

Identifying and managing adverse environmental health effects:

5. Persistent organic pollutants

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Abstract

CONCERN AND AWARENESS IS GROWING about the health effects of exposures to environmental contaminants, including those found in food. Most primary care physicians lack knowledge and training in the clinical recognition and management of the health effects of environmental exposures. We have found that the use of a simple history-taking tool — the CH²OPD² mnemonic (Community, Home, Hobbies, Occupation, Personal habits, Diet and Drugs) — can help physicians identify patients at risk of such health effects. We present an illustrative case of a mother who is concerned about eating fish and wild game because her 7-year-old son has been found to have learning difficulties and she is planning another pregnancy. Potential exposures to persistent organic pollutants (POPs) and mercury are considered. The neurodevelopmental effects of POPs on the fetus are reviewed. We provide advice to limit a patient's exposure to these contaminants and discuss the relevance of these exposures to the learning difficulties of the 7-year-old child and to the planning of future pregnancies.

Case

A 27-year-old woman who lives in a town on the shore of Lake Huron wants to have a second child but has concerns. Her 7-year-old son is being assessed by the school psychologist for a learning disorder. She tells her family physician that she saw something on television about contaminants in fish affecting children's intelligence. She is worried that her diet may have caused her son's learning disorder and wants advice on how to protect her second child against environmental contaminants that may cause learning problems. Her past medical history is unremarkable. She is taking no medications other than folate (0.4 mg/d). She has had only the one pregnancy. Her pregnancy and delivery of her son were uncomplicated, and the boy met the developmental milestones. The concern about a learning disorder is recent. There is no family history of congenital anomalies, early deafness or twins. Her maternal grandmother had type 2 diabetes, and her father-in-law has hypertension; the rest of the family is healthy. Because the woman is worried about environmental exposures, you take an exposure history using the CH²OPD² mnemonic (Community, Home, Hobbies, Occupation, Personal habits, Diet and Drugs)¹ to identify possible sources of environmental contaminants (Table 1).

The environmental contaminants that can affect the neurobehavioural development of the fetus include metals (lead, mercury and manganese), nicotine, pesticides (e.g., organophosphates), dioxins, polychlorinated biphenyls (PCBs) and solvents (e.g., alcohol).^{2,3} In this article we focus on persistent organic pollutants (POPs) and mercury. These are the contaminants identified in the environmental exposure history of the case subject (Table 1). Although lead exposure was also noted in the exposure history (through renovating an 80-year-old home), it is discussed in an earlier article in this series.⁴

Review

Synthèse

From the Departments of
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Medicine and †Public Health
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POPs are carbon-containing chemicals that share several properties. They are lipophilic, accumulating in the fat of living organisms, and increase in quantity up the food chain. Most are semivolatile, which means that they can travel in the air thousands of miles from their source before they settle. They resist photolytic, biological and chemical degradation and persist in the environment, taking as long as a century to degrade.⁵ Twelve POPs, including 9 pesticides, have been identified by the United Nations Environment Programme as powerful threats to the health of humans and wildlife and have been targeted for elimination (Table 2).⁶ In the 1970s many countries banned or severely restricted the use of the 9 pesticides and PCBs and implemented pollution control strategies to reduce the amount of dioxin and furan released in the environment. However, it is thought that all 9 pesticides and PCBs are still used in many countries today.

Despite significant achievements in reducing the production and use of POPs, these pollutants remain ubiquitous, as evident by the global distribution of PCBs and organochlorine pesticides in butter samples from around the world.⁷ Most human exposure comes from dietary sources. POPs are ingested, stored in fatty tissue and excreted in feces and breast milk. The concentration of certain chemical contaminants in breast milk serves as an indicator of population exposure. From 1967 to 1992, there was a downward trend in the concentrations of organochlo-

rine pesticides and PCB hydrocarbons in samples of Canadian breast milk during the phase-out of these chemicals.⁸ The estimated daily intake of PCBs from the current diet of the average Canadian is less than 1 µg/d.⁹

Although everyone is exposed to a background level of POPs, certain people may have higher levels of POPs exposure because of their eating habits. Some people eat more fish than the general population. Southeast Asian Canadians, Native Americans, sport anglers and hunters who regularly eat large amounts of Great Lakes fatty fish or wildlife from the top of the food chain, such as waterfowl and waterfowl eggs, turtles and turtle eggs, muskrat, otter, moose and deer, may be at risk of high exposure.¹⁰ Northern Aboriginals, such as the Inuit of Nunavik, who consume the fat of seals and beluga and narwhal whales, have been found to have higher body burdens of POPs.^{11,12}

Health effects

Persistent organic pollutants

Concerns about the health effects of exposure to POPs arose initially from studies of wildlife communities that showed reproductive, developmental, endocrine, immunologic and carcinogenic effects.¹³⁻¹⁵ The wildlife in these communities had high rates of malformed genitalia, aberrant mating behaviour, sterility, cancer, and immune system and thyroid dysfunction. Toxicological and laboratory studies largely confirmed the links between POPs exposure and effects observed in these studies. There is growing evidence that some POPs act as endocrine disrupters, mimicking hormones by binding to or blocking hormone receptors.¹⁶⁻¹⁹

Neurodevelopmental, hematological, immunologic and reproductive effects have been found in animals at levels of exposure that overlap the range of exposures and body burdens found in humans.¹⁴ The health effects of POPs in humans is unclear, although available epidemiological evidence suggests they are similar to those in animals, affecting neurodevelopment,²⁰⁻²² and thyroid,²³ estrogen¹⁹ and immune function.¹⁵ The developing brain and nervous system may be most vulnerable. According to a landmark longitudinal study, babies whose mothers ate large amounts of highly contaminated fish (PCBs were measured) from Lake Michigan had lower birth weights, smaller head circumferences and shorter attention spans than babies whose mothers did not eat fish.^{24,25} Followed over 11 years, the exposed children have continued to do more poorly in a range of skills and development tests, including deficits in general intellectual functioning, short- and long-term memory, and attention span.²⁶

A systematic review²¹ of the literature on the relation between neurological development in children and prenatal exposure to PCBs identified 7 studies, 2 of which evaluated children with high exposures. Abnormal reflexes were reported in all 4 studies that evaluated reflexes; delayed motor skills were identified in the first months of life among

Table 1: Environmental exposure history of case subject using the CH²OPD² mnemonic¹

Community	The patient lives in a small town (population 5000) on the shore of Lake Huron. The main industries are tourism, cattle and dairy farming, and fishing. The town's municipal water supply is drawn from the lake. There are occasionally summer smog advisories for the area. The patient knows of no polluting industries in the area.
Home	The family moved to a new home last year. Their previous house was 80 years old and under constant renovation. Like the old house, the new home is supplied by municipal water. There is a gas stove and forced-air heating.
Hobbies	The patient gardens and knits. Her husband is an avid sport fisherman and hunter.
Occupation	The patient is a kindergarten teacher and works weekends in her husband's hardware store.
Personal habits	Neither she nor her husband smokes. She admits to feeling worried about her 7-year-old son's learning disability but does not report any symptoms of depression or anxiety.
Diet	The family consumes sport fish and wild game about twice a week during the summer and fall; otherwise they buy their food at the supermarket and eat a basic "meat and potatoes" diet. The patient has an occasional beer; her husband drinks 2-3 beers daily.
Drugs	The patient is not taking any medication except for folate (0.4 mg/d).

children in 4 of 5 studies that evaluated this area of development; and cognitive development was found to be affected in children at 4 years of age in 4 of 5 studies that looked at this aspect of development. The reviewers concluded that these studies suggested a subtle adverse effect of prenatal PCB exposure on child neurodevelopment. Because of limitations such as differences in study design, inconsistency in some results, a lack of comparable end points and the lack of adequate quantitative exposure data, the reviewers could not associate degree of risk with levels of exposure. Also, it is unclear to what extent postnatal exposure contributed to the children's outcomes, although the reviewers concluded that postnatal exposure to PCBs through breast-feeding was not clearly related to any effect on neurological development. This finding is consistent with the general recommendation that women should breast-feed even if they have chemical residues in their breast milk.²⁷

Our understanding of the adverse health effects of exposure to POPs is limited by available research methods and measures of exposure and outcome. Methods of epidemiological studies to measure exposure may not be precise or

valid.²⁸ For example, contaminated fish contain a large number of putative neurotoxicants (methyl mercury, PCBs and pesticides), so it may not be possible to determine which contaminants might be responsible. PCB body burdens may simply reflect exposure to other fish-borne contaminants.²⁹ A battery of tests have been developed to assess neurodevelopment and function, yet sensitive outcome measures for assessing neurobehavioural development in children relative to normative standards across a wide range of exposure levels are not currently available.^{30,31} Moreover, the nervous system develops in specific phases or stages, making it differentially vulnerable to chemical exposure. The conditions under which children are differentially sensitive are not well understood, although the weight of evidence suggests that exposure in utero has both transient and lasting effects.^{21,26,29}

Methyl mercury

Mercury exists naturally in the environment, but levels have risen because of discharge from hydroelectric, mining, pulp and paper industries, incineration of municipal and

Table 2: Environmental and dietary sources of persistent organic pollutants (the "dirty dozen")

Type	Environmental sources	Examples of dietary sources
Dioxins, furans	Byproducts of petrochemical industry and chlorine bleaching in pulp and paper mills; hospital and municipal incinerators	Meat, poultry and dairy products, sport fish (e.g., lake trout, salmon, walleye), wildlife (e.g., waterfowl and waterfowl eggs, muskrat, otter, moose, deer)
PCBs	"Fire resistant" synthetic products made before 1977, old electrical equipment, leaky containers in PCB disposal sites	Great Lakes fish (e.g., lake trout, salmon), Arctic marine mammals, breast milk
Aldrin	Pesticide used against insects in the soil, to protect crops such as corn and potatoes	Dairy products, meat, fish, oils and fats, potatoes, root vegetables
Chlordane	Broad-spectrum contact insecticide used on vegetables, grains, maize, oilseed, potatoes, sugar cane, beets, fruits, nuts, cotton and jute	Use has been severely restricted, so food does not appear to be a major pathway of exposure; air may be a pathway because of continued use in termite control (in the United States)
DDT	Pesticide widely used during World War II to protect soldiers and civilians against diseases spread by insects	Fish, dairy products, fat of cattle, hogs, poultry and sheep, eggs, vegetables
Dieldrin	Insecticide used to control insects in soil	Same as for aldrin
Endrin	Foliar (leaf) insecticide used on field crops such as cotton	Current dietary exposure thought to be minimal because of restricted use
Heptachlor	Nonsystemic stomach and contact insecticide used to control insects in soil	Detected in the blood of US and Australian cattle in 1990; current dietary exposure thought to be minimal because of restricted use
HCB	Fungicide used for seed treatment	HCB-treated grain; current dietary exposure thought to be very low because of severely restricted use
Mirex	Stomach insecticide used to control ants, termites and mealy bugs	Meat, fish, wild game, marine bird eggs, sea mammals
Toxaphene	Contact insecticide used primarily on cotton, cereal, grains, fruits, nuts and vegetables and used to control tick and mites in livestock	Dietary exposure thought to be very low because of restricted use; however, there is a local problem with some fish in Lake Superior

Note: PCBs = polychlorinated biphenyls, DDT = dichlorodiphenyltrichloroethane, HCB = hexachlorobenzene.

Source: Contaminant profiles. In: *Health and the environment. The health and environment handbook for health professionals*. Ottawa: Health Canada; 1998. Cat no H46-2/98-2111. Available: www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/98ehd211/98ehd211.htm

medical waste, and from power plants, especially those using coal.³² Microbes in soils and in river and lake sediments convert elemental mercury into organic methyl mercury, which is more bioavailable. Methyl mercury concentrations increase in food chains, being highest in fish species at the top of the food chain, such as pike, walleye and bass in freshwater, and tuna, swordfish and shark in sea water.³³ When ingested, almost all of the methyl mercury is absorbed. The half-life is about 44 days. Most methyl mercury is converted in inorganic mercury and excreted in feces.

There is good evidence in animal studies that exposure to methyl mercury in utero has neurotoxic effects.¹⁴ There is also good evidence that high-dose exposure to methyl mercury in utero in humans is neurotoxic. In the 1950s, in Minimata Bay, Japan, 1422 infants who appeared healthy at birth were later found to have mental retardation, disturbances of gait, speech, sucking and swallowing, and abnormal reflexes. Mercury was discovered to have been discharged into the bay from a factory. Mothers, who were asymptomatic, were exposed to high doses of methyl mercury by eating fish from the bay, and their babies were exposed in utero.³⁴ However, the human epidemiologic studies related to low-level methyl mercury exposure in utero remain controversial with respect to a threshold for significant effects. Lower level exposures from maternal consumption of fish have not been consistently associated with adverse neurodevelopmental outcomes in children.^{35,36}

Clinical management

Environmental exposure to low levels of POPs and mercury is ubiquitous. The clinical challenge lies in identifying which patients are exposed to higher than average levels of these substances and who might reduce their exposure by changing their diet and lifestyle habits. Use of the CHOPD² mnemonic¹ when taking an environmental exposure history can help physicians direct questions about possible exposures from the patient's community, home, hobbies, occupation, personal habits, drugs and diet. Specific questions pertaining to the patient's hobbies (e.g., Do you hunt game?), diet (e.g., Do you eat sport fish?) and personal history (e.g., Have you lived in the Arctic or on a native reserve?) can be used to identify patients with possibly high exposures to POPs and mercury.

The environmental exposure history of the case subject (Table 1) identifies some exposure for both the mother and her son to POPs such as PCBs and dioxin-like compounds and to mercury through the consumption of sport fish and wild game. Information on mercury and PCB levels in Lake Huron fish can be found in the *Guide to Eating Ontario Sport Fish*.³⁷ Most provinces issue similar guides. The possible exposure to lead from lead-based paint (mobilized during renovations), contaminated soil and lead shot in game meat should be investigated by measuring blood lead levels in both the mother and the son (see the article on lead exposure in this series⁴).

Testing the mother's hair or blood for mercury levels may be indicated if she had consumed fish with high mercury levels³⁷ just before or during her pregnancy with her son. Laboratory tests to measure in vivo levels of PCBs and organochlorine pesticides are available, but they are quite expensive and not widely used. Testing the current PCB and pesticide levels in the son is not indicated or relevant, because the evidence indicates that the neurodevelopmental effects related to PCBs are the result of in utero exposure.

The mother should be informed about the available scientific evidence and about the uncertainties. Existing scientific evidence of ecological correlations observed in populations between loss of intellectual potential and exposure to specific PCBs cannot be extrapolated to individual cases. Of public health concern is the average shift in the distribution curve of intellectual capacity in the population as a whole.^{31,14} It is unlikely that the in utero exposure of the woman's son to PCBs and mercury from the mother's consumption of Great Lakes fish would have been large enough to produce clinically significant neurodevelopmental effects on its own. The effect, if any, would instead have been a subtle reduction in the son's learning potential. The onset of learning difficulties at age 7 suggests the involvement of other factors. A full case assessment should address other determinants of child development, including psychosocial, biological, genetic and nutritional.

Whether the patient should delay her second pregnancy should be discussed with the physician. A waiting period would not significantly reduce her PCB or dioxin body burdens, because of their persistence. She should be advised to follow the latest edition of the *Guide to Eating Ontario Sport Fish*.³⁷ She should also reduce or avoid consumption of other wildlife, which can be contaminated with organochlorines, methyl mercury or lead from lead shot. However, waiting 3 to 6 months would significantly reduce her mercury body burden if further exposure is avoided, and therefore reduce the exposure of her fetus to mercury.

Prevention

The risks of eating contaminated fish must be balanced against the benefits. The health policy message is that most fish are highly nutritious and safe to eat.¹⁰ Fish are high in protein and unsaturated fatty acids. Women of child-bearing age and parents with young children should be advised to obtain a copy of their province's guide to eating sport fish.^{37,38} Mercury levels in fish are site-specific. Lake trout and salmon are the primary species with high concentrations of PCBs.

The tables in the Ontario guide to eating sport fish give size-specific consumption advice for each species of fish tested from many locations.³⁷ This advice is based on health protection guidelines developed by Health Canada.³⁹ The use of cleaning and cooking methods that can substantially reduce the exposure to fat-soluble contaminants in a fish

meal should be used.^{10,37} Store-bought fish are routinely tested for contaminants to ensure that they meet Canadian standards. Health Canada recommends that women of child-bearing age and children should not consume more than 1 or 2 meals of shark, swordfish or fresh tuna (not canned tuna) per month, because these fish are known to contain higher levels of mercury.⁴⁰ This exposure would be additive to potential mercury exposure from freshwater fish. US data indicate that people who are most at risk, especially women and minority groups, are the least informed about existing fish advisories.^{14,41} Physicians can play an important role in relaying information from advisories to their patients.

The long-term solution lies in pollution prevention and the virtual elimination of POPs and mercury from industrial processes. Although the actual burden of illness related to POPs is unknown, the weight of evidence from laboratory, animal and human epidemiological studies clearly indicates that there may be some impairment of children's intellectual function because of these exposures. The precautionary principle instructs us to take any reasonable measures that would prevent this harm. These measures will require changes to industrial processes and methods of waste incineration and power generation to virtually eliminate the release of these pollutants. Already contaminated sites and sediments need to be cleaned up.

Physicians may be interested in the work of the Canadian Association of Physicians for the Environment (www.cape.ca). This group is part of the Canadian Coalition for Green Health Care. The comparable group in the United States is Health Care Without Harm (www.hcwh.org). These groups are working to eliminate the use of mercury in the health care system and to bring in substitutes for products made from polyvinyl chloride, which generate dioxins when incinerated. In 1996 the Intergovernmental Forum on Chemical Safety agreed on a list of 12 POPs for virtual elimination from the environment. The Binding Convention on Persistent Organic Pollutants, sponsored by the United Nations Environment Programme, was formally adopted and signed in Stockholm in May 2001.⁴² It called for an immediate ban on 11 of the "dirty dozen"; a health-related exemption has been granted for DDT (dichlorodiphenyltrichloroethane), which is still needed in many countries to control malaria-transmitting mosquitoes.

[A detailed exposure history questionnaire is available on the Ontario College of Family Physicians Web site (www.cfpc.ca/ocfp/index.html) — click on "Exposure History Sheets in MS Word" in the scrolling menu located in the middle of the page). The different components (Community, Home and Hobbies, Occupation, Personal habits, Diet and Drugs) can be printed on coloured paper for easy identification in patient charts. The questionnaire may be given to a patient to complete at home and bring to the next appointment for review and interpretation.]

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Additional resources

- Information on endocrine disrupters: www.som.tulane.edu/ecme/eehome and www.ourstolenfuture.org
- *In harms way. Toxic threats to child development*: www.igc.org/psr/iwh.htm
- International Programme on Chemical Safety: www.who.int/pcs
- National Fish and Wildlife Contamination Program, Office of Water, US Environmental Protection Agency: www.epa.gov/ost/fish
- United Nations Environment Programme: www.chem.unep.ch/pops/default.html

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