Adverse pregnancy outcomes in a population exposed to the emissions of a municipal waste incinerator

Marco Vinceti⁎, Carlotta Malagoli, Sergio Teggi, Sara Fabbri, Carlo Goldoni, Gianfranco De Girolamo, Paola Ferrari, Gianni Astolfi, Francesca Rivieri, Margherita Bergomi

CREAGEN-Environmental, Genetic and Nutritional Epidemiology Research Center, Department of Public Health Sciences, University of Modena and Reggio Emilia, Modena, Italy
LARMA-Laboratory of Environmental Analysis, Surveying and Environmental Monitoring, Department of Mechanical and Civil Engineering, University of Modena and Reggio Emilia, Modena, Italy
Unit of Epidemiology, Department of Public Health, Local Health Unit of Modena, Modena, Italy
Department of Paediatrics, University of Modena and Reggio Emilia, Policlinico Hospital, Modena, Italy
IMER Registry, Department of Reproduction and Growth, St. Anna Hospital, Ferrara, Italy

ARTICLE DATA

Article history:
Received 17 March 2008
Received in revised form 6 August 2008
Accepted 7 August 2008
Available online 27 September 2008

ABSTRACT

Some contaminants emitted by municipal waste incinerators are believed to adversely affect reproductive health in the exposed populations; yet only limited and conflicting epidemiologic evidence on this issue has been provided so far. In this study we analyzed rates of spontaneous abortion and prevalence at birth of congenital anomalies in women residing or working near the municipal solid waste incinerator of Modena, northern Italy, during the 2003–2006 period and who experienced higher levels of exposure to polychlorinated dibenzo-p-dioxins and dibenzofurans, compared to the remaining municipal population. In women residing in two areas close to the incinerator plant with increasing exposure to dioxins, we did not detect an excess risk of miscarriage (relative risk [RR] 1.00, 95% confidence interval [CI] 0.65–1.48) and of birth defects (RR 0.64, 95% CI 0.20–1.55), nor did any indication of dose–response relation emerge. Among female workers employed in the factories located in the exposed areas, we did not observe a higher risk of spontaneous abortion (RR 1.04, 95% CI 0.38–2.30); however, an increase in prevalence of birth defects was noted (RR 2.26), although this risk estimate was statistically very unstable (95% CI 0.57–6.14). Overall, the study results provide little evidence of an excess risk of adverse pregnancy outcomes in women exposed to emissions from a modern municipal solid waste incinerator.

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Keywords:
Waste incineration
Spontaneous abortion
Birth defects
Cohort study
Environmental pollution

1. Introduction

Emissions from municipal waste incinerators contain pollutants such as heavy metals and polychlorinated dibenzo-p-dioxins, dibenzofurans and biphenyls, which are of considerable toxicological interest. Some of these contaminants are alleged to increase the incidence of cancer and contribute to adverse pregnancy outcomes on the basis of laboratory and epidemiologic data (Dolk and Vrijheid, 2003; Rushton, 2003; World Health Organization, 2007; Signorelli et al., 2008),

⁎ Corresponding author. Dipartimento di Scienze di Sanità Pubblica, Università di Modena e Reggio Emilia, Via Campi 287, 41100 Modena, Italia. Tel.: +39 059 2055 481; fax: +39 059 2055 483.
E-mail address: marco.vinceti@unimore.it (M. Vinceti).

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doi:10.1016/j.scitotenv.2008.08.027
consequently inducing considerable concern in the populations surrounding the plants. In particular, recent studies have examined the possible relation between the environmental pollution associated with waste incineration and risk of adverse pregnancy outcomes such as miscarriage and birth defects, but their results have been conflicting and inconclusive (Cresswell et al., 2003; Dummer et al., 2003; Cordier et al., 2004; Tango et al., 2004). Such an issue is also of strong public health interest due to the short induction time of the reproductive outcomes when compared with other endpoints such as cancer, thus making pregnancy outcomes particularly suitable to timely monitoring the health effects of waste incinerators, as more generally of chemical exposures associated with environmental pollution.

The present investigation summarizes the results of a cohort study carried out in an Italian community in order to assess the rates of adverse pregnancy outcomes in women living or working near a municipal waste incinerator, exposed to higher levels of environmental contamination with polychlorinated dibenzo-p-dioxins and dibenzofurans compared with the remaining municipal population.

2. Methods

2.1. Study area

We examined the surrounding area of the municipal solid waste incinerator in the town of Modena, northern Italy (extension 183 km², population approximately 180,000). The plant, with a yearly capacity of 120,000 tons and three grate combustion lines, started its operation in 1984 and underwent substantial upgrades in 1989 and at the beginning of 2003. It is equipped with a dry scrubbing of flue gas, based on sodium bicarbonate for acidic pollutants, added with activated carbon for dioxin and mercury adsorption and with a selective non catalytic reducer (SNCR) for NOx abatement.

We identified three municipal areas with different degree of incinerator emissions exposure by using the estimated fall-out of polychlorinated dibenzo-p-dioxins and dibenzofurans (henceforth referred to as ‘dioxins’) in the lower part (0–10 m altitude span) of the atmosphere and by defining two areas characterized by higher levels of exposure in comparison to the remaining municipal population.
municipal territory, using cutoff points at 0.5 (area B) and 1.0 (area A) \(10^{-9} \text{ g/m}^3\) (Fig. 1). We estimated these concentration levels through two models based on maximum incinerator allowed plant emissions, the Industrial Source Complex model-short term (ISC3ST) (Lee et al., 2007; U.S. EPA, 1995) for the 2003–05 period and the stochastic lagrangian dispersion model SPRAY (Gariazzo et al., 2007) for the 2006 period, inputting the meteorological values for the periods between 1.1.1999 and 31.12.2002 and between 1.10.2005 and 1.10.2006, respectively. The meteorological database used was the ‘CALMET’ pre-processor developed by the Emilia-Romagna Region Meteorological Service, containing hourly data for the various meteorological and atmospheric turbulence parameters, calculated on wide domain (Northern Italy) with resolution of 5 km: wind, temperature, stability class, friction velocity, mixing height, Monin–Obukhov length and convective velocity scale Stull (Stull, 1988). The dispersion model ISC3ST (U.S. EPA, 1995) is a steady-state Gaussian plume model allowing for the assessment of pollutant concentrations from a wide variety of sources associated with an industrial complex, and accounting for processes of settling and dry deposition of particles, downwash, plume rise as a function of downwind distance, separation of point sources and limited terrain adjustment. In the present study, the extension of computation domain was 4 km×5.5 km centered to emission source, with 1013 receptors. For the 2006 period, we reassessed exposure areas through the more advanced lagrangian modeling procedure of the dispersion package ARIA Industry (Arianeet s.r.l., Milan). This modeling system is mainly made up of three models: the meteorological pre-processor, Minerve, the turbulence pre-processing, Surfpro and the lagrangian stochastic pollution dispersion model, Spray. Spray, in particular, simulates the dispersion, transport, dry and wet deposition and radioactive decay of airborne inert pollutants from different types of emission sources over complex topography (point, line, area and volumetric source). It also creates 3D concentration and deposition fields in non homogenous (vertical wind share, breeze due to the terrain discontinuities, etc.) and non stationary meteorological conditions, allowing for a more realistic simulation of complex situations when compared to the more traditional models. We used the computational domain of 15 km×15 km (horizontal)×1.5 km (vertical) subdivided in 100 m×100 m cells (horizontal) and in 30 layers (vertical). The emission source was located to the center domain centre. Using the dispersion models we obtained maps of different ground-level exposure (highest and intermediate) to dioxins incinerator emissions, which were represented through a Geographic Information System (GIS) project based on the national cartographic representation system (Roma40-Gauss Boaga). Reanalysis of dispersion models Fig. 1 shows the exposure areas obtained using the ARIA Industry dispersion model for the 2006 period placed over the urban cartography of Modena city. Finally, using both models we calculated the atmospheric dispersion around the incinerator plant of some heavy metals of major toxicological importance, including arsenic, chromium, lead, nickel and cadmium, which resulted as being substantially comparable to dioxins.

2.2 Study population and data analysis

By accessing the databases of the Modena Municipality and using coordinates of the exact address of each municipal resident between January 1, 2003 and December 31, 2006 in the above-mentioned GIS, we identified all females aged 16–49, who at any time during that period were residing in the high and intermediate-exposure areas. We also retrieved with the cooperation of the Modena Office of the Istituto Nazionale di Previdenza Sociale (INPS) all the firms registered as having their location in the A and B exposure areas, and we traced all female workers working in those firms for at least one week during one of the years included in the study and already residing in Modena municipality since the beginning of that year. INPS data were unavailable for 2004 and therefore no analysis could be carried out for that year.

We then attempted to identify all cases of spontaneous abortions and birth defects that occurred in the Modena municipal population during the follow-up period by reviewing the hospital discharges in the Emilia-Romagna region and the remaining Italian regions which reported the ICD9-CM diagnostic codes 630–634 or 637 (for miscarriages) and 740–759 for birth defects, as well as the 2003–2006 files of the Emilia-Romagna Region IMER Birth Defects Registry, a population-based registry participating in the Eurocat program (Calzolari et al., 2007). Only congenital anomalies in stillbirths and in livebirths identified within 28 days after birth were included in the analysis throughout the study period, and for 2006 anomalies identified in voluntary abortions in the main Modena hospital (University Policlinico) could also be included.

In the next phase we computed incidence of spontaneous abortions in women residing and working in the two highest exposure areas between 2003 and 2006. For residents, we started the follow-up from January 1, 2003 or, in case of immigration in these areas after March 31, 2002, nine months after the beginning of continuous residence into the exposed areas, until December 31, 2006 or date of emigration or death, whichever occurred first. Women employed in a firm located in the exposed areas were included in the follow-up of each of the years for which we had information available (2003, 2005 and 2006), provided that they were residing in the municipality since the beginning of that year. When a female resident or worker experienced a miscarriage, she was removed from the follow-up for a three-month period from that date, whilst in case of parturition the follow-up was interrupted from three months before the date of delivery until three months after delivery. We also obtained data regarding the socioeconomic status of members of these two residential cohorts for 2003 by reviewing the 2001 National Census database (Table 1). To obtain the number of expected cases in the exposed (residential and occupational) cohorts, we accumulated their age- and

<table>
<thead>
<tr>
<th>Educational attainment level (%) of the residential cohort exposed to the Modena incinerator emissions in 2003 and of the remaining municipal population (data from National Census 2001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational attainment level</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Less than primary school</td>
</tr>
<tr>
<td>Primary school</td>
</tr>
<tr>
<td>Secondary school</td>
</tr>
<tr>
<td>University</td>
</tr>
</tbody>
</table>
calendar year-specific person-years of follow-up (3796.64 in residents and 695.58 in workers, Table 2), and we multiplied this person-time for incidence of spontaneous abortions in the whole Modena municipal population. For the birth defects analysis, we computed expected cases of congenital anomalies at birth in the offspring of women residing and working in the two highest exposure areas between 2003 and 2006, by considering the overall live- and stillbirths occurred to cohort members during the follow-up and by using age-adjusted prevalence in the remaining municipal population as reference rate. Relative risk (RR) of adverse pregnancy outcomes was computed as the ratio between observed and expected incidence for miscarriage and between observed and expected prevalence for birth defects, and precision of these risk estimates was evaluated through their mid-P 95% confidence intervals (CI) (Rothman and Greenland, 1998).

### 3. Results

The number of spontaneous abortions occurring in the residential cohort was 23 (7, 7, 5 and 4 in the first, second, third and fourth year, respectively), yielding an overall age- and calendar-year-adjusted RR 1.00 (95% CI 0.65–1.48); the RR for the most exposed cohort (A) was 0.87 (95% CI 0.22–2.38), whilst the corresponding value for the cohort B was 1.03 (95% CI 0.64–1.56) (Table 3). For the occupational cohort, we found an overall RR of 1.04 (95% CI 0.38–2.30), with values of 0.00 (0.00–1.46) for cohort A and 1.81 for cohort B (0.66–4.02) (Table 3).

Concerning the birth defects analysis (Table 4), in the entire residential cohort we found a RR of 0.64 (95% CI 0.20–1.55) based on the detection of 4 cases of congenital anomalies, with values of 0.68 (95% CI 0.00–4.41) and 0.72 (95% CI 0.23–1.75) for the A and B subcohorts, respectively. Of these anomalies, two were facial clefts (in one case associated with brain and upper limb deformities), another was an esophageal abnormality and the last case was an intraventricular septal defect. The corresponding analyses in workers, based on the observation of three cases, two of which occurring in area A and one in area B, yielded a RR of 2.26 (95% CI 0.57–6.14), with values of 2.22 (0.37–7.34) and 2.27 (0.11–11.21) for women working in the area A and B, respectively. These abnormalities consisted in an ear anomaly, a urinary system defect and a case of syndactyly associated with undescended testicle.

### Table 2 – Person-years of follow-up of residential and occupational cohort exposed to the emissions of Modena municipal solid waste incinerator, 2003–06

<table>
<thead>
<tr>
<th>Cohort</th>
<th>All residents</th>
<th>Area A residents (highest exposure)</th>
<th>Area B residents (intermediate exposure)</th>
<th>All workers</th>
<th>Area A workers (highest exposure)</th>
<th>Area B workers (intermediate exposure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>994.15</td>
<td>155.98</td>
<td>838.17</td>
<td>189.35</td>
<td>106.14</td>
<td>83.21</td>
</tr>
<tr>
<td>2004</td>
<td>985.19</td>
<td>172.72</td>
<td>812.47</td>
<td>182.44</td>
<td>101.13</td>
<td>81.31</td>
</tr>
<tr>
<td>2005</td>
<td>973.11</td>
<td>110.70</td>
<td>862.41</td>
<td>182.44</td>
<td>101.13</td>
<td>81.31</td>
</tr>
<tr>
<td>2006</td>
<td>844.19</td>
<td>78.38</td>
<td>765.81</td>
<td>323.79</td>
<td>91.63</td>
<td>232.16</td>
</tr>
<tr>
<td>2003–06</td>
<td>3796.64</td>
<td>517.78</td>
<td>3278.86</td>
<td>695.58</td>
<td>298.9</td>
<td>396.68</td>
</tr>
</tbody>
</table>

No data available in 2004 for workers.

### Table 3 – Risk of spontaneous abortion among residents and workers exposed to emissions from Modena municipal solid waste incineration in the 2003–06 period

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Observed cases</th>
<th>Expected cases</th>
<th>Relative risk</th>
<th>95% Confidence limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>All residents</td>
<td>23</td>
<td>22.93</td>
<td>1.00</td>
<td>0.65–1.48</td>
</tr>
<tr>
<td>Area A residents (highest exposure)</td>
<td>3</td>
<td>3.43</td>
<td>0.87</td>
<td>0.22–2.38</td>
</tr>
<tr>
<td>Area B residents (intermediate exposure)</td>
<td>20</td>
<td>19.48</td>
<td>1.03</td>
<td>0.64–1.56</td>
</tr>
<tr>
<td>All workers</td>
<td>5</td>
<td>4.81</td>
<td>1.04</td>
<td>0.38–2.30</td>
</tr>
<tr>
<td>Area A workers</td>
<td>0</td>
<td>2.05</td>
<td>0.00</td>
<td>0.00–1.46</td>
</tr>
<tr>
<td>Area B workers</td>
<td>5</td>
<td>2.76</td>
<td>1.81</td>
<td>0.66–4.02</td>
</tr>
</tbody>
</table>

### Table 4 – Risk of birth defects in the offspring among female residents and workers exposed to emissions from Modena municipal solid waste incinerator in the 2003–06 period

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Observed cases</th>
<th>Expected cases</th>
<th>Relative risk</th>
<th>95% Confidence limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>All residents</td>
<td>4</td>
<td>6.21</td>
<td>0.64</td>
<td>0.20–1.55</td>
</tr>
<tr>
<td>Area A residents (highest exposure)</td>
<td>0</td>
<td>0.68</td>
<td>0.00</td>
<td>0.00–4.41</td>
</tr>
<tr>
<td>Area B residents (intermediate exposure)</td>
<td>4</td>
<td>5.52</td>
<td>0.72</td>
<td>0.23–1.75</td>
</tr>
<tr>
<td>All workers</td>
<td>3</td>
<td>1.33</td>
<td>2.26</td>
<td>0.57–6.14</td>
</tr>
<tr>
<td>Area A workers</td>
<td>2</td>
<td>0.90</td>
<td>2.22</td>
<td>0.37–7.34</td>
</tr>
<tr>
<td>Area B workers</td>
<td>1</td>
<td>0.44</td>
<td>2.27</td>
<td>0.11–11.21</td>
</tr>
</tbody>
</table>
### 4. Discussion

In this study, we find no substantial evidence that maternal exposure to dioxins emissions from the municipal waste incinerator under examination increased the risk of miscarriage and of birth defects in the offspring, since overall relative risks were low in most exposed groups and no indication of dose–response relations emerged. The increased risk of birth defects occurred in the offspring of women working in the exposed areas might have been due to factors related to the occupational environment and activity or to lifestyle factors, although none of these data was collected and analyzed and therefore any explanation of such excess risk remains largely hypothetical.

Some recent studies have examined the possible relation between exposure to incinerator emissions and reproductive health, suggesting in two cases a relation with mortality from congenital anomalies (particularly from spina bifida and heart defects) (Dummer et al., 2003) and with facial cleft and urinary defects (Cordier et al., 2004), whilst two other investigations found little if any evidence of adverse effects (Cresswell et al., 2003; Tango et al., 2004). These investigations, however, were hampered by important methodological limitations, such as the use of maternal residence at birth (or at occurrence of spontaneous or induced abortion, or fetal death) and not at the beginning of the pregnancy to assess antecedent individual exposure, and the lack of detailed models of contaminants emission and deposition as well of individual data about potential life-style confounders. It should also be noted that this study was concerned with the risk assessment of a ‘modern’ waste incinerator equipped with advanced air pollution control technology, and therefore our results must be extended with caution to older plants.

Though the small number of cases prevented the analysis of specific categories of birth defects, the occurrence of two cases of facial clefts in the exposed cohort is interesting, also considering the results of two ecologic studies (ten Tusscher et al., 2000; Cordier et al., 2004), and should be carefully evaluated. However, in one case, facial cleft was associated with other severe congenital defects, and both cases belonged to the offspring of women residing in the intermediate-exposure study area, while no case occurred in the most exposed area. Moreover, a ecologic study carried out in Sweden did not suggest an association between clefts and incinerators emissions (Jansson and Voog, 1989).

We must acknowledge some limitations of the present study. First, the analyses were based on a rather small number of cases, due to the scarcity of exposed women and the low number of outcomes occurring in the exposed populations particularly for the birth defects analysis, and therefore the inherent statistical instability of the risk estimates cannot rule out a possible relation between the exposure under study and ‘small’ increases in teratogenic risk. However, the study results were generally consistent in both the residential and the occupational cohorts and tended to be similar in each calendar year-specific analyses (data not shown); in addition, no dose–response relation emerged when RRs in the population with the highest exposure were compared to those observed in intermediate-exposure subgroups.

Data concerning induced abortions associated to severe congenital malformations in the offspring were unavailable for most of the study period, and therefore results of the present study should be extended with caution to lethal congenital anomalies such as neural tube defect, severe heart defects and some types of chromosomal anomalies.

Some degree of exposure misclassification almost certainly occurred in the present study. It appears likely that a few women residing in the exposed areas underwent a miscarriage or delivered a child during the study period while having resided in the exposed areas too little to fulfill the criteria for inclusion in the exposed cohorts. Such cases would have therefore been included in the unexposed group, i.e. in the remaining municipal population, thus biasing the estimates towards the null and reducing the ability of the study to detect small changes in risk. Some inadequacy of exposure assessment also occurred in women working in the exposed areas, since we did not have available data about the number of weeks spent at work during each year of the follow-up or the employment type (including full-time/part-time status).

We did not collect at the individual level information about lifestyle potential confounders such as smoking, diet, occupation and reproductive history. However, we reviewed socioeconomic status information collected for most members of the exposed and unexposed cohorts during the 2001 National Census, finding evidence that characteristics of the exposed residents were rather comparable to that of the remaining municipal population, with a tendency towards lower educational attainment in the former group. Such difference should have had little relation with teratogenic risk, though lower maternal socioeconomic status has been associated in some studies with increased risk (Cattaruzza and Spinelli, 2000; Osborn et al., 2000; Price, 2006; Yang et al., 2008), thus further strengthening the findings of the present study, i.e. the lack of relation between exposure to waste incinerator emissions and adverse pregnancy outcomes.

Finally, the comparable socioeconomic status across the cohorts examined in the present study, and the expected limited consumption in this urban area of locally-produced foods (generally the major source of exposure to dioxins compared with inhalation and dermal absorption (Domingo, 2002; Fierens et al., 2007; Lonati et al., 2007)), suggests that dioxin intake through food was very similar in these groups. Differences in dioxins exposure were therefore likely restricted to the two remaining sources of intake, suggesting that the gradient of exposure that occurred in the study area might have been too limited to enhance the risk of adverse pregnancy outcomes. Therefore, results of the present study represent a risk assessment of municipal waste incineration for two major reproductive health outcomes, but they clearly do not allow us to rule out that at higher levels of exposure, such as those induced by consumption of severely contaminated foods, dioxins can increase the risk of miscarriage or birth defects.

**Acknowledgements**

We acknowledge the kind cooperation in this study of Sonia Fiorini, Giovanni Bigi, Giuseppe Zini of Modena Municipality, Marta Castelli of the National Institute of Social Previdence,
and the personnel of the Modena Local Health Unit and Policlinico University Hospital. We also thank Kenneth J. Rothman of the Boston University School of Public Health for his useful comments and suggestions to an early draft of this paper. The study was supported by a contract of Modena and Reggio Emilia University with the society operating Modena municipal solid waste incinerator (HERA).

REFERENCES


