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Estimated infant intake of persistent organic pollutants through breast milk in New Zealand

Andrea 't Mannetje, Jonathan Coakley, Phil Bridgen, Allan H Smith, Deborah Read, Neil Pearce, Jeroen Douwes

Abstract

Aim To estimate average infant daily intake of chlorinated persistent organic pollutants (POPs) through the consumption of breast milk in New Zealand.

Method Breast milk of 39 first-time mothers aged 20–30 years was collected during 2007–2010 and analysed for persistent organic pollutants including dioxin-like compounds and organochlorine pesticides. The quantity of POPs consumed by infants assuming exclusive breast feeding was estimated by calculating the Estimated Daily Intake (EDI) expressed as amount consumed through breast milk per kilogram of body weight per day.

Results Of all POPs quantified, the EDI of DDT (principally in the form of its metabolite *p,p'*-DDE) was the highest (1.6 µg/kg/day), and above the tolerable daily intake (TDI) of 0.5 µg/kg/day. The mean EDI for dioxin-like compounds (including PCDD/Fs and PCBs) was 19.7 pg TEQ(toxic equivalency)/kg/day, which is among the lowest reported worldwide, yet above the TDI of 1 pg TEQ/kg/day. The EDI of HCH, HCB, dieldrin, heptachlor and mirex were 32.9, 37.9, 39.4, 2.0, and 0.9 ng/kg/day respectively, all of which were below the current TDI. Age of the mother was positively associated with higher EDIs for the infant, particularly for total-TEQ and total-DDT.

Conclusion Infant daily intakes of chlorinated POPs through breast milk estimated for New Zealand are low or average by international comparison, and 5 times lower than 25 years ago. Future breast milk monitoring will determine whether this diminishing trend is continuing as well as providing monitoring information on other POPs.

Persistent organic pollutants (POPs) include a range of organic chemicals that enter the environment as a result of human activities, are persistent in the environment, and become widely distributed through air and water.

This group of chemicals includes polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs: unintentional by-products of industry), polychlorinated biphenyls (PCBs: historically widely used in electrical transformers and other applications) and organochlorine pesticides (OCP) such as dichlorodiphenyltrichloroethane (DDT), which have now largely been phased out.[1] For example, the use of DDT peaked in the 1950s and 60s, was restricted in the 1970s, and banned in 1989.[2]

Due to their stability and lipophilic properties, POPs are stored in fatty tissue and bioaccumulate in the food chain. Most POPs have long half-lives in humans, can

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cross the placenta, and are excreted in breast milk, resulting in exposure of offspring.[3] During the first year of life, breast milk is the primary source of postnatal exposure to POPs.[4]

Exposure to POPs has been associated with a range of toxic effects in wildlife [5] and humans,[6] and children are thought to be particularly vulnerable to their effects.[7] For example, early life exposure to background levels of POPs has been reported to affect the thyroid hormone system,[8] immunological functions [9] and neuropsychological development.[10]

The Stockholm Convention (www.pops.int) embodies the international recognition that through concerted action the environmental levels of POPs can and should be reduced. The Convention, which was ratified by New Zealand in 2004, requires parties to take measures to eliminate or reduce the release of POPs and regularly quantify the body burdens of POPs in order to measure the effects of the parties' actions to reduce exposure and allow for international comparisons.

The preferred matrix for these bio monitoring studies has been breast milk, as it can be obtained non-invasively and is lipid rich. In addition, breast milk bio monitoring studies of POPs provide the opportunity to estimate infant exposures to these compounds.

In New Zealand, three consecutive breast milk surveys have been conducted, measuring POPs in the milk of first time mothers in the 20–30 year age range, conducted in 1988,[11] 1998[12] and 2008.[13] These surveys have shown a substantial decline in breast milk levels of chlorinated POPs in nursing women, reflecting the effectiveness of national and international regulations related to POPs.

Here we report the findings of the latest breast milk survey [13] and calculate the estimated daily intake (EDI) of POPs through breast milk for infants in New Zealand, and compare them with EDIs reported for other countries and reference dose values set by regulatory agencies.

Methods

Breast milk collection—The recruitment methodology was modelled on the fourth WHO-Coordinated Survey of human milk for persistent organic pollutants [14] and is described in detail elsewhere.[13] Briefly, first-time mothers in the 20–30 year age range, exclusively breastfeeding, and resident within the study area for the last five years, were included in the study.

Participants were recruited from four study areas: Wellington (urban area in the North Island), Wairarapa (rural, North Island), Christchurch (urban, South Island) and North Canterbury (rural, South Island). Participants were recruited through midwives, medical doctors and breast feeding consultants, depending on what was most practicable in each area.

A total of 39 women self-collected breast milk, usually during the second but sometimes during the third month after birth; it was collected through hand expression directly into provided glass collection containers and stored in their home freezer.

When a maximum of up to 250 ml of breast milk was collected, or all of the eight provided collection containers had been used, the milk sample was collected for central storage in a -20°C freezer at the Centre for Public Health Research (CPHR) in Wellington until transport to the laboratory.

Laboratory analyses—All samples were analysed at AsureQuality (Lower Hutt, New Zealand) for a range of POPs including PCDD/Fs, PCBs, and OCPs. Concentrations of all analytes were determined through High-Resolution Gas Chromatography/High-Resolution Mass Spectrometry (HRGC/HRMS) with detail described elsewhere[13] and lipid content. OCPs and their metabolites that were detected in all samples included: Lindane (hexachlorocyclohexane (HCH): of which beta-HCH was detected in all

samples); hexachlorobenzene (HCB); Dieldrin; heptachlor-epoxide; dichlorodiphenyltrichloroethane (DDT) (of which *p,p'*-DDT; *o,p'*-DDT; *p,p'*-DDD and *p,p'*-DDE were detected in all samples); Mirex. Because two samples were of insufficient volume to allow testing for all analytes, PCDD/Fs and PCBs were tested for in all 39 samples, while 37 samples were analysed for OCPs.

All breast milk concentrations were expressed as pg/g lipid or ng/g lipid. Toxic equivalences for the PCDD/Fs and PCBs were calculated using 2005 WHO Toxic Equivalency Factors [15] (also including half the limit of detection (LOD) if below LOD[13]).

Estimated daily intakes—The estimated daily intake (EDI) was calculated for each individual based on the following formula:

EDI=concentration * lipid content * daily milk consumption/infant weight.

EDI: estimated daily intake (expressed in pg/kg/day).

Concentration: individual levels from the breast milk survey (½ LOD included for non-detects) pg/g lipid (mean breast milk concentrations have been reported[13])

Lipid content: individual levels from the breast milk survey (fraction)

Daily milk consumption: assumed to be 690 mL/day (<3 months) and 770 mL/day (3 to 6 months) (USEPA 2011)

Infant weight: assumed to be 5.9 kg (<3 months), 7.4 kg (3 to 6 months).[16]

The EDI was averaged over 6 months (assuming the individually determined POPs concentration and lipid content to be representative for a 6-month period[17]), and the total intake over 6 months was calculated, under the assumption of exclusive breast feeding over 6 months.

Ethical approval for the study was obtained from the Multi-Region Ethics Committee, reference MEC/06/10/119 and informed consent was provided by all participants.

Results

Study population—The study population included 39 mothers: 17 from Wellington, 10 from Wairarapa, 9 from Christchurch, and 3 from North Canterbury. The average age was 27.7 (range 20–30).

The average lipid concentration of the breast milk was 3.85% (SE 0.21) which was statistically significantly higher in urban areas 4.18% (SE 0.27) compared to rural areas 3.19% (SE 0.27).

Estimated daily intake—Table 1 lists the estimated infant daily intake of POPs through breast milk, under the assumption of exclusive breast feeding over their first 6 months of life. The highest EDI was observed for DDT, primarily in the form of its main metabolite *p,p'*-DDE, with infants consuming 1.6 µg/kg per day, which equals a total consumption of almost 2 milligram of DDT related compounds (primarily *p,p'*-DDE) over a 6-month period of exclusive breast feeding.

Table 1 also includes the tolerable daily intakes (TDI) set by various international agencies. The TDI is considered to be the quantity of a substance that can be ingested per kilogram bodyweight per day over a lifetime that is unlikely to produce adverse effects.

Table 1 indicates that breast feeding infants' EDI for total TEQ including dioxins, furans and PCBs (WHO-TEQ_{DFP}), is above the TDI set by New Zealand and FAO/WHO for all analysed samples. The EDI for total DDT is also above the New Zealand TDI for the majority of samples (32 out of 37).

The dieldrin EDI exceeded the US EPA TDI in a minority a samples (10 out of 37), and 1 out of 37 exceeded the New Zealand and FAO/WHO TDI. For all other POPs the EDI was below the TDI for all analysed samples.

Table 1. Estimated daily intake from breast milk (first-time mothers in the 20–30 age range in 2007–2010), and tolerable daily intake

Compound	Estimated daily intake (EDI)		Tolerable daily intake (TDI)		
	mean	min-max	US EPA[18]	NZ[19]	FAO/WHO[20,21]
PCDD/Fs and PCBs	**(pg/kg/d)**			**(pg/kg/d)**	
WHO-TEQ_{DFP}	19.7	6.7–42.1		1	1–4
WHO-$TEQ_{PCDD/Fs}$	14.3	4.7–34.2			
WHO-TEQ_{PCBs}	5.3	1.2–14.6			
Organochlorine pesticides	**(ng/kg/d)**			**(ng/kg/d)**	
HCH (total)[a]	32.9	2.7–421.4	300		5,000*
HCB	37.9	6.8–82.3	800		600
dieldrin	39.4	7.8–108.3	50	100	100
heptachlor (total)[b]	2.0	0.3–6.8	500		100
DDT (total)[c]	1,612.4	420–5,627	500	500	10,000
mirex	0.9	0.3–3.3	200		

PCDD/Fs: polychlorinated dibenzodioxins and polychlorinated dibenzofurans

PCBs: polychlorinated biphenyls

$WHO\text{-}TEQ_{DFP}$: Toxic Equivalence including PCDD/Fs and PCBs

HCH: hexachlorocyclohexane (*gamma*-HCH is Lindane)

HCB: hexachlorobenzene

DDT: dichlorodiphenyltrichloroethane

[a] (consisting of: *alpha*-HCH: 0.2; *beta*-HCH: 31.5; *gamma*-HCH: 0.9; *delta*-HCH: 0.3 ng/kg/day)

[b] (consisting of: heptachlor: 0.05; heptachlor-exoepoxide: 2.0 ng/kg/day)

[c] (consisting of: *p,p'*-DDT: 20.7; *o,p'*-DDT: 2.2; *p,p'*-DDD: 0.5; *o,p'*-DDD: 0.1; *p,p'*-DDE: 1,588.3; *o,p'*-DDE: 0.6 ng/kg/day)

* TDI for Lindane

Comparison with previous New Zealand breast milk surveys—Two previous breast milk surveys have been conducted in New Zealand measuring POPs in the milk of first time mothers in the 20–30 year age range, 20 years[11] and 10 years[12] before the 2008[13] survey.

The breast milk concentrations reported for these studies indicate that the EDIs through breast milk of children born 15 years ago would have been up to 2 times higher, and for children born 25 years ago would have been approximately 5 times higher than the EDIs reported here for most POPs [13].

Comparison with breast milk surveys overseas—Table 2 includes EDIs reported for other countries. To provide a fair comparison, only the EDIs reported in the most recent years (since 2000) are listed, given the significant decline in the measured concentrations of POPs in breast milk over time in most countries.

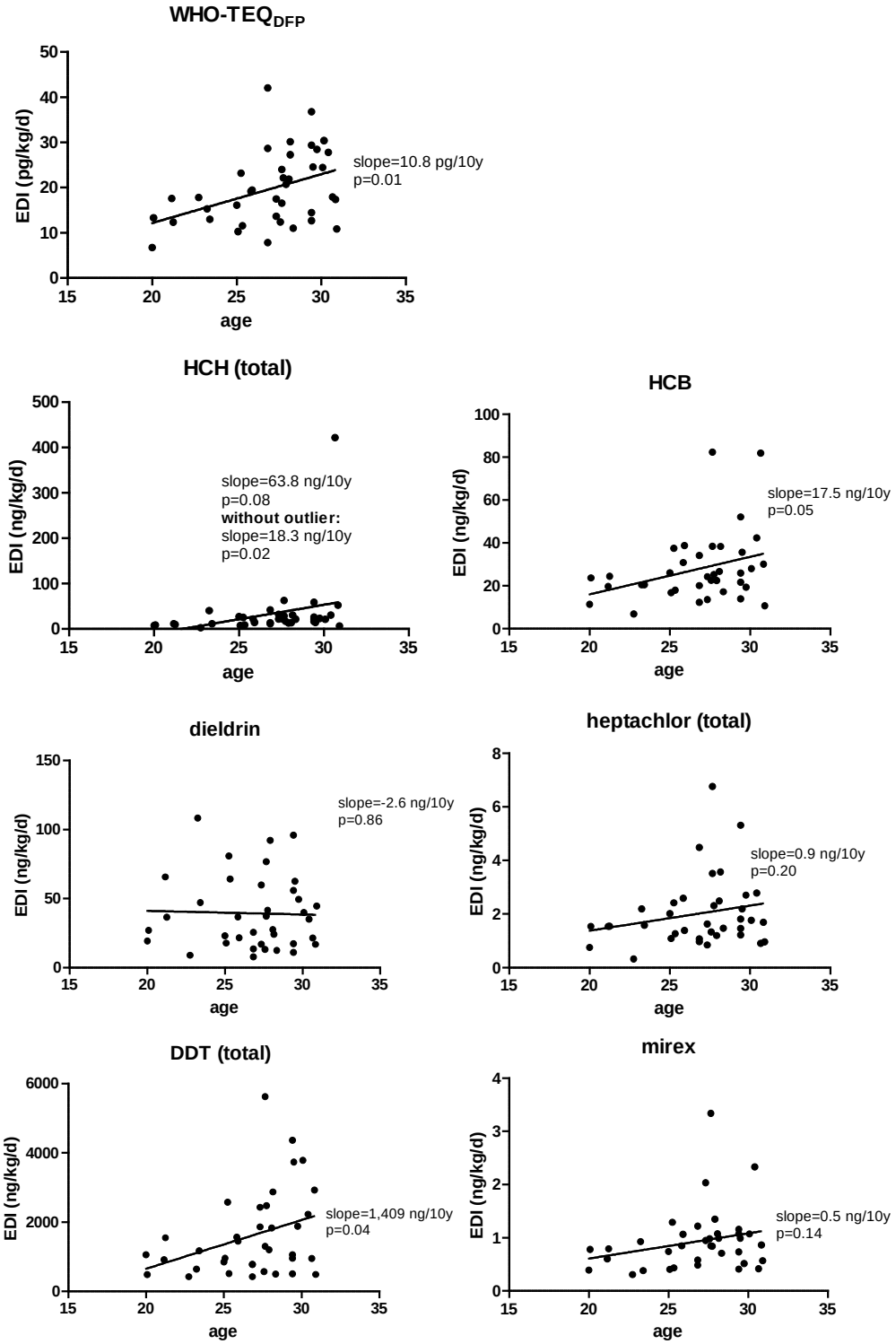
Table 2. Estimated daily intakes (EDI) through breast milk of POPs reported for different countries over the last 10 years

Compound	Location	Year sample collected	Mean EDI	Reference
PCDD/Fs and PCBs			**(pg/kg/day)**	
WHO-TEQ_{DFP}	New Zealand	2007–2010	19.7	this study
	12 provinces, China	2007	14.2–48.6	22
	Shenzhen, China	2007	48.2	23
	Turkey	2007	37.1–70.0	24
	Spain	2004	49.6	25
	Belgium	2000–2001	103	26
	Norway	2000–2001	68	27
	Germany	2000–2002	131	28
	Czech Republic	1999–2000	117–271	29
Organochlorine pesticides			**(ng/kg/day)**	
HCH (total)	New Zealand	2007–2010	32.9	this study
	China	2007	420–2,960	30
	Egypt	2001	192	31
	Poland	2000–2001	65	32
	Vietnam	2000–2001	60–170	33
	Czech Republic	1999–2000	110	34
HCB	New Zealand	2007–2010	37.9	this study
	Beijing, China	2009–2011	200	35
	Shanghai, China	2006–2010	100	36
	China	2007	10–340	30
	Egypt	2001	47	31
	Poland	2000–2001	86	32
	Vietnam	2000–2001	10	33
	Czech Republic	1999–2001	910	34
dieldrin	New Zealand	2007–2010	39.4	this study
	China	2007	30–100	30
heptachlor (total)	New Zealand	2007–2010	2	this study
	China	2007	20–160	30
DDT (total)	New Zealand	2007–2010	1,612	this study
	China	2007	1,100–11,370	30
	Brazil	2001–2002	3,290	37
	Egypt	2001	1,940	31
	Poland	2000–2001	3,789	32
	Vietnam	2000–2001	7,000–11,000	33
	Czech Republic	1999–2001	3,010	34
mirex	New Zealand	2007–2010	0.9	this study
	China	2007	10–60	30

As different countries only differ slightly with regards to their assumptions for volume of breast milk consumption and infant weight when calculating the EDI it is valid to compare EDIs between countries.

Table 2 indicates that for most POPs the daily intake through breast milk estimated for New Zealand is low or average by international comparison.

Figure 1. The association between age and EDI for POPs, based on the 39 participants in the 2008 New Zealand POPs breast milk survey



Comparison with a variety of countries, including European countries, was available for dioxin-like compounds (as expressed by the TEQ_{DFP}); New Zealand's EDI was among the lowest internationally. For most organochlorine pesticides the number and variety of comparison countries was more limited.

Among these countries, New Zealand's EDIs are low for HCH, heptachlor and mirex, while being low to average for HCB, dieldrin and DDT.

EDI and age of the mother—Figure 1 depicts the associations between the age of the mother and EDI for dioxin-like compounds (TEQ_{DFP}), HCH, HCB, dieldrin, heptachlor, DDT and mirex. For TEQ_{DFP} and DDT there is a strong and statistically significant positive association between the age of the mother and EDI.

Infants of 30-year-old mothers have, on average, a higher EDI of TEQ_{DFP} compared to infants of 20 year olds, a difference of 10.8 pg/kg/day, almost a doubling of EDI. Also, the EDI for DDT is strongly associated with the age of the mother: 10 year older age is associated with a higher EDI of 1,409 ng/kg/day.

Hexachlorocyclohexane and HCB have a very similar association with age, for both a 10 year older age of the mother is associated with 18 ng/kg/day higher EDI.

Heptachlor and mirex were only weakly associated with age, while the EDI for dieldrin was not associated with the age of the mother, within the age range of this study.

Discussion

This is the first study to estimate the daily intake of common chlorinated POPs through breast milk for New Zealand infants. It shows that New Zealand infants' estimated daily intake of dioxin-like compounds through breast milk is among the lowest world-wide and that EDIs are also low for the organochlorine pesticides HCH, heptachlor and mirex, while being low to mid-range for HCB, dieldrin and DDT.

This study also showed that breast milk concentrations of POPs have dramatically declined, and currently are 5 times lower than 25 years ago. This indicates that international efforts to reduce environmental contamination by POPs continue to have a positive impact on current and future generations.

A large number of studies that have compared health effects in breast fed children with those of formula fed children, have consistently reported a number of better health outcomes in breast-fed children compared to formula-fed children.[4] Considering that formula contains significantly lower levels of POPs,[38,39] this indicates that any negative effects possibly associated with POPs contamination are largely out-weighed by the positive effects of breast feeding.

Studies into the health effects of low dose POPs exposure in infancy are limited, and the strongest evidence of negative effects of early life exposure to POPs stems from highly-exposed populations. For example, health effects in children from mothers exposed to PCBs and PCDFs are evident from studies in the Yucheng cohort of Taiwan, who were highly exposed to these chemicals from ingesting contaminated rice oil in 1978–1979.[3]

Children from exposed mothers experienced long-lasting cognitive, behavioural, dermatological, immunological and endocrine effects, and effects on tooth and sexual development.[3] Prenatal exposure was reported to be associated with the health effects, but for some developmental effects the duration of breast feeding was also associated, indicating an additional role for postnatal exposure through breast milk.

More recent studies in populations exposed to much lower background levels of PCBs and dioxins have also reported health effects. Perinatal and/or postnatal exposure to POPs including pesticides, PCBs and PCDD/Fs, has been associated with significantly decreased infants' serum levels of thyroid hormones.[8]

Mothers with higher serum concentrations of PCBs have also been reported to give birth to neonates having smaller indices of thymus size at birth, suggestive of an effect on early immune development.[40] Neurotoxic effects of exposure to POPs (including PCBs, DDT and HCB) on infants have been reported repeatedly,[41-43] but have been suggested to be mainly attributable to prenatal exposure and not breast feeding.[10]

In utero as well as lactational exposure of children to relatively low dioxin doses has also been reported to permanently reduce sperm quality.[44] Several studies thus suggest that early life exposure to POPs, even at relatively low background levels, can be associated with a range of health effects, but the significance of both levels and the timing of exposure with respect to adverse health outcomes [45] remains uncertain. These studies nonetheless illustrate the importance of limiting early life exposure to POPs, both prenatal and postnatal, through limiting mothers' body burdens of POPs.

Although a significant reduction in breast milk contamination of POPs has been achieved and New Zealand's EDIs are relatively low internationally, EDIs of New Zealand infants continue to exceed the TDI, particularly for dioxin-like compounds and DDT. This needs to be interpreted in the light of the limitations of TDIs. TDIs are usually assessed based on animal experiments and limited human data, and their relevance to human health outcomes is not certain.[21]

The doses considered to be safe vary among regulatory agencies, further illustrating the uncertainties around TDIs. In addition, TDIs are determined for chronic exposure over a lifetime, while exposure through breast milk usually continues for less than 1 year.[46] During this period breast-fed infants accumulate higher body burdens of POPs compared to formula-fed infants,[38] but over time differences in body burden between breast fed and formula fed children diminish.[47,48,49] For example, relatively high EDIs of the dioxin 2,3,7,8-tetrachlorodibenzodioxin (TCDD) associated with breast feeding may not lead to high body burdens in later life, due to the short half-life of TCDD in infants which is estimated to be only 5–6 months, much shorter than the 7–11 years estimated for adults.[50]

The short half-life for POPs in young children is thought to be due to a combination of factors, including the effect of dilution from the rapid growth of the adipose mass, a faster rate of faecal lipid excretion, and increased metabolism.[50] Although the first year of life may represent a particularly vulnerable period in child development, TDIs set specifically for exposures in infants are not available.

This study also showed that a 10 year higher age of the mother is associated with an almost doubled EDI of the infant. The relatively narrow age range (20–30 years) is

therefore a limitation of this study, as the EDI for children of mothers older than 30 are likely to be higher than those presented here.

This age effect is however largely related to the birth year of the mother, rather than age itself, with women born in earlier years (and therefore older at time of sample collection) having been exposed to higher levels of POPs through diet and the environment than those born in later years when many measures had taken effect, as also illustrated by the time trend determined from the three breast milk surveys conducted to date.[13]

Another limitation of this study is that it only included primiparae mothers, which is likely to over-estimate the EDI resulting from breast milk of multiparea women. It has been estimated that over 6 months of breast feeding, women can lose 5%[49] or even up to 25% [51] of their PCB body burden.

Second and later order children will thus have lower prenatal exposure as well as lower postnatal exposure through breast milk, due to their mothers' lower body burden after having breast fed previous children.

A study from Germany reported that PCDD/F concentrations at 1 year of life were about half as high in the second infant as in the first one at the same age,[17] a pattern also seen for HCH, HCB and DDT.[52] It should also be noted that this study deliberately excluded women who could be occupationally exposed to POPs and it is therefore likely that EDIs may be significantly higher for some.

Higher POPs body burdens have been associated with consumption of foods from animal origin such as fish, milk, dairy products and meat.[53] As all mothers in this study consumed animal products, the effect of other dietary habits on EDIs could not be determined.

The here presented results did not include more recently introduced POPs such as the brominated and perfluorinated POPs, for which time trends of breast milk concentrations have not yet been determined in New Zealand.

We recently reported on EDIs for polybrominated diphenyl ethers (PBDEs) commonly used as flame retardants based on the same breast milk samples,[54] indicating they are currently below U.S. EPA reference dose values.

For the perfluorinated POPs, including for example perfluorooctane sulfonate (PFOS), currently no data are available on New Zealand breast milk concentrations. Further studies are needed to estimate EDIs and time trends in breast milk concentrations for these compounds.

In conclusion, the estimated daily intake of dioxin-like compounds through breast milk for New Zealand infants is among the lowest reported world-wide, and the estimated daily intakes for organochlorine pesticides are in the low or mid-range.

Future studies will show whether the notable decline in breast milk concentrations of chlorinated POPs is continuing and what the EDIs are for more recently introduced POPs.

Breast milk remains the best source of nutrition for babies, and on-going measures to assess and reduce POPs contaminants in the environment are therefore needed to protect breast milk as the first food source for infants.

Competing interests: Nil.

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