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Health effects of exposure to waste incinerator emissions: a review of epidemiological studies

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Summary. - This review evaluates the epidemiological literature on health effects in relation to incineration facilities. Several adverse health effects have been reported. Significant exposure-disease associations are reported by two thirds of the papers focusing on cancer (lung and larynx cancer, non-Hodgkin's lymphoma). Positive associations were found for congenital malformations and residence near incinerators. Exposure to PCB and heavy metals were associated with several health outcomes and in particular with reduction of thyroid hormones. Findings on non-carcinogen pathologies are inconclusive. Effect of biases and confounding factors must be considered in the explanation of findings. Methodological problems and insufficient exposure information generate difficulties on study results. Research needs include a better definition of exposure in qualitative and quantitative terms in particular by developing the use of biomarkers and by implementing environmental measurements.

Key words: incinerators, health effects, environmental exposure, epidemiology, review.

Riassunto *(Effetti sulla salute di esposizioni a inceneritori di rifiuti: rassegna di studi epidemiologici)*. - Viene presentata una rassegna della letteratura epidemiologica in tema di salute e inceneritori. Alcuni studi riferiscono effetti avversi sulla salute umana, in particolare per tumori (polmone, laringe, linfoma non-Hodgkin), altri hanno evidenziato eccessi di malformazioni congenite in aree con impianti. Esposizioni a PCB e metalli pesanti sono state associate ad alcune patologie, soprattutto riduzione degli ormoni tiroidei. I risultati riguardanti patologie non tumorali sono maggiormente inconsistenti. Fattori di distorsione e confondimento possono avere una rilevante influenza sulle associazioni identificate. Natura e complessità delle esposizioni, dimensioni delle popolazioni indagate, difficile definizione del profilo socio-economico, elevata variabilità di patologie e sintomi studiati, sono trattati in rassegna. Una nuova generazione di studi epidemiologici necessita di una migliore definizione dell'esposizione in termini qualitativi e quantitativi, in particolare mediante una evoluzione delle misurazioni ambientali e lo sviluppo dell'uso di bio-marcatori individuali di esposizione.

Parole chiave: inceneritori, effetti sulla salute, esposizione ambientale, epidemiologia, rassegna di studi.

Introduction

Although landfills are still widely used in Europe for the disposal of wastes, there is a rapid increase in the use of incineration instead of landfilling for the disposal of solid waste. Incinerators are known to release numerous toxic chemicals into the atmosphere and to produce ashes and other solid waste residues.

Adverse health effects associated with mass burn incineration are of great concern as large population groups and workers may be exposed to derived toxic substances. Many of these chemicals are known to be persistent, bioaccumulative, carcinogenic or endocrine disruptors [1].

Several studies have demonstrated that old but also new incinerators can contribute to the contamination of local soil and vegetation by organic and inorganic compounds present in variable quantities in fly ash and flue gases released from the plants. Similarly, in several European countries, cow's milk from farms located close to incinerators has been found to contain elevated levels of dioxins, in some cases above regulatory limits [2, 3].

Populations living near incinerators - alike those living near landfill sites - are potentially exposed to chemicals by way of inhalation of contaminated air, consumption of contaminated foods, water or dermal contact with contaminated soil [1, 4, 5]. People can

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also be occupationally exposed to chemicals emitted from incinerators. Occupational exposure is generally of higher intensity and duration compared with environmental exposures; quantitative levels of compounds can be more easily ascertained and defined. Extrapolation of results from occupational studies to the general population needs care since workers differ from the general population in terms of age, sex, lifestyle, and are also self selected to be relatively healthy (healthy worker effect) [1]. Several epidemiological and experimental studies were conducted to evaluate adverse effects in populations or workers exposed to the emission of incinerators. Health effects that have been reported to be associated with environmental exposure to incinerator emissions include increased risk of a range of cancers (especially lung and larynx cancer, leukemia, lymphoma, soft tissue sarcoma), respiratory symptoms and congenital malformations. Some studies have also revealed a higher incidence of multiple births, abnormal sex ratio of newborns and changes in blood levels of some thyroid hormones.

Chemical emissions

Incinerators are typically fed with mixed waste containing hazardous substances such as heavy metals and chlorinated organic chemicals. These substances can assume other forms during incineration that are likely to be more toxic than the original compounds. The range of metals emitted from the plants includes cadmium, thallium, lead, arsenic, antimony, chromium, cobalt, copper, manganese, nickel and mercury. Information on effects of environmental exposure to metals is very limited; also occupational surveys are not able to attribute particular effects to a single metal since workers have often been exposed to a range of heavy metals. Metal exposure is therefore associated with a range of adverse health effects concerning all body systems. In particular most heavy metals have been reported to be associated with kidney disease, respiratory diseases, cardiovascular damage, blood effects, and neurotoxicity [1]. Some are classified as proven or suspected carcinogens (Table 1). Some others are associated with particular health effects: lead acts as a modifier of children's cognitive and behavioural development, long term exposure to cadmium is likely to be responsible for disturbances in calcium metabolism and osteoporosis.

Airborne particles, nitrogen dioxide, sulphur dioxide and carbon monoxide are among pollutants emitted from incinerators. PM_{10} is generally considered as the most important component of urban air pollution and epidemiological studies have shown that long-term exposure to airborne particles is associated with increased risks of developing bronchitis [6, 7] and some loss of life expectancy [8, 9]. Furthermore particle traps used to reduce particle emission from incinerators cannot avoid emission of ultra-fine particles. However, it has been suggested that the ultra-fine component of vehicle emissions is more harmful as it carries a range of metals and toxic organic compounds as well.

The oxides of nitrogen and sulphur dioxide are associated with respiratory short-term effects especially in individuals with a particular susceptibility. NO_x and SO_x emissions will contribute respectively to the formation of ozone and acid aerosols.

Carbon monoxide is likely to increase the onset of heart disease.

Polyaromatic hydrocarbons (PAHs), released during the incomplete combustion or pyrolisis of organic matter, may have oestrogenic properties [10] and are reported in association with ischemic heart disease [11] and cancer, in particular cancer of lung [12] and bladder [13, 14].

Polycyclic aromatics (PCA) have been reported to be mutagenic and mutagenicity was found to be inversely proportional to the degree of completeness of refuse combustion [15].

Poorly controlled combustion processes can entail the production of dioxins, another class of compounds that include two families of chemicals, polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). These groups consist respectively of 75 and 135 cogeners that determine toxic effects on human health with different grades of severity.

Excluding occupational exposure, diet is the main route of dioxin contamination by accumulation along the food chain; newborns in particular are exposed through breast-feeding.

Epidemiological studies on health effects

The aim of the present paper is to present a review of the major epidemiological studies published from 1987 to 2003 on health effects in populations living in the neighbourhood of waste incinerators. Forty-six papers were considered: 32 concerning health effects on populations residing near incinerators, 11 on occupational exposure, 2 on environment and occupation and 1 was included as its environmental survey was designed to evaluate the relationship between a high cancer death rate and environmental concentration of dioxin analogues near an incinerator in Japan. To enrich evidence on association between some diseases and exposure to compounds emitted by incinerators, papers on occupational exposure were also included in this review (Table 2) although the

Table 1. - Carcinogenic effects of chemicals according to the IARC evaluation

Ref.	Chemical	Chemical group	Degree of evidence in humans	Evaluation (IARC)	Carcinogenic effects
[51]	Arsenic	Metals	Sufficient / carcinogenic	1	Skin, lung, liver, bladder, kidney, colon
[52]	Beryllium	Metals	Sufficient /carcinogenic	1	Lung
[52]	Cadmium	Heavy metals	Sufficient /carcinogenic	1	Lung, prostate
[53]	Chromium (VI)	Metals	Sufficient /carcinogenic	1	Lung
[53]	Nickel	Heavy metals	Sufficient / carcinogenic	1	Lung
[52]	Mercury	Heavy metals	Inadequate	2B	Lung, pancreatic, colon, prostate, brain, kidney
[51]	Lead	Heavy metals	Inadequate	2B	Lung, bladder, kidney, digestive system
[51]	Benzene	Polycyclic aromatics	Sufficient / carcinogenic	1	Leukemia
[51]	Carbon tetrachloride	Chlorinated hydrocarbons	Inadequate	2B	Liver, lung, leukemia
[54	Chloroform	Polycyclic aromatics	Inadequate	2B	Bladder, kidney, brain, lymphoma
[55]	Chlorophenols 55	Chlorinated aromatics	Inadequate	2B	Soft-tissue sarcoma, Hodgkin's and non Hodgkin's lymphoma
[56]	Trichloroethylene	Chlorinated solvent	Limited	2A	Liver, non Hodgkin's lymphoma
[57]	Dibenzo-para-dioxin	Dioxins	No adequate data	3	All cancer
	Polychlorinated	Dioxins	No adequate data	3	All cancer
[57]	Dibenzo-para dioxins				
[57]	Polychlorinated dibenzofurans	Dioxins	Inadequate	3	All cancer

intensity of exposure of workers differs from that of the general population (Table 3).

Most of the reviewed epidemiological studies were found through a systematic search using MEDLINE and several combinations of relevant key words (epidemiology, incineration, incinerator/s, waste incinerator). In addition, articles were traced through references in relevant papers and publications of the UK Institute for Environment and Health, the US National Academy of Sciences, and Greenpeace.

Papers have been grouped according to the following criteria: study design, pathways of exposure, type of significance of association between exposure and disease, and health outcomes. One risk assessment study is presented for its importance as it anticipates long-term putative consequences.

Follow-up study designs (a category in which before/after, perspective and retrospective cohort studies were included) are the most commonly used to evaluate association between environmental or occupational exposure to incineration and health effects. Some of the studies had methodological purposes and were therefore carried out to develop new techniques of statistical analysis or toxicological models of pollutant's intake. Investigations of single incineration sites are less frequent than those concerning multisites. Other studies focus on multiple sources of exposure but in this case effects of each single source are not recognized. The majority of the studies, particularly those on cancer, refer to old rather than modern incinerators. A wide range of effects on health were analysed including cancer, reproductive outcomes, respiratory effects and body tissue concentration of toxic compounds examined by using biomarkers of internal exposure especially in association with occupational exposure. The exposure assessment has been mainly based on surrogate measures such as residence in an area close to an incineration site or working at the plants.

Results on environmental exposure

Significant exposure-disease associations are reported by two thirds of the findings concerning cancer (mortality, incidence or prevalence). Results on

Table 2. - Occupational exposure outcomes

Ref.	Study design	Study sites	Study subjects	Exposure measure	Health outcome	Reported findings
[11]	Retrospective follow-up	Municipal waste incinerator in Stockholm (Sweden)	Mortality rates among 176 male workers employed for at least 1 year compared to local and national rates	Working at the plant	Cause of mortality	Significant association for lung cancer compared with local rates and significant association for ischemic heart disease compared with national rates
[63]	Cross-sectional	7 incineration plants in US	104 workers employed at the plants (exposed); 61 water treatment facilities employees (comparison)	Working at the plants	Frequency of urinary mutagens	Increased risk of producing urinary mutagens in exposed workers. Association between mutagens & habit of not wearing protective clothing
[64]	Cross-sectional	Incinerators in Philadelphia (US)	Actively employed cohort of 86 male workers	Work site	Hypertension, proteinuria, blood and serum measurements, pulmonary functions	No consistent association between exposure and health effects in workers
[65]	Cross-sectional	4 refuse incinerators in US	37 workers working at the plants (exposed); 35 workers working at water treatment facilities (comparison)	Working at the plants	Frequency of urinary mutagens	No clear association between exposure and urinary mutagens
[66]	Cross-sectional	3 incinerators in New York (US)	56 workers working at the plants (exposed); 25 workers working at water treatment facilities (comparison)	Working at the plants	Blood lead level	No increased risk among workers working at the plants. Association between blood lead level and the habit of not wearing protective clothing
[67]	Review	Multiple sources of exposure	Mortality rates in 4 cohorts of workers (chimney sweeps, waste incinerator workers, gas workers and bus garage workers)	Occupational exposure	Esophageal cancer	Increased risk for esophageal cancer among workers exposed to combustion products
[68]	Cross-sectional	2 incinerators of different age in Germany	Blood samples of 10 workers working at an old municipal waste plant and 11 workers from a new incinerator. Blood samples from 25 subjects from general population as comparison	Occupational exposure	Blood PCDD/F level	Relationship between exposure and blood PCDD/F concentrations minimised by modern pollution control technology

(continues)

Table 2. - (continued)

Ref.	Study design	Study sites	Study subjects	Exposure measure	Health outcome	Reported findings
[69]	Retrospective cohort	2 garbage recycling and incinerating municipal plants in Rome (Italy)	Mortality rates among 532 male workers employed at the plants compared to those of the general population	Occupational exposure	All cancer mortality	Increased risk for gastric cancer in the category with more than 10 years since first exposure
[32]	Follow-up	Municipal solid waste plant in Finland	Hair samples from people living at different distances from the plant and samples from people occupationally exposed to mercury	Residence near the plants and occupational exposure	Hair mercury level	Mercury exposure increased as distance from the plant decreased but the increase is minimal and did not pose a health risk
[31]	Before / after	Municipal solid waste treatment plant in Matarò (Spain)	Blood and urinary samples from 104 residents within 15 km from the plant, 97 who lived far from the incinerator and 17 workers at a new municipal solid waste incinerator. Samples were taken before the incinerator started functioning and 2 years later	Residential and occupational exposure	Blood levels of dioxins, furans and PCBs. Urinary concentrations of lead, cadmium, chromium and mercury	No association between small increase in blood PCDD/F levels and distance from the plant. No clear relationship between exposure and blood or urine levels of the other compounds evaluated
[70]	Cross-sectional	3 incinerators in Japan	Serum samples from 30 workers employed at the plants and 30 control workers	Occupational exposure	Serum concentrations of PCDD/F	No significant differences between exposed and non exposed workers. Dust seems to be the TCDD/F vehicle exposure
[71]	Cross-sectional	Municipal waste incinerators (Japan)	Blood samples from 94 workers from the plants	Occupational exposure	Blood concentration of PCDD/F and PCB	Significant positive association between dioxin level and some of the blood biochemical indicators
[72]	Cross-sectional	Bavaria (Germany)	Blood and urine samples from 300 male chimney sweeps compared to those from 60 male employees without occupational exposure to PCDD/F	Occupational exposure	Level of PCDD/F and PCBs in blood and urine samples	Significant association between occupational exposure and high levels of PCDD/F and PCB in blood and urine samples

Abbreviations: PCDD: polychlorinated dibenzo-*p*-dioxins; PCDF: polychlorinated dibenzofurans; PCB: polychlorinated biphenyls; TCDD: tetrachlorodibenzo-*p*-dioxin.

Table 3. - Environmental exposure outcomes (References are in square brackets)

Outcome	Study design and statistical significance of positive associations (RR >1) between exposure and outcome						Exposure measures	Confounders	Effect estimations
	Geographical[(a)]		Case – control		Follow-up[(b)]				
	S	NS	S	NS	S	NS			
Lung cancer	[16] Mortality						Residence near multiple sources of exposure in Italy	Smoking habits, occupational exposure, places of residence	RR small cell carcinoma: 2.0 (95% CI: 1.2-3.4) RR large cell carcinoma: 2.6 (95% CI: 1.2-5.3)
			[17]				Residence near multiple sources of exposure in Italy	Smoking habits, occupational exposure, places of residence	RR incinerator: 6.7 (p<0.0098)
					[18]		Residence near 72 solid waste incinerator plants in UK	Deprivation index	Conditional and unconditional Stone test (p<0.05)
		[19] Mortality					Residence near 10 incinerators of waste solvents and oils in England	Deprivation index	SIR
		[20] Mortality					Residence near multiple sources of combustion in Italy	Socioeconomic status	SMR males : 92 – 104 (range) SMR females: 55 – 108 (range)
Non - Hodgkin's lymphoma					[18]		Residence near 72 solid waste incinerator plants in England	Deprivation index	Conditional and unconditional Stone test (p<0.05)
		[20] Mortality					Residence near multiple sources of combustion in Italy	Deprivation index	SMR males: 83 – 251 (range) SMR females:108 – 152 (range)
			[21]				Residence near a municipal solid waste incinerator with high dioxin emission levels in France		SIR: 1.27 (p<0.00003)
			[22]				Residence near a municipal solid waste incinerator with high dioxin emission levels in France	Wide range of socioeconomic characteristics	Exposure Very low (reference category) Low OR = 1.0 (95% CI 0.7–1.5) Intermediate OR = 0.9 (95% CI 0.6 – 1.4) High OR = 2.3 (95% CI 1.4–3.8)
Soft tissue sarcoma			[21]				Residence near a municipal solid waste incinerator with high dioxin emission levels in France		SIR: 1.44 (p<0.004)

(continues)

Table 3. - (continued)

Outcome	Study design and statistical significance of positive associations (RR >1) between exposure and outcome						Exposure measures	Confounders	Effect estimations
	Geographical[(a)]		Case – control		Follow-up[(b)]				
	S	NS	S	NS	S	NS			
			[23]				Residence near multiple sources of exposure in Italy	Age, gender, occupational exposure	OR: 25.1 (logistic regression) (95% CI: 4.2-150.8)
Liver cancer					[18]		Residence near 72 solid waste incinerator plants in Great Britain	Deprivation index	Conditional and unconditional Stone test (p<0.05)
	[24]						Residence near 72 solid waste incinerator plants in Great Britain	Deprivation index	Proportion of true primaries liver cancer after histopathological review: 55 – 82 % and revised estimates between 0.53 and 0.78 excess cases per 105 per year within 1 km
		20 Mortality					Residence near multiple sources of combustion in Italy	Deprivation index	SMR males: 0 – 95 (range) SMR females: 0 – 115 (range)
Larynx cancer		[19] Mortality					Residence near 10 incinerators waste solvents and oils in Great Britain	Socioeconomic status	SIR
		[20] Mortality					Residence near multiple sources of combustion in Italy	Socioeconomic status	SMR males: 72 – 236 (range) SMR females: 0 – 168 (range)
Stomach cancer					[18]		Residence near 72 solid waste incinerator plants in Great Britain	Deprivation index	Conditional and unconditional Stone test (p<0.05)
Colorectal cancer					[18]		Residence near 72 solid waste incinerator plants in Great Britain	Deprivation index	Conditional and unconditional Stone test (p<0.05)
Bladder cancer					[18]		Residence near 72 solid waste incinerator plants in Great Britain	Deprivation index	Conditional and unconditional Stone test (p<0.05)
Kidney cancer		[20] Mortality					Residence near multiple sources of combustion in Italy	Socioeconomic status	SMR males: 112 – 276 (range)

(continues)

Table 3. - (continued)

Outcome	Study design and statistical significance of positive associations (RR >1) between exposure and outcome						Exposure measures	Confounders	Effect estimations
	Geographical[(a)] S	Geographical[(a)] NS	Case – control S	Case – control NS	Follow-up[(b)] S	Follow-up[(b)] NS			
	[20] Mortality						Residence near multiple sources of combustion in Italy	Socioeconomic status	SMR females (3-8 km): 198 (95% CI: 111-325)
Childhood cancer	[25] Mortality						Residence near: 70 municipal incinerators, 307 hospital incinerators and 460 toxic waste landfill sites in Great Britain		Distances from birth and death addresses to the source of VOC
	[26] Mortality						Residence near: 70 municipal incinerators, 307 hospital incinerators and 460 toxic waste landfill sites in Great Britain		Outward / inward ratio = 2 (p<0.001)
Cancer		[58] Mortality					Residence near a municipal waste incinerator in Japan		Levels of PCDDs, PCDFs and PCB in soil and sediment from a high cancer area
Biomarkers	[2]						Cow's milk samples from farms near multiple sources of dioxin in Spain		Level of PCDD in cow's milk
	[28]						Residence near a hazardous waste incinerator in Germany	Age, sex, breast feeding, passive smoking, BMI	Blood levels of PCB (children)
		[29]					Residence near a municipal waste incinerator in Germany	Age, sex, body weight, occupation and life habits	Levels of PCDD/ PCDF in human blood and milk
						[30]	Residence near an incinerator burning materials contaminated with TCDD, located in Missouri (US)	Age, sex, body weight, occupational exposure and life habits	Levels of TCDD in blood serum
Biomarkers						[31]	Residential and occupational exposure to a municipal solid waste treatment in Spain	Age, sex, body weight, occupation, life habits, diet, odor perception and reproductive outcome	Levels of PCDD / PCDF in blood; PCB and heavy metals in urine
						[32]	Residential and occupational exposure to a hazardous-waste-treatment plant in Finland	Levels of exposure	Hair mercury concentration

(continues)

Table 3. - (continued)

Outcome	Study design and statistical significance of positive associations (RR >1) between exposure and outcome						Exposure measures	Confounders	Effect estimations
	Geographical[(a)] S	Geographical[(a)] NS	Case – control S	Case – control NS	Follow-up[(b)] S	Follow-up[(b)] NS			
		[33]					Residence near a waste incinerator in Spain	Diet, medication drugs during the previous 48 h, environmental tobacco	Urinary elimination of thioethers (children)
	[34]						Residence near a toxic waste incinerator in Germany	Exposure to passive smoking	Blood concentration of PCB (children)
	[35]						Residence near a lead smelter and 2 waste incinerators in Belgium	Lifestyle, use of tobacco and alcohol, intake of medicine, social class of parents	Concentration of heavy metals dioxins and PCB in serum samples and VOC in urine
	[59]						Mothers living near multiple sources of exposure in different countries		Body concentration and cumulative dose of PCDDs and PCDFs for breast-fed infants
		[60]					TCDD and TCDF concentrations in food		Long-term average of daily dioxin intake through food
						[61]	Cow's milk samples from farms located in Connecticut (US)		Level of PCDD in cow's milk
Birth defects			[40]				Maternal residence near 21 landfill sites in 5 European countries	Maternal age and socioeconomic status	Combined OR: 1.33 (95% CI: 1.11-1.59)
					[41]		Birth clinic near an open chemical combustion site in Amsterdam (The Netherlands)	Socioeconomic status, smoking habits	Trend of incidence analysed by ranking and spatial autocorrelation
Sex ratio and twinning					[10]		Maternal residence near 2 incinerators in Scotland and a chemical factory in Eire		Frequency of human twinning
					[43]		Place of birth near 2 waste incinerators in UK		3D mapping technique of sex ratio values
						[42]	Place of birth near 14 refuse incinerators in Sweden		RR of twin birth in 3 largest cities: 1.05 (95% CI: 1.01-1.10)

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Table 3. - (continued)

Outcome	Study design and statistical significance of positive associations (RR >1) between exposure and outcome						Exposure measures	Confounders	Effect estimations
	Geographical[(a)]		Case – control		Follow-up[(b)]				
	S	NS	S	NS	S	NS			
Respiratory diseases or symptoms						[36]	Residence near a waste incinerator in France	Occupational exposure, smoking habits, sex, age, socioeconomic status	Drug consumption
		[37]					Residence near 2 high temperature incinerators in Australia and environmental measurements		Prevalence of respiratory illness
						[38]	Residence near 3 incinerators (biomedical, municipal, and liquid hazardous waste burning industrial furnace) in North Carolina (US)	Age, sex, occupational exposure, smoking, habits perceived quality of outdoor air	Prevalence of chronic or acute respiratory symptoms in terms of FEV and PEFR
		[39]					Residence near 3 incinerators in South Carolina (US)	Sociodemographic factors, smoking habits, respiratory symptoms, occupational exposure	Data on pulmonary functions collected by spirometric tests
Others	[46]						Residence near multiple sources of exposure in Italy	Sociodemographic factors, smoking habits and occupational exposure	RR: 1.25 mucous and membrane symptoms (95% IC: 1.02-1.53) RR: 2.44 anemia in cross sectional setting (95% IC: 1.08-5.48) RR: 3.21 anemia in longitudinal setting (95% IC: 1.52-6.72)
		[62][(c)]					Residence near a modern municipal waste incinerator in France	Data on time-activity patterns according to demographic characteristics of the population	Life-long personal distribution of exposures to benzene, trichloroethane, cadmium and nickel

Abbreviations: S: statistically significant ($p<0,05$ at least) association (RR >1) between exposure and outcome; NS: statistically not significant association (RR >1) between exposure and outcome; RR: relative risk; SIR: standardised incidence ratio; SMR: standardised mortality ratio; OR: odds ratio; PCDD: polychlorinated dibenzo-p-dioxins; PCB: polychlorinated biphenyls; PCDF: polychlorinated dibenzofurans; TCDD: tetrachlorodibenzo-p-dioxins; FEV: forced expiratory volume; PEFR: peak expiratory flow rate; VOC: volatile organic compounds.
(a) Geographical studies include also cross-sectional studies; *(b)* follow-up studies include also perspective, before/after and retrospective cohort studies; *(c)* health risk assessment study.

association between lung cancer and exposure to incinerators or exposure to multiple sources including incinerators are mainly positive. Some studies show statistical significance [16-18] while in other studies no statistical significance emerges after adjustment for deprivation or distance from the source of exposure [19, 20].

Two studies reported a significant association between non-Hodgkin's lymphoma and environmental exposure to incinerators located in UK and France [18, 21, 22] and a significant increase in risk of soft tissue sarcomas was found in France [21] and in Italy [23] in association with residence close to waste incinerators.

A UK study pointed out a small increased risk of liver cancer associated with living within 1 km of an incinerator [18] also after adjustment for deprivation. As possible misdiagnosis of primary liver cancer could have affected results of this study, the same author conducted a further study to evaluate the proportion of true primary liver cancer after histopathological review. This second study found a proportion of 55 - 82% of true primary liver cancer and gave revised estimates of between 0.53 and 0.78 excess cases per 105 per year within 1 km. [24] Elliott *et al.* [18] also reported a significant association between exposure and stomach, colorectal and bladder cancer by using the Stone's test.

An Italian small area analysis of mortality among residents near multiple sources of combustion products did not indicate any clear association between liver cancer mortality rates and distance from sources of exposure [20] but highlighted an increase - though not significant - of cancer of the larynx in males as distance from the plants decreased and a significant excess of mortality for kidney cancer in females between 3 and 8 km from the exposure sources. A previous study conducted in the UK concluded that the apparent cluster of cases of cancer of the larynx reported near one waste oil incinerator was not associated with this plant [19].

Studies on childhood cancer and industrial emissions did not show a clear relationship between health effects among children and incinerator emissions even if some results were statistically significant.

Two studies were carried out to compare - among other objectives - statistical methods of geographical analysis to put emphasis on the effects of residing in proximity to several industrial sources [25, 26]. The risk seems to be greater for children who were born or lived near incinerators though it is very difficult to discriminate between the effects of the plants and those of other sources of industrial pollution.

Studies on biological monitoring of blood, urine, and milk samples assess the internal dose of exposure (biomarkers of exposure) or the biological response to exposure (biomarkers of early effect) to substances that are likely to be mutagenic, carcinogenic or teratogenic when metabolised by the body tissues. This approach takes into account inter-individual differences in absorption, distribution and excretion of xenobiotic compounds giving measures of exposure which are likely to be more directly associated with possible adverse health effects [1, 27]. A German study reported elevated levels of PCBs in blood samples from children living near an hazardous waste incinerator [28] while three other studies did not find increased levels of dioxins in body tissues of residents near the plants [29-31]. Elevated but not statistically significant levels of mercury and thioethers were found in hair of people residing in the vicinity of an incinerator in Finland [32] and in urine samples from children living near a modern plant in Spain [33]. Exposure to PCB and heavy metals was also associated with reduction of thyroid hormones and the consequent delay in neurologic and sexual development. A German study carried out on blood samples from children exposed to industrial pollution reported small but significant changes in thyroid hormones [34] and a Belgian study [35] found that children living near waste incinerators reached sexual maturity at a later age.

Straight evidence was not provided on the association between residence near incinerators and non-carcinogenic outcomes i.e. chronic or acute respiratory effects in children and adults [36-39].

Most of the studies on congenital malformations were conducted around landfill sites though some of them included incinerators in the study area. On the whole, results of both landfill and incinerator studies found significantly raised risk and increased incidence of birth defects [5, 40, 41]. Positive associations were also found between residence near an incinerator and an increased probability of multiple births [10, 42] or a higher proportion of female births [43].

Discussion

The aim of the present review is to highlight some crucial points that should be taken into account in the design of surveys to be conducted to evaluate effects of waste incinerators on health.

Most of the epidemiological studies on environmental contamination confirm difficulties in defining unequivocally levels of exposure to which individuals are exposed. This mainly depends on lack of information on waste feed, type of chemicals emitted and off-site migration routes from incineration sites.

Technical features of the emission source (stack chimney height and diameter, pollution control equipment, fly and bottom ashes map, different kinds of toxic materials released, age of the plant) represent important variables to be considered.

Also location of the plants may influence study results: generally incineration facilities are situated within industrial areas near other kinds of plants and very often close to landfill sites used for waste deposit or for parallel activities of waste disposal. Therefore it is complicated to ascertain the extent to which incinerator emissions contribute to adverse health effects with respect to other sources of pollution. Consequently it is hard to define indicators of exposure relevant to the nature and levels of contamination. Residence, in particular, is commonly used as a proxy of the exposure though in many cases is likely to introduce misclassification problems if not supported by accurate environmental measures [1, 23, 44, 45]. In addition, residence intended as residence near or distance from a source of contamination leads, in both cases, to a non-comparability problem among studies as residence can only be evaluated within each specific study which is based on the local topography and prevailing winds. Moreover, people living in the vicinity of more than one incinerator are likely to be exposed to higher doses of chemicals. As an appropriate model on how exposure lessens with distance is not always available, simple algorithms such as distance from the nearest site [1, 40] or distance from the major source - both in terms of size and importance - are used [1, 46].

The exposure model needed may vary depending on the health outcome considered. For congenital anomalies peak exposures in short time windows of fetal development may matter while, for cancer, average exposures over long time periods may be more relevant. To improve measurement of exposure, duration of residence could prove useful, if relevant. In general, surrogate exposure measures are likely to lead to misclassification of exposure, which if non differential, may dilute true effects in these investigations [44, 47].

The use of biomarkers, biological monitors of internal dose, allows a better definition of individual exposure, but still presents some limitations. The monitoring of biomarkers of exposure is currently difficult and costly and can generally measure only a limited number of chemicals that have been previously indicated by environmental monitoring data [1, 27].

Population-based studies on the effects of incinerators are affected not only by incomplete or inaccurate exposure data, but are also characterized by low-level exposure over long periods of time. This determines a small increase in relative risk that is difficult to detect. Moreover, the long latency period between exposure and diagnosis of the chronic disease may lead to misclassification of exposure as people investigated may have migrated into or out of the exposed area during the latency period [25, 26].

Another important problem in studies on environmental exposure is that the size of populations living near the plants is generally small [23]. This can considerably limit their statistical power and the likelihood of detecting any moderate increase of the risk especially when the outcome is a rare disease. Single-incinerator studies, generally conducted in response to community concerns, are those most affected by the problem of small population size and by the lack of a specific a priori disease hypothesis. The latter is also a multi-incinerator study problem. Multi-incinerator studies mainly investigate rare diseases such as cancer and reproductive outcomes and generally include a large number of subjects who increase statistical power. However, results obtained by this kind of studies do not provide specific information on the risk level of each single site.

Choice among study designs is tightly linked to the availability of information on exposure, outcomes and other factors likely to be determinant for the relationship between exposure and disease. Studies based on data routinely collected are often limited by the lack of information about possible confounders or effect modifiers (smoking, diet, education, occupation, socioeconomic status and residential history).

The variation pattern of socioeconomic profile with distance from sources of pollution is still unclear. Though some studies show that the relationship between health outcomes and residence near landfills or incinerators is not significant after adjusting for sociodemographic factors findings of other studies may vary after adjustment.

On the other hand, questionnaire surveys may be affected by low response rates and possible recall bias since people who perceive themselves as exposed may report more symptoms and be the ones who return the questionnaire [48-50].

Differences in study designs and high variability of health outcomes - very often aspecific and grouped into categories having different etiopathogenesis - both limit comparability among results of environmental studies. The recent use of biomarkers measuring biological responses such as chromosomal and molecular changes give epidemiological studies a greater statistical power. However, interpretation of these effect biomarkers is still unclear and it is still difficult to correlate specific diseases to incinerator exposure, which is the primary interest of people living in the vicinity of waste sites.

Finally it has to be noted that often grey data is not published in the literature and therefore findings of published studies may be incomplete.

Conclusions

The majority of the studies concern old plants often in association with other sources of pollution. Despite chemical emissions of modern incinerators are more limited, toxic substances are still released in the atmosphere as well as in other residues such as fly ash and bottom ash. Often the lack of comparability among study results make findings on health effects of incinerators inconsistent though some significant results were found. In addition, in most studies health effects that have been associated with incinerators can not be tied down to a particular pollutant and therefore no causal role can be established.

Analysis by specific cause, notwithstanding the poor evidence for each disease, has found nevertheless significant results for lung cancer, non-Hodgkin lymphoma, soft tissue sarcomas and childhood cancers. On the other hand studies on cancer of the larynx and liver found contradictory results.

Findings on non-carcinogen pathologies are inconclusive, in particular for acute and chronic respiratory disease.

Some results point out a relationship between exposure to incinerators and congenital malformations but the lack of statistical consistency makes it difficult to conclude if the association is causal or not.

Results of biomonitoring of internal exposure seem to confirm that accumulation of substances investigated in biological tissues is likely to trigger a neoplastic process.

Further research into the potential environmental and health risks of incinerators in particular by a more accurate characterization of individual exposure together with an improved knowledge of chemical and toxicological data on specific compounds or more complex interactions between chemicals could improve our current understanding. More multisite studies on large populations, to increase statistical power, are needed to draw conclusions on general risks.

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