



Increased risk of non-Hodgkin lymphoma and serum organochlorine concentrations among neighbors of a municipal solid waste incinerator

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ABSTRACT

Organochlorine chemicals may contribute to an increased risk of non-Hodgkin lymphoma (NHL) within non-occupationally exposed populations. Among these chemicals, dioxins and furans were mainly released by municipal solid waste incinerators (MSWIs) until a recent past in France, a source of exposure that is of public concern. We investigated organochlorines and the risk of NHL among neighbors of a French MSWI with high levels of dioxin emissions (Besançon, France), using serum concentrations to assess exposure. The study area consisted of three electoral wards, containing or surrounding the MSWI. Pesticides, dioxins, furans, and polychlorinated biphenyls (PCBs) were measured in the serum of 34 newly diagnosed NHL cases (2003–2005) and 34 controls. Risks of NHL associated with each lipid-corrected serum concentration were estimated using exact logistic regression. The pesticides β -hexachlorocyclohexane (odds ratio [OR]=1.05, 95% confidence interval [CI]=1.00–1.12, per 10 ng/g lipid) and *p,p'* dichloro-diphenyl-trichloroethane (DDT) (OR=1.20, 95% CI=1.01–1.45, per 10 ng/g lipid) were associated with NHL risk. Evidence indicated an increased NHL risk associated with cumulative WHO₁₉₉₈-toxic equivalency factor (TEQ) concentrations (dioxins, OR=1.12, 95% CI=1.03–1.26; furans, OR=1.16, 95% CI=1.03–1.35; dioxin-like PCBs, OR=1.04, 95% CI=1.00–1.07; and total TEQ, OR=1.04, 95% CI=1.01–1.05), as well as with non dioxin-like PCBs (OR=1.02, 95% CI=1.01–1.05, per 10 ng/g lipid). Most congener-specific associations were statistically significant. This study provides strong and consistent support for an association between serum cumulative WHO₁₉₉₈-TEQ concentrations, at levels experienced by people residing in the vicinity of a polluting MSWI, and risk of NHL.

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1. Introduction

The etiology of the most common types of non-Hodgkin's lymphoma (NHL) remains elusive, and the well established risk factors (immunodeficiency disorders, autoimmune diseases, some infectious agents in specific subtypes) explain only a small percentage

of the NHL cases (Alexander et al., 2007). The epidemic of NHL observed during the second half of the 20th century has now started to level off in North America and Europe. This trend might be partly explained by a decrease in the widespread exposure to common chemicals (such as pesticides and persistent organic pollutants) following enforcement of regulations in the 1970s and 1980s (Hardell and Eriksson, 2003).

One dioxin congener (2,3,7,8-T₄CDD or TCDD) and one furan congener (2,3,4,7,8-P₅CDF) are considered carcinogenic to humans by the International Agency for Research on Cancer (IARC) for all cancers (Baan et al., 2009). For NHL specifically, increased incidence and mortality have been reported in several investigations conducted on cohorts of workers exposed to TCDD (Becher et al., 1996; Kogevinas et al., 1997; Hooiveld et al., 1998; Bodner et al., 2003), and on an exposed population following an accidental industrial release of TCDD in Seveso (Italy) (Consonni et al., 2008). However, few studies have examined the effects of environmental dioxin exposure. Emissions from municipal solid waste incinerators (MSWIs) are one of the major

Abbreviations: CI, confidence interval; DDE, dichloro-diphenyl-dichloroethylene; DDT, *p,p'* dichloro-diphenyl-trichloroethane; EBV, Epstein-Barr virus; HCB, hexachlorobenzene; HCCH, hexachlorocyclohexane; IARC, International Agency for Research on Cancer; I-TEQ, international toxic equivalency factor; LOQ, limit of quantification; MSWI, municipal solid waste incinerator; NDL-PCB, non dioxin-like polychlorinated biphenyls; NHL, non-Hodgkin lymphoma; OR, odds ratio; PCB, polychlorinated biphenyls; PCDD, polychlorinated dibenzo-*p*-dioxins; PCDF, polychlorinated dibenzofurans; TCDD, tetrachlorodibenzo-*p*-dioxin; WHO, World Health Organization.

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sources of dioxins and furans in France, and are therefore a source of exposure that is of public concern. Our team first detected a cluster of NHL in an area surrounding an MSWI with high levels of dioxin emissions (Besançon, France) (Viel et al., 2000). Subsequently, an increased risk (odds ratio [OR] = 2.3, 95% confidence interval [CI] 1.4 to 3.8) of NHL was associated with residence under the plume of this MSWI (Floret et al., 2003). These findings have recently been replicated at the national level with a similar exposure assessment approach (Viel et al., 2008).

Polychlorinated biphenyls (PCBs) are considered probable human carcinogens by the IARC, with the exception of the recent classification of PCB 126 as carcinogenic to humans (Baan et al., 2009). Dioxin-like (DL) PCBs exhibit similar toxicologic properties as dioxins through their potential to bind to the arylhydrocarbon receptor, whereas non dioxin-like (NDL) PCBs elicit biological responses that are primarily mediated through other pathways such as immunosuppression (Safe, 1993). Several studies have suggested a role for PCBs in the development of NHL (Hardell et al., 1996; Rothman et al., 1997; Engel et al., 2007).

There has been also considerable interest in the question of whether exposure to pesticides causes NHL, with recent reviews highlighting pesticide exposure as one of the likely occupational risk factors for this cancer (Baris and Zahm, 2000; Fisher and Fisher, 2004).

The lipid-soluble nature of the different organochlorine classes results in similar bioaccumulation patterns. Owing to their prolonged half-lives, organochlorine levels in blood reflect cumulative exposure over time and can cause chronic toxicity after long-term exposure, even if the exposure dose is relatively low (Dich et al., 1997).

Our goal, therefore, was to investigate the association between risk of NHL and serum concentrations of organochlorines in the vicinity of a polluting MSWI (Besançon, France).

2. Materials and Methods

2.1. Study area

The MSWI of Besançon was put into service in 1971. Some legal guidelines for incinerator emissions have not been followed at this location. For example, in 1997, exhaust gases were not maintained at sufficient temperatures, allowing dioxins to be emitted. The first time that the dioxin concentration of an exhaust gas was ever measured (December 1997), it was found to be 16.3 ng WHO₁₉₉₈-toxic equivalency factor (TEQ)/m³, whereas the European guide value is 0.1 ng WHO₁₉₉₈-TEQ/m³.

The study area consisted of three electoral wards (170,000 inhabitants), containing or surrounding the MSWI. As a result, exposed people could live, work, do outdoor leisure activities, or eat locally produced food in the impact area of the MSWI's plume.

2.2. Study population

Cases included subjects with newly diagnosed NHL between January 1, 2003, and December 31, 2005, at the Department of Hematology of the University Hospital (the only tertiary referral hospital in the region) who were living in the study area. The completeness of case ascertainment was verified by linkages with computerized hospital discharge data. The total number of eligible cases was 53 (vs. a mean of 56 forecasted cases according to the local populations and rates in 2002). Of the eligible cases, three rapidly died, five could not participate due to poor health, eight refused, and 37 consented. Unfortunately, three blood samples could not be tested due to hepatitis B, hepatitis C, and suspected HTLV-1 seropositivities, leaving 34 cases for analysis.

Controls were randomly selected from the donor registry of the regional blood bank living in the study area according to a one-to-one matching procedure. Matching criteria were sex, age (± 5 years), and

date of blood draw (± 1 year). Five eligible controls refused to participate, and each of them was replaced by another control of similar characteristics for matching variables. Thus the present study encompassed 34 cases and 34 controls.

2.3. Biomarkers

A fasting blood sample of 150 ml was drawn from each participant. All blood was processed at the regional blood bank in the same laboratory. Serum was separated from clotted blood by centrifugation and frozen at -80 °C until analysis was conducted. The samples were shipped in one batch that consisted of mixed cases and controls to the CART Mass Spectrometry Laboratory, University of Liège, Belgium. Samples were identified only by a unique sample code and thus were blinded for case-control status.

We measured a wide spectrum of organochlorines including 10 pesticides or pesticide metabolites (hexachlorobenzene [HCB], β - and γ -hexachlorocyclohexane [HCCH], oxychlorodane, *trans*-nonachlor, *cis*-nonachlor, *p,p'*-dichloro-diphenyl-dichloroethylene [DDE], *o,p'*-dichloro-diphenyl-trichloroethane [DDT], *p,p'*-DDT, and mirex), the 17 2,3,7,8-substituted dioxins (PCDDs) and furans (PCDFs), 12 DL-PCBs (non-*ortho* substituted—77, 81, 126, 169, and mono-*ortho* substituted—105, 114, 118, 123, 156, 157, 167, 189), and 6 NDL-PCBs (28, 52, 101, 138, 153, 209). Pesticides were measured by gas chromatography coupled to electron-capture detection. PCDD/Fs and PCBs were measured by gas chromatography coupled to isotope-dilution high-resolution mass spectrometry. The methods have been validated under International Organization for Standardization 17025 criteria. Instrument performance, multi-level quality control, and blank levels were monitored following Focant et al. (2006). For four pesticide analytes (*trans*-nonachlor, *cis*-nonachlor, *o,p'*-DDT, and mirex), four PCDF congeners (1,2,3,7,8-P₅CDF, 1,2,3,7,8,9-H₆CDF, 1,2,3,4,6,7,8-H₇CDF, and 1,2,3,4,7,8,9-H₇CDF), and three NDL-PCBs (28, 52, 101), fewer than 50% of the samples had levels above the limit of quantification (LOQ). Following Engel et al. (2007), these compounds were not considered to minimize any distortion of exposure measurement due to high proportions of input values.

Total lipid concentration was calculated for each serum sample using enzymatic methods. Concentrations of PCDDs, PCDFs, and DL-PCBs were expressed in pg WHO₁₉₉₈-TEQ per gram of lipids, while concentrations of pesticides and NDL-PCBs were expressed in ng per gram of lipids.

2.4. Questionnaires

Written informed consent was obtained from each participant before the interview. A single epidemiologist collected data through a face-to-face interview.

Socio-demographic and physiological factors included age, sex, tobacco status, education, occupational social class (I, managers, professionals, and self-employed workers; II, non-manual employees [higher grade]; III, non-manual employees [lower grade]; IV, skilled workers, non-skilled workers, and agricultural laborers), and length of residency in the study area since the incinerator installation. Body mass index (BMI) was calculated based on self-reported height and weight at the time of inclusion.

Participants were asked if they had ever worked in any of six industries previously defined to potentially expose workers to dioxins or other organochlorine compounds: metal, pulp and paper, incineration, petroleum, pesticide manufacturing, and textile industries.

Food intake was quantified by a simplified food frequency questionnaire focusing on the food vectors for animal lipids that are also the food vectors for organochlorines: meat (beef, pork, and sheep), poultry and eggs, fish (lean fish and fatty fish), shellfish, and dairy products (cheese and milk).

2.5. Statistical analysis

Serum values below the LOQ were assigned half the LOQ. The Wilcoxon–Mann–Whitney test was used to compare mean serum lipid levels. Spearman rank correlations were calculated between lipid-adjusted organochlorine concentrations. OR and 95% CI for the risk of NHL associated with each biomarker were estimated using exact logistic regression models. For the sake of clarity, the ORs associated with pesticides and NDL-PCBs were given for a 10-unit increase. All the above analyses were conducted using LogXact software (Cytel Inc., Cambridge, MA USA). All statistical tests were two-sided.

No subgroup analyses of the associations between organochlorines and NHL were performed for histological subtypes because of the small sample size.

2.6. Ethics

Ethical clearance for this study was granted by the Consulting Committee for the Treatment of Information in Medical Research (no. 02.16), the National Commission for the Confidentiality of Computerized Data (no. 902087), and the regional Consultative Committee for the Protection of Persons involved in Biomedical Research.

3. Results

The evaluated subtypes of NHL comprised the following: diffuse large B cell lymphoma ($n=11$), marginal zone lymphoma ($n=9$), follicular lymphoma ($n=3$), small lymphocytic lymphoma/chronic lymphocytic leukemia ($n=3$), mantle cell lymphoma ($n=3$), peripheral ($n=2$) and anaplastic ($n=2$) T-cell lymphoma, and Burkitt's lymphoma ($n=1$).

Although we attempted to enroll cases prior to the onset of chemotherapy, 10 patients underwent blood withdrawal after initiating chemotherapy (median time to blood draw from disease diagnosis: 71 days). The total serum lipid level did not differ between these cases (mean = 700 mg/100 mL) and those who provided blood prior to the onset of chemotherapy ($n=24$, mean = 626 mg/100 mL) (p -value = 0.93).

Selected characteristics of the study population are provided in Table 1. Cases and controls were well matched by sex and age. There was no appreciable difference in cigarette use, education, occupational social class, BMI, or length of residency in the study area. No participant had ever worked in a dioxin-generating industry. Regarding food frequencies, no difference was noted between cases and controls (Supplemental Table 1), and very few people reported occasional consumption of locally produced food.

Dioxin, furan, DL-PCB, and NDL-PCB concentrations showed strong correlation with each other, but low to moderate correlation with pesticides or pesticide metabolites (Table 2).

β -HCCH (OR = 1.05, 95% CI = 1.00–1.12, per 10 ng/g lipid) and p,p' -DDT (OR = 1.20, 95% CI = 1.01–1.45, per 10 ng/g lipid) were positively linked with NHL risk (Table 3). There were no other significant or noteworthy findings for the organochlorine pesticides or pesticide metabolites.

There was strong evidence of increased NHL risk associated with cumulative WHO₁₉₉₈-TEQ concentrations: PCDDs, OR = 1.12, 95% CI = 1.03–1.26; PCDFs, OR = 1.16, 95% CI = 1.03–1.35; DL-PCBs, OR = 1.04, 95% CI = 1.00–1.07; and total TEQ, OR = 1.04, 95% CI = 1.01–1.05 (Table 4). The risk associated with NDL-PCBs was also significant (OR = 1.02, 95% CI = 1.01–1.05, per 10 ng/g lipid). To explore potential confounding, we included in turn, BMI, one of the two pesticides that were significantly associated with NHL (β -HCCH, and p,p' -DDT), and cumulative NDL-PCBs in the models. The ORs did not substantially change when adjusting for BMI or pesticides, but were more or less attenuated by inclusion of NDL-PCBs (Supplemental Table 2).

Congener-specific results are reported in the Supplemental Table 3 for PCDDs and PCDFs, and the Supplemental Table 4 for PCBs. Each of the dioxin congeners was significantly associated with increased NHL risk (p -values ranging from 0.006 to 0.05). Of the furan congeners, 1,2,3,4,7,8-H₆CDF was most strongly associated with NHL risk (p -value < 0.001). Risks associated with PCB congeners were all statistically significant, with the exceptions of PCB 77 and PCB 114.

4. Discussion

This study is the first report of an association between cumulative serum WHO₁₉₉₈-TEQ concentrations and risk of NHL, at levels experienced by the general population in the vicinity of an MSWI. Our results also contribute to the body of evidence indicating that exposure to NDL-PCBs increases the risk of NHL.

Table 1

Selected characteristics of non-Hodgkin lymphoma cases (No = 34) and controls (No = 34).

Variable	Cases No (%)	Controls No (%)
Gender		
male	15 (44.1)	15 (44.1)
female	19 (55.9)	19 (55.9)
Age, y		
<55	12 (35.3)	12 (35.3)
55–63	14 (41.2)	14 (41.2)
≥64	8 (23.5)	8 (23.5)
Cigarette use		
current	5 (14.7)	5 (14.7)
former	12 (35.3)	14 (41.2)
never	17 (50.0)	15 (44.1)
Education, y		
<12	22 (64.7)	22 (64.7)
≥12	12 (35.3)	12 (35.3)
Occupational social class		
I	11 (32.4)	8 (23.5)
II	2 (5.9)	4 (11.8)
III	10 (29.3)	14 (41.2)
IV	11 (32.4)	8 (23.5)
Body mass index		
<18.5	1 (2.9)	1 (2.9)
18.5–24.9	20 (58.8)	25 (73.5)
25–29.9	9 (26.5)	8 (23.5)
≥30	4 (11.8)	0 (0.0)
Length of residency, y		
<20	20 (58.8)	19 (55.9)
≥20	14 (41.2)	15 (44.1)

The major strength of this study is represented by the exposure assessment method which does not rely on participant recall and reflects short-to-long-term exposure. Fasting samples avoided methodological challenges with regard to lipids when using nonfasting blood specimens to estimate health risk (Schisterman et al., 2005). The serum sample volume allowed for the measurement of a broad range of organochlorines and the detection of compounds at low concentration. Other strengths of our study include the demographic matching of cases and controls, and the detailed information available about the subjects at the time of inclusion, such as lifestyle factors, occupation, and diet. However, no information was available on any temporal changes in body weight prior to disease diagnostic that could have influenced serum organochlorine concentrations among cases.

The moderate size of the study (which could not be controlled because of the nature of the study design) has not limited the statistical power of the analysis to identify significant findings but restricted multivariate adjustments, and did not allow for analysis by NHL subtype.

Although control subjects were recruited among blood bank donors, they can be considered broadly representative of the general population at least for two reasons. First, there was a balanced distribution of demographic characteristics (including BMI) among cases and controls, which cannot, therefore, bias the observed associations. Second, the cumulative serum PCDD/F WHO₁₉₉₈-TEQ concentrations among controls were similar to those measured among randomly selected people in the vicinity of eight other French MSWIs during the corresponding time period (Table 5) (Frery et al., 2009). In contrast, the observed increase of the DL-PCB WHO₁₉₉₈-TEQ concentrations suggests that a past exposure of the study area to PCBs may have occurred, possibly reflecting the environmental impact of the local MSWI.

The main limitation of this study is that eight cases with rapid death or poor prognosis were not included, as it was considered unethical to add to these patients' burden by drawing a 150-ml blood sample. Our estimated increased risks from exposure to organochlorine compounds may not be applicable to all patients with NHL.

Table 2
Spearman rank correlations between lipid-adjusted organochlorine concentrations.

	HCB	β -HCCH	γ -HCCH	Oxychlorodane	<i>p,p'</i> -DDE	<i>p,p'</i> -DDT	Σ PCDD	Σ PCDF	Σ DL-PCB	Σ NDL-PCB
HCB	1.00									
β -HCCH	0.73	1.00								
γ -HCCH	0.55	0.51	1.00							
Oxychlorodane	0.61	0.30	0.47	1.00						
<i>p,p'</i> -DDE	0.65	0.61	0.50	0.36	1.00					
<i>p,p'</i> -DDT	0.60	0.54	0.47	0.43	0.54	1.00				
Σ PCDD	0.64	0.78	0.34	0.11	0.55	0.50	1.00			
Σ PCDF	0.67	0.74	0.34	0.18	0.55	0.52	0.92	1.00		
Σ DL-PCB	0.59	0.78	0.31	0.05	0.54	0.51	0.89	0.87	1.00	
Σ NDL-PCB	0.57	0.67	0.34	0.09	0.62	0.61	0.80	0.79	0.91	1.00

DDE, dichloro-diphenyl-dichloroethylene; DDT, dichloro-diphenyl-trichloroethane; DL-PCB, dioxin-like polychlorinated biphenyls; HCB, hexachlorobenzene; HCCH, hexachlorocyclohexane; NDL-PCB, non dioxin-like polychlorinated biphenyls; PCDD, polychlorinated dibenzo-*p*-dioxins; PCDF, polychlorinated dibenzofurans.

One further limitation, shared with most prior studies on this topic, is the substantial correlation between dioxins, furans, and PCBs, making it difficult to tease apart which of these organochlorine classes are the true risk factors. We found evidence of some confounding by NDL-PCBs, although the risk of NHL associated with TEQ concentrations remained elevated. Epstein–Barr virus (EBV) serology was not performed because an interaction between EBV and organochlorines (Rothman et al., 1997; Hardell et al., 2001; Hardell et al., 2009) would not have been apparent, due to the limited number of participants.

Interference by the disease process and/or chemotherapy among NHL patients must be mentioned because blood withdrawal was performed after initiating chemotherapy for 29% of the cases. This interference should not have distorted our results for the following reasons. First, NHL treatment might depress, and not increase, organochlorine levels (Baris et al., 2000), and would (if ever) bias the ORs towards the null. Second, no substantial differences in the OR point estimates were seen after limiting the analyses to the 24 cases who underwent blood withdrawal before initiating chemotherapy (results not shown). Third, differential weight loss that could release stored organochlorines into the blood stream and induce an increase in organochlorine levels is not to be considered a factor as lipid levels did not differ between untreated and treated cases (being even slightly higher among treated patients). Fourth, the median interval between treatment and blood draw was rather short among the 10 concerned cases (71 days).

Very few studies have evaluated exposure to organochlorines in serum or plasma in relation to NHL within the general population. We found an increased risk of NHL with serum β -HCCH concentrations, in agreement with Spinelli et al. (2007). However, three other case-control studies did not observe such an association (De Roos et al., 2005; Cantor et al., 2003; Cocco et al., 2008). Our significant findings for *p,p'*-DDT concentrations is contradictory to two other case-control studies that found no association with NHL (De Roos et al., 2005; Cantor et al., 2003; Bertrand et al., 2010).

Table 3
Odds ratios for the risk of non-Hodgkin lymphoma in relation to lipid-corrected serum concentrations of organochlorine pesticides.

Pesticide (ng/g lipid)	Cases (mean)	Controls (mean)	OR (95% CI) ^a	<i>p</i> -value
HCB	50.71	37.35	1.10 (0.97–1.28)	0.16
β -HCCH	98.61	48.08	1.05 (1.00–1.12)	0.05
γ -HCCH	24.89	17.77	1.16 (0.93–1.49)	0.20
Oxychlorodane	44.67	45.68	0.99 (0.88–1.13)	0.91
<i>p,p'</i> -DDE	153.10	89.49	1.03 (0.99–1.08)	0.07
<i>p,p'</i> -DDT	36.83	18.87	1.20 (1.01–1.45)	0.03

DDE, dichloro-diphenyl-dichloroethylene; DDT, dichloro-diphenyl-trichloroethane; HCB, hexachlorobenzene; HCCH, hexachlorocyclohexane.

^a per 10 ng/g lipid.

To our knowledge, only one other study has addressed the issue of PCDD/F levels and NHL risk within a non-occupationally exposed population. In line with our results, De Roos et al. (2005) showed that plasma levels of total PCDFs, several individual PCDF congeners, and cumulative WHO₁₉₉₈-TEQ concentrations were positively associated with NHL risk.

Concerning PCBs, our findings are consistent with previously reported studies. Rothman et al. (1997) showed that total PCB levels measured in serum were strongly associated with increased risk of NHL in a nested case-control study. Engel et al. (2007) found exposure-response trends for several congeners (118, 138, and 153) across three cohorts. Hardell et al. (2001) reported an increased risk of NHL incidence for the group of immunotoxic PCB congeners. De Roos et al. (2005) found exposure-response trends for PCB 156, PCB 180, and PCB 194 levels, Spinelli et al. (2007) for DL-PCBs (total, 118, 156) and NDL-PCBs (total, 99, 138, 153, 170, 180, 187), and Bertrand et al. (2010) for the sum of 51 PCBs and the group of immunotoxic congeners. Hardell et al. (2009) found an association of borderline significance between total PCBs and NHL risk. Inconsistent with our findings, Cocco et al. (2008) did not find evidence of an association between NHL risk and levels of PCBs.

In conclusion, we report a strong and consistent association between NHL risk and serum levels of PCDDs, PCDFs, and DL-PCBs, among people residing in the vicinity of an MSWI with high dioxin emission levels (Besançon, France). These pollutants could involve the development of NHL through a chromosomal translocation t(14;18) pathway. Two case-control studies found that the association between pesticide exposure and risk of NHL was limited to t(14;18)-positive NHL cases (Schroeder et al., 2001; Chiu et al., 2006), suggesting that exposure to organochlorines could cause expansion of t(14;18)-positive clones. These findings are supported by two

Table 4
Odds ratios for the risk of non-Hodgkin lymphoma in relation to lipid-corrected cumulative serum concentrations of dioxins, furans, dioxin-like polychlorinated biphenyls, and non dioxin-like polychlorinated biphenyls.

Cumulative concentrations	Cases (mean)	Controls (mean)	OR (95% CI)	<i>p</i> -value
Σ PCDD ^a	13.39	8.73	1.12 (1.03–1.26)	<0.01
Σ PCDF ^a	9.44	6.27	1.16 (1.03–1.35)	0.01
Σ DL-PCB ^a	33.13	20.10	1.04 (1.00–1.07)	0.02
Σ (PCDD + PCDF + DL-PCB) ^a	55.96	35.10	1.04 (1.01–1.05)	0.01
Σ NDL-PCB ^b	541.30	335.5	1.02 ^c (1.01–1.05)	0.01

DL-PCB, dioxin-like polychlorinated biphenyls; NDL-PCB, non dioxin-like polychlorinated biphenyls; PCDD, polychlorinated dibenzo-*p*-dioxins; PCDF, polychlorinated dibenzofurans; TEQ, toxic equivalency factor; WHO, World Health Organization.

^a pg WHO₁₉₉₈-TEQ/g lipid.

^b ng/g lipid.

^c per 10 ng/g lipid.

Table 5

Cumulative serum organochlorine concentrations in non-occupationally exposed populations living near French municipal solid waste incinerators.

Cumulative concentrations	This study (2003–2005)	France (2005) ^a
Σ PCDD ^b	8.73	8.4
Σ PCDF ^b	6.27	6.7
Σ DL-PCB ^b	20.10	15.8
Σ (PCDD + PCDF + DL-PCB) ^b	35.10	30.9
Σ NDL-PCB ^c	335.5	387.0

DL-PCB, dioxin-like polychlorinated biphenyls; NDL-PCB, non dioxin-like polychlorinated biphenyls; PCDD, polychlorinated dibenzo-*p*-dioxins; PCDF, polychlorinated dibenzofurans; TEQ, toxic equivalency factor; WHO, World Health Organization.

^a Frery et al., 2009.

^b pg WHO₁₉₉₈-TEQ/g lipid.

^c ng/g lipid.

recent biological studies. Baccarelli et al. (2006) found that TCDD exposure was associated with increased numbers of t(14;18)-positive circulating lymphocytes in healthy individuals from Seveso. Agopian et al. (2009) demonstrated that expanded t(14;18)-positive clones provide a molecular connection between agricultural pesticide exposure, t(14;18) frequency in blood, and clonal expansion.

However, assuming that the association found in our study reflects a true causal relationship, it is unclear which source and route of exposure lead to the pathogenesis of NHL in the study area. Although the amounts of organochlorines emitted by the local MSWI into the environment before compliance with the stringent emission standards cannot be readily estimated, some further arguments point to the potential responsibility of the MSWI: a high dioxin emission level in 1997, no adjacent industrial sources of exposure, and high serum PCB levels among controls.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.envint.2010.11.009.

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