	0.165
	High	29	1.61	0.88-2.94	0.125
	Trend		*1.28*		*0.098*
Small for gestational age	Low	203	1		
	Medium	171	1.13	0.86-1.48	0.388
	High	82	1.30	0.90-1.88	0.156
	Trend		*1.14*		*0.155*
Low birth weight	Low	37	1		
	Medium	27	0.98	0.53-1.81	0.950
	High	10	0.85	0.34-2.08	0.718
	Trend		*0.93*		*0.751*
Sex ratio	Low	721	1		
	Medium	600	1.07	0.89-1.29	0.484
	High	259	1.17	0.89-1.52	0.253
	Trend		*1.08*		*0.250*

Odds Ratio with 95% Confidence Interval and p value, Trend with p value, 2001-2010.
ORs are adjusted for: maternal age, mother educational level, pregnancy order, country of origin, newborn sex, socioeconomic status, exposure to other pollution sources.

gestation as an end-point in epidemiological studies as well as surveillance activities in areas with waste incinerators and other sources of air pollution.

Even if the scientific evidence is considered limited, public health policies should reinforce reproductive health promotion and surveillance, especially in areas

Table 3
Associations between class of exposure to waste incinerator and preterm births among primiparous mothers

Exposure	N.	OR	95% CI	p
Low	38	1		
Medium	42	1.55	0.88-2.71	0.128
High	23	2.18	1.05-4.53	0.036
Trend		*1.48*		*0.033*

Odds Ratio with 95% Confidence Interval and p value, Trend with p value, 2001-2010.
ORs are adjusted for: maternal age, mother educational level, country of origin, newborn sex, socioeconomic status, exposure to other pollution sources.

characterized by environmental pressures. More widely, being fetuses and newborns more sensitive to environmental insults, they have to be considered vulnerable subgroups of population and precautionary actions for their protection should be taken into in account in the policy making process.

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Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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