Environmental Research 164 (2018) 444–451

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Adverse pregnancy outcomes in women with changing patterns of exposure to the emissions of a municipal waste incinerator

Marco Vinceti[a,b,*], Carlotta Malagoli[a], Martha M. Werler[b], Tommaso Filippini[a], Gianfranco De Girolamo[c], Grazia Ghermandi[d], Sara Fabbi[d], Gianni Astolfi[e], Sergio Teggi[d]

[a] CREAGEN Research Center of Environmental, Genetic and Nutritional Epidemiology and Center for Neurosciences and Neurotechnology, Department of Biomedical, Metabolic and Neural Sciences, University of Modena and Reggio Emilia, Modena, Italy
[b] Department of Epidemiology, Boston University School of Public Health, Boston, MA, USA
[c] Unit of Epidemiology and Risk Communication, Department of Public Health, Local Health Unit of Modena, Modena, Italy
[d] School of Environmental Engineering and Department of Engineering 'Enzo Ferrari', University of Modena and Reggio Emilia, Modena, Italy
[e] IMER Registry, Department of Biomedical and Surgical Sciences, University of Ferrara, Ferrara, Italy

ARTICLE INFO

Keywords:
Waste incineration
Miscarriage
Birth defects
Cohort study
Environment
Dioxins
Environmental pollution

ABSTRACT

Municipal solid waste incinerators emissions contain pollutants that, despite their low concentration, might adversely affect reproductive health. In the present study, we examined rates of miscarriage and birth defects among women who resided or were employed in the vicinity of a municipal solid waste incinerator plant from 2003 to 2013. In 2009, a progressive shutdown of the old incineration lines and operation of a new line caused considerably higher atmospheric release of polycyclic aromatic hydrocarbons, particularly of dioxins, due to these irregular operating conditions, technological renovation, and increased capacity. We used dioxin emission levels, based on a dispersion model, to define exposure status of the residing population to air pollutants emitted by the waste incinerator. In women who resided in areas characterized by higher emission exposures compared with a referent area, the relative risk (RR) of miscarriage was 1.04 (95% confidence interval (CI) 0.80–1.32) based on 62 cases overall, with little evidence of a dose-response relation. RRs were similarly null for both 2003–2008 and 2010–2013 periods (RR 1.12 (95% CI 0.80–1.53) and 0.98 (95% CI 0.63–1.48), respectively). Concerning birth defects in the offspring of women residing in the exposed area, no evidence of increased risk emerged, since the prevalence ratio at birth was 0.64 (95% CI 0.29–1.26), with comparable results in the 2003–2008 and 2010–2013 period. Corresponding analyses carried out in municipal residents who worked in the exposed area confirmed these findings. We also did not detect abnormally high rates of miscarriage and birth defects in the exposed cohorts in the single year 2009.

Overall, these results do not suggest an effect of exposure to the emissions of the municipal solid waste incinerator we investigated on two indicators of reproductive health. However, the limited statistical stability of the estimates and the absence of individual-based information on some potential confounders suggest caution in the interpretation of study findings.

1. Introduction

Potentially toxic emissions from most incinerators of municipal solid waste have been markedly reduced in the last decades, due to the technological improvements of these plants (Signorelli et al., 2008; Ashworth et al., 2014). However, such emissions continue to be a major source of concern for populations residing in the vicinity of these plants, with implication in public health and decision-making in waste management planning (Signorelli et al., 2008; Linzalone et al., 2017). Several are the air contaminants of potential concern for residents in the vicinity of incinerators, including among others heavy metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and particularly polychlorinated dibenzo-p-dioxins and dibenzofurans ("dioxins") (Domingo, 2002).

Studies on environmental and biomonitoring around incineration plants have investigated the associations between emission exposures and a range of adverse health effects (Starek, 2005; Ferre-Huguet et al., 2006; Mattiello et al., 2013; Ashworth et al., 2014; Vilavert et al., 2015; Bocca et al., 2016; Ncube et al., 2016; Domingo et al., 2017). In particular, interest has arisen about the possibility that exposure to these

* Correspondence to: Department of Biomedical, Metabolic and Neural Sciences, University of Modena and Reggio Emilia, Via Campi 287, 41125 Modena, Italy.
E-mail address: marco.vinceti@unimore.it (M. Vinceti).

https://doi.org/10.1016/j.envres.2018.03.024
Received 11 October 2017; Received in revised form 13 March 2018; Accepted 14 March 2018

contaminants during pregnancy increases the risk of adverse reproductive effects, including birth defects and miscarriages, though also null results have been reported (Hutz et al., 2006; Cordier et al., 2010; Candela et al., 2013, 2015; Mattiello et al., 2013; Ashworth et al., 2014; Santoro et al., 2016; Kihal-Talantikite et al., 2017). These serious adverse effects can also carry substantial psychosocial burden and can have negative life-long family impacts. For instance, parents of child born with anomalies are more prone to present increased levels of anxiety, depression, and stress, while affected children more frequently develop dysfunctional and insecure relationships with their caregivers (Coppola et al., 2012). However, results of epidemiologic studies on adverse reproductive outcomes in individuals residing nearby incinerators are inconsistent (Mattiello et al., 2013; Ashworth et al., 2014; Kihal-Talantikite et al., 2017), possibly due to limitations incurred by inadequate exposure assessment and other unmeasured confounding such previous investigations (Pan et al., 2015).

A previous report by our group on an Italian community exposed to the emissions of a municipal solid waste incinerator for the period 2003–2008 did not support an increased risk of miscarriages and birth defects (Vinceti et al., 2008). However, since 2009 the doubling of the processing potential of the incinerator, its technological improvement and the shutdown of the old incinerator lines modified the emission pattern of the plant. We therefore investigated if these changes in incinerators emissions and an extension of the period of follow-up compared with the previous study could allow the detection of increased rates of miscarriage and of prevalence of birth defects in the offspring among exposed women.

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 km^2, population approximately 185,000). The plant, located 4 km away from the city center, started its operation in 1984 with three grate combustion lines for a yearly capacity of 120,000 t of waste. A fourth line was eventually constructed and started to continuously operate in April 2010, yielding a final configuration with a maximum authorized capacity of 240,000 t/year of solid waste, though the final amount of solid waste actually incinerated has been lower so far (ARPAE-Emilia Romagna, 2015). The recent time trend of incinerated waste amount, as abstracted from the Emilia-Romagna Regional Agency for Environmental Protection website and reported in Fig. 1 (ARPAE-Emilia Romagna, 2015), shows that its great majority is composed by municipal urban solid waste, with a slightly increased amount of special and medical waste from 2010. The plant was 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 not-catalytic reducer for NO_x abatement. The total amount of

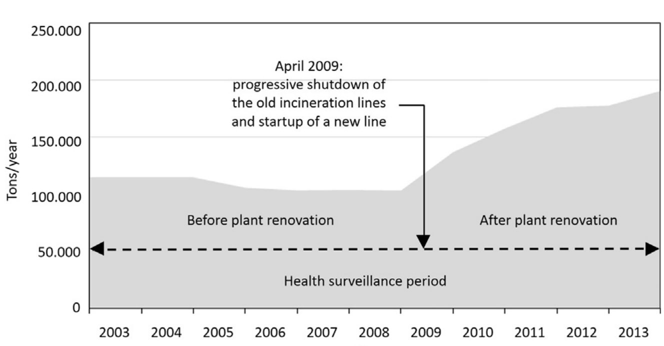

Fig. 1. Time trend of amount (tons/year) of municipal solid waste incinerated in the Modena plant in the 2003–2013 period.

incinerated waste incinerated in the plant increased over time, being around 100,000 t/year until 2008, then 137,000 in 2009 and then up to 190,000 in 2013 (ARPAE-Emilia Romagna, 2015). Despite this, the total amount of contaminants emitted in the atmosphere by the plant showed a mixed and highly inconsistent pattern as shown by the systematic environmental monitoring program in the 2006–2015 period managed by the local Environmental Health Authority in connection with the plant operating company, based on a very large number of analytical determinations (ARPAE-Emilia Romagna, 2015). The plant emissions increased over time for some pollutants (carbon monoxide and total organic carbon, chloridric acid, particulate matter, total amount of metals), decreased for others (mercury, dioxin total equivalents, polycyclic aromatic hydrocarbons, hydrogen fluoride, nitrogen oxides, ammonia) and finally remained unchanged for two contaminants, sulfur oxides and cadmium. However, in the year 2009 the operating conditions of the plant were irregular and mixed, due to the contemporary start-up of the new incinerator oven and the partial shut-down of the old ovens, and this transient period was accompanied by a markedly increased emission of two contaminants, polycyclic aromatic hydrocarbons and particularly dioxins, as expected (Tejima et al., 2007; Wang et al., 2007; Chen et al., 2008; Li et al., 2017). In that year, the total amount of dioxin toxic equivalents emitted by the plant was 27.94 g, compared with amounts ranging from 1.24 to 2.67 in 2006–2008 and from 0.74 to 1.75 in 2010–2013, while the corresponding figures for polycyclic aromatic hydrocarbons were 309, 56–215, and 1–2 g (ARPAE-Emilia Romagna, 2015).

We ran several atmospheric dispersion models in the area around the incinerator to estimate the concentration of contaminants emitted by the plant (Domingo et al., 2015) in the lower part (0–10 m altitude span) of the atmosphere, including heavy metals, particulate matter and polychlorinated dibenzo-p-dioxins plus dibenzofurans (henceforth referred to as ‘dioxins’). We found a very high correlation between the different atmospheric modeled pollutants, in line with what observed by others authors (Floret et al., 2003; Candela et al., 2015; Douglas et al., 2017). We eventually chose dioxins as tracer for the whole air pollutants released by the incinerator, also taking into account their high human reproductive toxicity (Toft et al., 2004; Hombach-Klonisch et al., 2005; Silbergeld and Patrick, 2005; Brucker-Davis et al., 2008; Faure et al., 2014). Dioxins are persistent organic pollutants, a group of potential endocrine disrupting chemicals that are toxic, persistent, able to bio-accumulate, and to move at long distances by natural processes in soil, water, air, and biota. Several studies indicate that these compounds can compromise the entire reproductive path, e.g. adversely affecting semen quality and cause testicular cancer in males, inducing menstrual cycle abnormalities and spontaneous abortions in females, and altering waiting time pregnancy, reduced birth weight, skewed sex ratio and altered age of sexual development (Toft et al., 2004).

Therefore, we identified three municipal areas with different levels of incinerator emissions exposure on the basis of atmospheric dioxins concentration by defining two areas, A and B, characterized by higher levels of exposure in comparison to the remaining municipal territory (Fig. 2). The *a priori* defined cutpoints of dioxin exposure that we used to identify these areas were 0.5×10^{-9} $\mu g/m^3$ for the intermediate exposure area B and 1.0×10^{-9} $\mu g/m^3$ for the high exposure area A. These cutpoints were originally identified during the preliminary assessment of the environmental impact of the plant renovation in early 2000s, roughly corresponding to the 90th and 99th percentiles of modeled dioxins concentration. These two exposed areas, characterized by an irregular shape (Fig. 2), were comprised in a distance of less than 2 km and 5 km from the plant, for the A and B areas respectively. We estimated dioxin concentration levels using two models: the Industrial Source Complex model (ISC3ST) (U.S., 1995; Lee et al., 2007) for the 2003–2005 period, and the more advanced lagrangian stochastic dispersion model SPRAY that we had later available (Gariazzo et al., 2007; Ghermandi et al., 2012) for 2006–2013 period. ISC3ST is a steady-state Gaussian plume model, known to account for settling and dry