Children's exposure to brominated flame retardants in indoor microenvironments

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Introduction

Brominated flame retardants (BFRs) are used in a wide range of products such as clothes, children's toys, carpets, mattresses, housing and wiring of TV sets, computers, upholstery and textiles, building materials and many plastic products. The main routes of human exposure are diet, inhalation, dust ingestion in indoor spaces and dermal absorption. House dust in particular is a significant medium for exposure to BFRs and is the subject of growing concern in recent years [1]. In children exposure to BFRs may occur through ingestion of dust, air inhalation, dermal absorption from indoor dust, toy chewing, hand-to-mouth behaviour and dietary intake. As children spend the majority of their time indoors in houses, schools, cars and public facilities, it is important to assess their exposure to pollutants present in these environments. The present study reviews data on children's exposure and levels of the following legacy and emerging BFRs (EBFRs) in indoor microenvironments based on their environmental occurrence and children's exposure data availability: PBDEs, HBCDD, TBBPA, DBDPE, 1,2-Bis(2,4,6-tribromophenoxy) ethane (BTBPE), 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (EH-TBB), bis(2-ethylhexyl) tetrabromophthalate (BEH-TEBP), and hexabromobenzene (HBB). All chemical abbreviations referred to in this study are as described in Bergman et al. [2].

Materials and methods

Literature searches were carried out in PubMed, Scopus, Web of Science and Science Direct covering studies published from 2002 to March 2017 using the following keywords (and their combinations): a) regarding FRs: "BFRs" (or "brominated flame retardants"), "polybrominated diphenyl ethers" (or "PBDEs), "HBCDD" (or HBCD), "TBBPA", "emerging brominated flame retardants" (or "EBFRs") and "NBFRs" (or "novel brominated flame retardants"), b) regarding microenvironments and children: "daycare", "classroom", "indoor environment", "school", "dust", "indoor air", "exposure", "children", "toddlers" and "infants". The search was limited to the English language and studies on non-occupationally and non-dietary exposed humans and the last search was conducted on April 1st 2017.

Results and discussion

PBDEs

The highest indoor dust concentrations were found for BDE-47 and BDE-209 compared to all the other congeners. Large geographical variations were observed, with North America having the highest BDE-47 concentrations. Worldwide BDE-47 levels ranged from 0.11 in Pakistan to 3100 ng/g in the United States [3,4]. BDE-209 concentrations were in the range of <1.8 in South African homes to 190000 in car dust from the UK [5,6] (Figure 1). In Asia most studies did not find high levels of BDE-47 and BDE-209, except for locations near e-waste recycling sites. In the rest of the world (Middle East, Australia and Africa) BDE levels were lower than Europe, Asia and North America (Figure 1). The differences observed in dust PBDE levels worldwide could be due to a variety of reasons (analytical and sampling method differences aside), such as each country's fire safety regulations, dusting and/or cleaning habits, building characteristics, use of electrical and electronic equipment, use of carpets, different timing for the replacement of PBDEs, sampling season, wet deposition and temperature/sunlight which could affect compound degradation. Several potential determinants of PBDEs in dust have been recently identified, such as furniture condition, urban density, resident ethnicity, household income, presence of upholstered furniture and foam napping equipment [7,8]. A few studies compared dust PBDE levels in cars, homes and/or schools in general found higher levels in cars than in other indoor spaces, suggesting that vehicles are a source of human exposure to their occupants, including children.

Despite the similar inhalation and ingestion pathway, studies measuring PBDEs in indoor air were fewer (n=14) than those measuring dust (n=75), possibly due to the ease of dust sampling compared to indoor air sampling. The highest concentrations in air were observed in Korea and Norway (maximum value was 16620 pg/m^3 for BDE-47 in Korean elementary schools and 4150 pg/m^3 for BDE-209 in Norwegian homes) [9,10]. PBDEs have also been measured in children's toys, children's handwipes, baby products and product surface wipes. All samples had measurable levels of PBDEs, with toys and baby products having the highest concentrations (53000 to 32.27 million ng/g) [11,12]. Longitudinal changes in PBDE levels in handwipes collected from children 8-10 years of age from the United States at an average interval of two years showed no significant correlations in the samples over time, suggesting that although sources in the home remain relatively constant, children's behavior likely changes as they age. Increasing handwipe BFR levels were also observed with age, again suggesting that children's behavior may play a role in their exposure to these chemicals [13]. A study that measured PBDEs in handwipes, as well as dust and indoor air from various children's facilities (schools, private academies, houses, public libraries and malls), observed that PBDE exposure occurred predominantly at home, because of the longer the exposure time and frequency (approximately 80%) [9].

TBBPA and HBCDDs
In dust and indoor air samples TBBPA levels range from <0.06 ng/g in Kazakhstan to 1156 ng/g in South Africa [14,15]. Handwipes from 43 children in the US contained very low levels of TBBPA (geometric mean: 0.40 ng/g) [16]. The sum for all three HBCDD isomers (HBCDDs) was reported in dust samples, indoor air and hand wipes. Median dust worldwide levels ranged from 6.15 ng/g to 340 ng/g, with the highest levels reported in UK daycare centers and primary schools and Japanese houses (4100 and 13000 ng/g respectively) [17,18]. Concentrations of HBCDDs were also higher in cars than homes.

Emerging brominated flame retardants (EBFRs)
The highest concentrations were measured for DBDPE, with dust concentrations ranging from 9 ng/g in New Zealand to 45400 ng/g in China (e-waste area) [19,20]. BTBPE levels were higher in North America than Europe and the rest of the world, with the exception of dust from Chinese homes near e-waste sites. EH-TBB was also higher in indoor microenvironments in North America, with median house dust values ranging from 120 to 337 ng/g in Canada and Northern California respectively [21,22]. These geographical differences could be due to the fact that EH-TBB was used in North America in Firemaster 550, an additive FR. The highest BEH-TEBP concentrations in dust were measured in China near e-waste recycling facilities (median: 7120, maximum: 17600) [20]. HBB concentrations were on the lower end of the other EBFRs, ranging from 0.04 to 3.7 ng/g.

In conclusion, more data on children's exposure exist for PBDEs, than for any other brominated flame retardant or EBFRs. Until 2010 most studies were conducted in Europe and the US, whereas after 2010 the majority of studies are from Asia. On the other hand, relatively few data exist on children's BFR exposure in Australia, New Zealand, Africa and the Middle East and none from Central and South America. It was surprising that while children spend about a third of their daily life in daycare centers and schools, only about 10% of studies sampled these microenvironments. This clearly highlights the need for more studies in schools, nurseries and daycare centers. In addition, very few studies measured BFRs in cars, despite the levels being comparable to (or often higher than) house dust, so further monitoring of BFR contamination in cars is warranted. Handwipes and silicone wristbands may be useful in monitoring children's BFR exposure, compared to more invasive methods such as blood sampling, as shown in recent studies [23,24]. Finally, considering the frequent hand-to-mouth behaviour of toddlers and the fact that many toys contain BFRs, more studies should be conducted with toys to estimate exposure via mouthing. More detailed information regarding infant, toddler and children's daily intake exposure from different indoor microenvironments will be presented in the presentation.

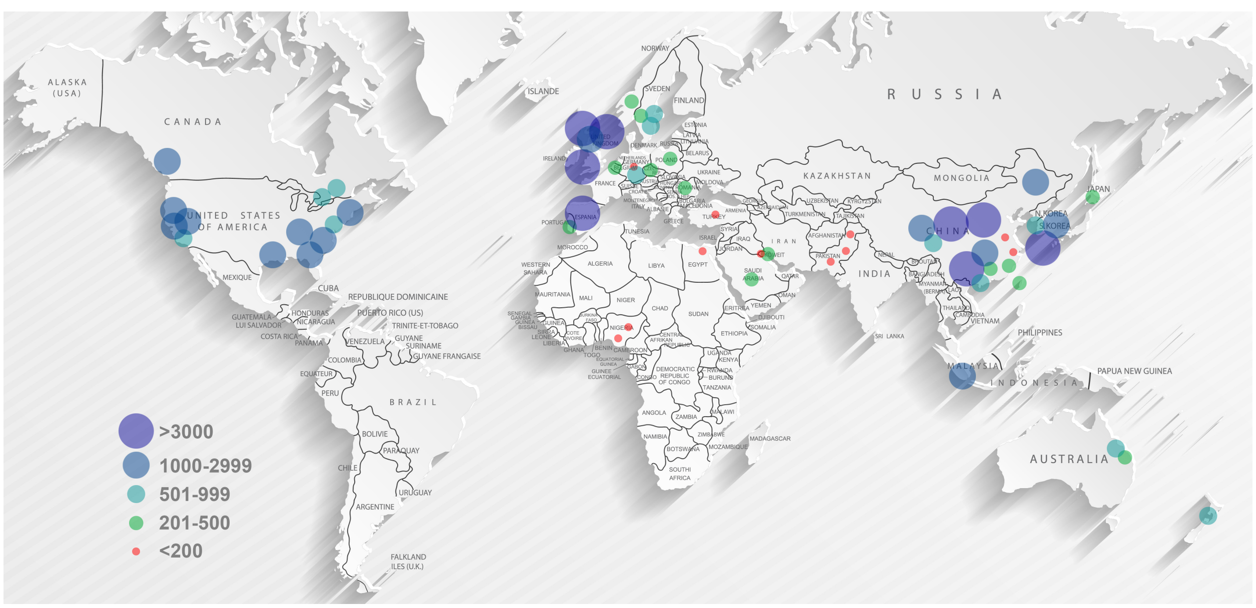

Figure 1 – Median BDE-209 indoor house dust concentrations (ng/g) in different countries

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