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Indoor tetrachloroethylene levels and determinants in Paris dwellings ☆

Célina Roda [a], Isabelle Kousignian [a], Anna Ramond [a], Isabelle Momas [a,b,*]

[a] Univ Paris Descartes, Sorbonne Paris Cité, Laboratoire Santé Publique et Environnement, EA 4064, F-75270, Paris, France
[b] Mairie de Paris, Direction de l'Action Sociale de l'Enfance et de la Santé, Cellule Cohorte, F-75012, Paris, France

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ABSTRACT

There is growing public health concern about indoor air quality. Tetrachloroethylene (PERC), a chlorinated volatile organic compound widely used as a solvent in dry cleaning facilities, can be a residential indoor air pollutant. As part of an environmental investigation included in the PARIS (Pollution and asthma Risk: an Infant Study) birth cohort, this study firstly aimed to document domestic PERC levels, and then to identify the factors influencing these levels using standardized questionnaires about housing characteristics and living conditions. Air samples were collected in the child's bedroom over one week using passive devices when infants were 1, 6, 9, and 12 months. PERC was identified and quantified by gas chromatography/mass spectrometry. PERC annual domestic level was calculated by averaging seasonal levels.

PERC was omnipresent indoors, annual levels ranged from 0.6 to 124.2 μg/m^3. Multivariate linear and logistic regression models showed that proximity to dry cleaning facilities, do-it-yourself activities (e.g.: photographic development, silverware), presence of air vents, and building construction date (< 1945) were responsible for higher domestic levels of PERC.

This study, conducted in an urban context, provides helpful information on PERC contamination in dwellings, and identifies parameters influencing this contamination.

1. Introduction

Tetrachloroethylene (CAS Registry Number 127-18-4), also called tetrachloroethene or perchloroethylene (PERC), is a volatile, nonflammable, and colorless liquid with a sweet odor. It is one of the most important chlorinated solvent worldwide, has been commercially used since the early 1900s, and widely used by dry cleaning facilities. In 1994, 90% of the total solvent used by the dry cleaning industry within the European Union was PERC (European Chemicals Bureau, 2005).

The United States Environmental Protection Agency-US EPA (2008) ranks PERC as a hazardous air pollutant because of its health impact. The International Agency for Research on Cancer (IARC) classified PERC as a probable human carcinogen (Group 2A) (WHO, 1995). In occupational studies, chronic exposure to PERC has been shown to adversely affect the kidneys, liver, central nervous system, and reproductive system.

Few studies have sought to assess domestic levels of this pollutant, even though people spend most of their time indoors, especially young children. Residential levels ranged from one to thousands of micrograms per cubic meter in dwellings located in the same buildings as dry cleaning facilities (Altmann et al., 1995, Ohura et al., 2006). The French Observatory for Indoor Air Quality conducted a nationwide study throughout France in 567 dwellings, finding that indoor PERC levels were higher than those outdoors. Indoor levels reached 684 μg/m^3 versus 17.7 μg/m^3 out of doors (Kirchner et al., 2006). Populations living close to dry cleaning facilities are often exposed to levels that are significantly higher than the background level (Ma et al., 2009). The volatility of PERC generated by sources outside dwellings leads to it being transported and penetrating into homes. To date there has been little research into predictors that contribute to PERC entry into homes.

In this context, and as part of the environmental investigation included in the PARIS (Pollution and Asthma Risk: an Infant

Abbreviations: 95% CI, 95% confidence interval; OR, odds ratio; PERC, Tetrachloroethylene or perchloroethylene; VOCs, volatile organic compounds

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* Corresponding author at: Université Paris Descartes—UFR des Sciences pharmaceutiques et biologiques, Département Santé publique et biostatistique—EA 4064 Santé Publique et Environnement, 4 avenue de l'Observatoire, 75006 Paris, France. Fax: +33 1 43 25 38 76.

E-mail address: isabelle.momas@parisdescartes.fr (I. Momas).

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Study) birth cohort, our purpose is to firstly assess indoor air PERC levels in a sample of dwellings in the Paris metropolitan area, and then to identify determinants of these levels from housing factors and living conditions.

2. Materials and methods

2.1. Study design

The environmental investigation was carried out in a random sample of 196 babies' homes from the PARIS birth cohort described elsewhere (Clarisse et al., 2007). Environmental measurements were planned at 1, 6, 9 and 12 months of the infant (Dassonville et al., 2009; Roda et al., 2011).

2.2. Air sampling

Between April 2003 and November 2007, passive Volatile Organic Compounds (VOCs) samplers (Radiello®, Fondazione Salvatore Maugeri—IRCCS, Italy) were placed in the infant bedroom for 7 days.

VOCs were adsorbed on a Carbograph 4 type support. Collected compounds were then thermally desorbed and quantified by gas chromatography coupled to a mass spectrometry detector (Hewlett Packard 5890 Gas Chromatograph with 5971 A Mass Selective Detector). Quantification limit of PERC was 0.4 $\mu g/m^3$.

Six per cent of field blanks were used as control contamination during transport and sampling, and 6% of duplicates were realized. Duplicates were highly correlated with an intraclass correlation coefficient of 0.99.

2.3. Housing characteristics and family living conditions

During maternity leave, a phone interview was conducted by a trained interviewer to describe in detail home characteristics and family living conditions. At other time points (3, 6, 9, and 12 months), a new questionnaire was sent to the parents to record any change in home characteristics or lifestyle habits.

Questions dealt with the type of accommodation (house or apartment), date of building construction, number of occupants, home surface area, heating and cooking amenities (central heating, gas heater at home, electric convector at home, gas or electric stove and ovens), smoking at home, wall and floor coverings (presence and age of wood-pressed products for flooring, carpet, linoleum, etc.). Information related to ventilation, aeration (presence of double glazing, air vents, and length of window opening), and signs of dampness (damp stains, mold stains, water damage, and/or mold odor) were also collected along with data on frequency of use of cleaning products, do-it-yourself activities using paint, varnish, glue or other odorous compounds (e.g.: photographic development, silverware).

Dwellings addresses and dry cleaning facilities were geocoded using Google Geocoding API. The dry cleaning facility in the neighborhood of each dwelling was identified and the distance to the closest facility was assigned for each dwelling.

2.4. Statistical analysis

An annual pollutant level was calculated for each dwelling by averaging seasonal levels (hot season: between April and September, cold season: between October and March). Normality of PERC level distribution was analyzed using the Shapiro–Wilk test and Henry's graphical method. Seasonal and annual PERC distributions were summarized by geometric mean (GM) with geometric standard deviation (GSD), range (minimum–maximum), median value, and interquartile range (IQR). Seasonal levels were compared using paired Student's *t*-test.

The study of the determinants of the annual PERC levels was conducted using two statistical approaches: a linear regression model as a continuous approach, and a logistic regression model as a discrete approach. For the linear regression model an inverse square root transformation was considered to improve normality of PERC distribution, whereas for the logistic regression model the observed median value was used as a threshold to define two PERC classes.

Potential determinants of PERC levels previously identified in the literature and/or variables associated with a *p*-value under 20% in univariate analyses were included in the multivariate regression models.

The linear regression model assumptions were checked using both a residual analysis and a multicollinearity study of selected variables. Performances of the model were assessed using Akaike information criterion value and the percentage of variance explained by the model, expressed as determination coefficient (R^2). Results of this model were summarized by their adjusted regression coefficient (β) with their 95% confidence interval (95% CI).

Goodness of fit of the logistic regression model was assessed using the Hosmer–Lemeshow test. Sensitivity, specificity, correctly-classified rate, and area under the Receiver Operating Characteristic Curve (ROC) were given to describe performances of the logistic regression model. Results of this model were presented with adjusted odds-ratio (OR) with their 95% CI.

Predicted inverse square root PERC levels from the multivariate linear regression model were dichotomized at the observed median value, and an agreement degree of the dwellings' classification between linear and logistic models was thus defined.

In order to obtain non-transformed PERC distributions, an iterative sampling distribution of the inverse square root PERC levels was generated using the estimated linear regression coefficients. At each iteration, regression coefficients were drawn from a normal distribution of which the parameters are the estimated mean and standard deviation (SD) of each coefficient. Different exposure situations were then defined by fixing surrogates, and by varying modalities of the major determinants of PERC levels. Predicted distributions were summarized by the mean, range (minimum–maximum), and compared using Student's *t*-test.

Statistical analyses were performed with STATA® statistical software (released 11.1; Stata Corporation, TX, USA), and using software R.12.0 (R Development Core Team, 2011). A *p*-value below 0.05 was considered to be statistically significant.

3. Results

Results are from the 177 investigated dwellings where annual PERC could be calculated.

3.1. Housing characteristics and living conditions

Housing characteristics and living conditions of families are summarized in Table 1.

The investigated dwellings were mainly apartments located in Paris *intra-muros* for two thirds of them. The surface area ranged from 27 to 250 m^2 with a mean (SD) of 71.4 (24.9) m^2. More than one quarter of buildings were built after 1975, and about 27% were equipped with mechanical ventilation. Almost all windows in the baby's room were opened daily, and length of window opening ranged from 3 min to 24 h.

None of the investigated dwelling was located directly above a dry cleaning facility. The mean distance from a dwelling to a dry cleaning facility was 285 (253) m, the smallest distance being 12 m.

3.2. Domestic tetrachloroethylene levels

PERC was quantified in all dwellings. Distributions of seasonal and annual levels measured are given in Table 2. Levels were statistically higher in cold season, GM (GSD): 2.8 (2.2) $\mu g/m^3$, than in hot season, GM (GSD): 2.4 (2.4) $\mu g/m^3$ (paired Student's *t*-test, $p=0.003$). The GM (GSD) of annual PERC levels was 2.8 (2.3) $\mu g/m^3$. Annual domestic PERC levels ranged from 0.6 to 124.2 $\mu g/m^3$, and the median value was 2.3 $\mu g/m^3$ (IQR: 2.3 $\mu g/m^3$).

3.3. Determinants of tetrachloroethylene levels

Fig. 1 shows the distribution of annual PERC indoor levels by proximity to dry cleaning facilities (≤ 100, 100–250, and > 250 m). This proximity increased annual domestic PERC levels, especially when the distance was small *($p<0.001$).* Dwellings located 100 m or less from a dry cleaning facility had a GM (GSD) of PERC levels of 6.1 (3.3) $\mu g/m^3$ versus 2.1 (1.9) $\mu g/m^3$ in dwellings more than 250 m from a facility.

Table 3 gives adjusted regression coefficients and ORs associated with predictive factors of PERC exposure levels and classes, respectively. The models included the proximity to dry cleaning facility and do-it-yourself activities, as sources of PERC, and parameters of aeration, such as air vents, and length of window opening, and home characteristics, such as construction date, and housing area.

The linear regression model explained 25.1% (R^2) of the variability of PERC levels. Sensitivity, specificity, and area under ROC curve of the logistic regression model were 67.1%, 68.5%, and