

# Maternal Levels of Xenobiotics that Affect Fetal Development and Childhood Health

Walter J. Crinnion, ND

## Abstract

Children are not only being born into a chemically toxic world, they are exposed to these toxins throughout their gestational development. They are exposed to hundreds of toxic compounds via cord blood and release many of them in the meconium. These toxins include numerous neuro-, immuno-, and endocrine-toxic compounds present during the critical stages of hormonal, immunological, and neurological development. Outcome studies have shown that animal and human offspring who are so exposed can not only be born with birth defects, but suffer from lifelong health and behavior problems. This article discusses the effect of xenobiotics on fetal and child health, essential information for any health care provider working with women of childbearing age. Recommendations for maternal testing and dietary changes to avoid the greatest sources of exposure are also included. (*Altern Med Rev* 2009;14(3):212-222)

## Introduction

The use of thalidomide from 1957 to 1961 for the treatment of multiple myeloma and as a sedative resulted in a number of babies born without limbs. A decade later an observant clinician noted that young women born to mothers who had taken diethylstilbestrol (DES) while they were *in utero* developed clear cell carcinoma of the vagina. While thalidomide caused birth defects when the children were exposed *in utero*, DES led to health problems that did not show up in the offspring for a couple of decades. These two drugs, with different adverse health effects on the child, set the stage for the recognition that chemicals can seriously affect health and dramatically impact the quality of life of children.

The concept that environmental toxins (other than prescribed medications) could impact the health of the next generation, rather than the generation directly exposed, was brought into focus by the groundbreaking work of Theo Colburn, PhD. When Colburn studied the effect of Great Lakes pollution on local wildlife, she made the startling discovery that reproductive problems caused by environmental pollution were found in the offspring of the exposed animal, not the exposed adult. She also found the animals were not dying from cancers as she expected. Instead, their demise was due to a variety of endocrine problems that seemed to be magnified in animals higher up the food chain. In fact, of the fourteen species studied, all of which were in population decline, the two most commonly found problems were wasting and reproductive effects in the next generation (11/14 each).<sup>1</sup>

Contrary to the previously held belief that the placenta protects the fetus from toxic compounds in the mother's blood, it is now known that xenobiotics readily cross through the placenta and flow into the fetus.<sup>2</sup> The developing fetus is exposed to the chemicals, persistent pollutants, and those with a limited half-life, that are in the mother's bloodstream. Many of these compounds are potent toxins to the immune, neurological, and endocrine systems, which are going through critical developmental milestones in the fetus.

---

Walter Crinnion, ND – 1982 graduate of Bastyr University; private practice since 1982 with a special focus on treating chronic diseases caused by environmental toxic burden; conducts post-graduate seminars in environmental medicine; Professor and Chair of Environmental Medicine, Southwest College of Naturopathic Medicine.  
E-mail: [w.crinnion@scnm.edu](mailto:w.crinnion@scnm.edu)

Table 1. Xenobiotics Found in Cord Blood

Compound	Number of Compounds Tested	Number of Compounds Found	How Used/Where Found
Heavy metal mercury	1	1	Dental amalgams; present in seafood
Polycyclic aromatic hydrocarbons (PAH)	18	9	Combustion by-product (from tailpipes and cigarettes)
Polybrominated dioxins and furans (PBDD/F)	12	7	Contaminants of brominated fire retardants
Polychlorinated dioxins and furans (PCDD/F)	17	11	By-products of plastic production (PVC), industrial bleaching, and incineration
Perfluorinated chemicals (PFCs)	12	9	Teflon, Scotchgard, fabric and carpet protectors, food wrap coatings
Chlorinated pesticides	28	21	Most are now banned for use; found in farmed salmon and other fat-containing foods
Polybrominated diphenyl ethers (PBDE)	46	32	Flame retardants; high in farmed salmon
Polychlorinated naphthalenes	70	50	Wood preservatives, varnishes
Polychlorinated biphenyls (PCBs)	209	147	Used as lubricants and insulation; a worldwide ban on production and use; high in farmed salmon.

Measurement of xenobiotics in cord blood of newborns is one method for determining the toxic exposure of the fetus during the time spent *in utero*. One of the most comprehensive measurements of cord blood was conducted by the Environmental Working Group (EWG).<sup>3</sup> The EWG assessed the cord blood of 10 babies born in U.S. hospitals for the presence of 413 toxic compounds and found a total of 287 to be present. Of these toxins, the babies had an average of 200 in their cord blood. This begs the question, of course, "What effect, if any, do these compounds have on the child?" Table 1 outlines the compounds looked for in the cord blood samples and how many were found.

The vast majority of the compounds listed in Table 1 are fat-soluble and bioaccumulative (with the exception of polycyclic aromatic hydrocarbons). These lipophilic compounds are not present in the

blood as free-floating chemicals, but are carried by serum lipids. Since cord blood is known to contain a smaller percentage of lipids than adult blood, the sampling of toxins in cord blood may not reveal the total burden.<sup>4</sup>

A review of studies on the level of certain xenobiotic compounds in meconium samples reveals a large number of compounds also present in the child's first bowel movement.<sup>5</sup> These compounds include pharmaceutical agents, illegal drugs, heavy metals, and pesticides (Table 2).

The meconium studies picked up organophosphate pesticides that were not looked for in the EWG cord blood study. Organophosphate pesticides and pyrethroid pesticides are the most commonly used insecticidal agents. They are water-soluble and do not have the biological persistence found in their chlorinated

Table 2. Xenobiotics Found in Meconium

Pharmaceuticals	Drugs of Abuse	Heavy Metals	Pesticides & PCBs
Anesthetics	Cocaine	Lead	Arochlor (PCB)
Analgesics	Opiates	Cadmium	Chlordane
Antihistamines	Cannabinoids	Mercury	Chlorpyrifos
Adrenergics	Morphine		Organophosphate metabolites
Expectorants	Methadone		DDT
Antidepressants	Stimulants		Lindane
Anticonvulsants	Cotinine (nicotine)		Malathion
			Parathion

predecessors. So these compounds, and others present in the environment that have a short half-life in the bloodstream, represent a portion of the toxic load on adults and fetuses and should not be overlooked.

### Adverse Birth Outcomes

Some of the problems caused by *in utero* toxin exposure are clearly visible at birth, while others do not show up until later in life. A number of compounds have been positively and significantly associated with low birth weight, short length, and small head circumference. Included in the list of toxins affecting infant growth are the chlorinated pesticide metabolite dichlorodiphenyldichloroethylene (DDE), organophosphate pesticides, and the polycyclic aromatic hydrocarbons (PAHs).

PAHs are by-products of combustion and are emitted from cigarettes, tailpipes, factory smokestacks, jet engines, barbecue grills, volcanoes, and forest fires. For decades it has been known that maternal cigarette smoking is associated with the delivery of small-for-gestational-age babies.<sup>6</sup> Sufficient studies have been done to quantify the fetal weight reduction due to maternal smoking to 30-40 g. In addition, common urban outdoor air pollution, another source of PAH exposure, has been associated with smaller infants.<sup>7,8</sup>

*In utero* exposure to the organophosphate pesticide chlorpyrifos is also associated with reduced birth weight, length, and head circumference.<sup>9</sup> Although chlorpyrifos has been banned for use in the United States, many other organophosphate pesticides are still being used. The metabolite of organophosphate pesticides is cleared from the bloodstream by the phase 2

enzyme paraoxonase (PON), which has been shown to be polymorphic. Mothers who have a PON polymorphism, leading to reduced blood clearance of organophosphates, are much more likely to give birth to smaller children.<sup>10</sup> This same study also revealed that DDE presence is associated with smaller birth weight and head

circumference. Presence of the herbicide atrazine in the municipal drinking water supply has also been positively associated with smaller babies and preterm delivery.<sup>11</sup>

In addition to causing *in utero* growth restriction, chlorpyrifos has been linked to severe birth defects. A review of four cases revealed that *in utero* exposure to this organophosphate pesticide was associated with defects of the brain, eyes, ears, palate, teeth, heart, feet, nipples, and genitalia.<sup>12</sup> Brain defects were present in the ventricles, corpus callosum, choroid plexus, and septum pellucidum. Genital defects were present in both males and females in the form of undescended testes, microphallus, and fused labia. Three of the four children also exhibited severe mental retardation. The publication of this association persuaded the U.S. Environmental Protection Agency to ban this chemical from agricultural and residential use.

A number of cases of anencephaly and hydrocephaly have also been reported in children exposed to organic solvents *in utero*.<sup>13</sup> Organic solvents have been linked to the formation of cleft-palate.<sup>14</sup> Other defects in the renal-urinary system and gastrointestinal systems have been associated with maternal exposure to toluene, a commonly used solvent.<sup>15</sup>

### Adverse Effects on Immune Development and Function

The impact of ubiquitous xenobiotics on the developing immune system is similar to environmentally burdened adults. Some xenobiotic compounds, including lead, have been found to shift the fetal immune system to greater T-helper 2 (Th2) dominance,

**Table 3. Gestational Development of the Immune System**

Area of Immune Development	Approximate Gestational Time Period	Trimester
Macrophage differentiation and seeding	Weeks 4-24	1-2
Thymus seeding with pro-T cells	Weeks 6-12	1
B-cell production begins in the liver	Weeks 7-8	1
IgE production in the liver	Weeks 8-12	1
IgE production in spleen and lung	Weeks 10-22	1-2
Thymus cortex formation	Weeks 10-12	1
Bone marrow lymphopoiesis begins	Weeks 12- 14	1
Thymus medulla fully formed	Weeks 14-16	2
T-cell clonal expansion	Weeks 12-28	1-2
IgM production	Weeks 18-38	2-3
Allergen and microbial specific antibody response	Weeks 24-birth	2-3
Development of Th1 capacity	Weeks 37-birth	3

Adapted from: Hertz-Picciotto I, Park HY, Dostal M, et al. Prenatal exposures to persistent and non-persistent organic compounds and effects on immune system development. *Basic Clin Pharmacol Toxicol* 2008;102:146-154.

which appears to lead to increased asthma and allergy for the neonate and child.<sup>16,17</sup> This Th2 imbalance can also potentially lead to increased rates of autoimmunity. Perinatal exposure to dioxin in animals has already been associated with adult onset of autoimmunity.<sup>18</sup>

Not all exposures, even by the same compound, cause consistent immune problems. The key to the downstream effect on the immune system appears to be the timing of exposure. Since different parts of the immune system develop throughout the 38 weeks of gestation, the areas of potential impact will change. The major developmental events during gestation for the immune system are represented in Table 3. As can be seen, most developmental activities occur during the first trimester; thus, a toxic insult during this time could result in a wide range of childhood health problems that could persist into adulthood.

Prenatal and post-natal exposure to cigarette smoke is associated with increased rates of respiratory infection, asthma, wheezing, otitis media, and even sudden infant death syndrome.<sup>19</sup> Non-cigarette smoke PAH exposure, depending on the timing of exposure, can lead to various immune system imbalances including a reduction in T-cells, increases in B-cells, and elevation of IgE levels.<sup>20</sup>

Several animal studies have shown early exposure to polychlorinated biphenyls (PCBs) can lead to atrophy of the thymus gland.<sup>21,22</sup> Human children with fetal exposure to PCBs have a problem with more frequent and recurrent infections than children without that exposure.<sup>23</sup> The most common recurrent infections are respiratory, with cough and otitis media also found

in children with prenatal exposures to DDE.<sup>24,25</sup> Not only can infection rates be higher, but response to immunizations can be weaker. A study of Dutch children revealed gestational exposures to PCBs resulted in reduced levels of antibody formation after the measles-mumps-rubella (MMR) vaccination.<sup>22</sup>

The immune damage from exposure to xenobiotics while *in utero* is also being explored as a possible etiological factor for childhood leukemia and autism.<sup>26,27</sup>

### Adverse Effects on Neurological Development and Function

The developing brain is also a unique target for a wide range of xenobiotic compounds. In adults, fat-soluble pollutants such as chlorinated pesticides, PCBs, and solvents can easily cross the blood-brain barrier and

cause damage. In a developing neurological system the blood-brain barrier is not even developed, making the fetus even more susceptible to such neurotoxins (all pesticides kill the insect by neurotoxicity). The most commonly recognized and studied developmental neurotoxins are the heavy metals, lead and mercury. But published studies also show chlorinated and organophosphate pesticides, PCBs, and solvents impact the developing neurological system.

### Effects of Mercury

Significant research indicates that when expectant mothers consume fish or fish oil daily their offspring will have better brain function. Yet the most common source of methylmercury is the large carnivorous fish. Thus, even with the brain-enhancing value of consuming oily fish, the neurotoxic effect of methylmercury outweighs the benefit. This has been demonstrated in a study of mother-child pairs in Massachusetts. The amount of fish intake during the second trimester was recorded along with maternal RBC mercury levels. At six months of age the children who ate more fish had better brain function; for each additional serving of fish per week the child scored 4 points higher on visual recognition memory tests.<sup>28</sup> But when the child's hair mercury (a specific indicator of methylmercury exposure) was measured, it was found that for each ppm of mercury a 7.5 point reduction in visual recognition memory was demonstrated. The children dropped almost twice the number of points from mercury as they gained by fish consumption. When the children were three years old they were assessed for cognitive performance. Children born to mothers who consumed more fish had significantly better cognitive function, while those whose mothers had higher mercury values had poorer function.<sup>29</sup> Not only can methylmercury adversely affect cognition, it can also affect behavior.<sup>30</sup> Expectant mothers should carefully pick the fish they consume and avoid the most mercury-toxic varieties.

### Effects of Lead

When rats were exposed to lead prior to breeding, their offspring exhibited increasing difficulty with memory and problem-solving abilities.<sup>31</sup> When children were exposed to high levels of lead *in utero* from their mothers' bone stores they also showed reduced mental abilities at age 24 months.<sup>32</sup> As the estimated levels of

trabecular (bone) lead of the mother increased, there was a corresponding decrease in mental function as measured by the Bayley Scales of Infant Development-II. This occurred two years after delivery, demonstrating the lead exposure to the growing fetus resulted in long-term neurological impairment.

### Effects of Chlorinated Compounds

Polychlorinated biphenyls are industrial chemicals historically used as coolants or heat transfer agents in electrical transformers. They were also used in microscope immersion oils, carbonless copy paper, cutting oils, and as a pesticide inert ingredient. The use of PCBs began in the 1930s and continued until their restriction in the 1970s. Because of widespread environmental PCB spills, it is now a fairly ubiquitous environmental contaminant in ocean and fresh-water fish, butter from around the globe, and numerous other foodstuffs. Neonatal exposure of mice to PCBs results in long-term neurologic deficits. Exposed mice exhibit persistent behavior aberrations that only get worse as they age.<sup>33</sup> PCB exposure also adversely affects learning and memory function when the mice reach adulthood. PCB exposure from fish can affect intellectual functioning when children are exposed *in utero*.<sup>34</sup>

The effect of PCB contamination has been studied in different populations where it was present as a dietary contaminant. In 1979, 2,000 people became ill after exposure to PCB-contaminated rice bran cooking oil. This group developed primary symptoms of hyperpigmentation, chloracne, and peripheral neuropathy in what was termed "yu cheng" (Chinese for "oil disease"). Individuals had used the contaminated oil for as long as nine months, consuming about 1 g of PCBs and 3.8 mg of polychlorinated dibenzofurans (PCDFs). PCDFs are created when PCBs are repeatedly heated, as had occurred in this case. The first 39 children born to exposed mothers were hyperpigmented and eight of them died.<sup>35</sup> The exposed individuals and surviving offspring are now followed in a Taiwan registry.

Children born to mothers who consumed the contaminated oil have been followed for cognitive development. They were tested between ages 4-7 years and scored 5-8 IQ points lower on cognitive tests.<sup>36</sup> Reduced cognition was found in children born up to six years after the mother's exposure. These children had more behavioral and activity problems than matched

controls.<sup>37</sup> Twelve to 16 years after exposure, these children continued to show adverse cognitive effects as evidenced by reduced IQ points and increased behavior and activity difficulties.<sup>38</sup> This group showed higher urinary porphyrin levels, specifically coproporphyrins, than controls.<sup>39</sup> While elevated porphyrins can have adverse mental and emotional effects, the cognitive defects are thought to occur from the thyroxin-lowering effect that PCBs demonstrate.<sup>40</sup>

Studies examining the effect of PCBs and other persistent organic pollutants have been conducted on two U.S. populations. Children of women who consumed fish from the Great Lakes prior to giving birth were studied.<sup>41</sup> By the age of seven months, children with prenatal PCB exposure showed adverse cognitive effects using visual recognition cognitive testing. The results of the testing showed a significant inverse correlation with umbilical cord PCB levels. There was no significant association between breast milk PCB exposure and test responses. By the time the children were four years old, those with higher *in utero* PCB exposure had significantly worse short-term memory function and cognitive processing speed. By the time these children reached age 11, the children of fish eaters had lower IQ scores, poorer reading skills, memory problems, and more attention deficits.<sup>42</sup> The most alarming note was that the level of PCBs in the mothers was not much higher than published “normal background” levels.

A study population from North Carolina was also identified. Like the Great Lakes group, they also had exposure to a variety of persistent organic pollutants including PCBs and DDE. Children with *in utero* exposure showed motor abnormalities at birth.<sup>43</sup> The finding of hypotonicity and hyporeflexia was significantly associated with prenatal PCB exposure levels and hyporeflexia was associated with DDE levels. By age two years, those children with the highest *in utero* PCB exposure showed significant psychomotor delays<sup>44</sup> that were no longer identifiable when the children reached ages 5-10,<sup>45</sup> a finding that is gratifying, but not in line with other published studies. Studies from New York, Holland, Germany, and the Faroe Islands have all confirmed that *in utero* PCB exposure leads to reduced cognitive function in infancy and childhood. In fact, by the time these children are in school they typically exhibit greater impulsivity, poorer concentration, and

poorer verbal, pictorial, and auditory working memory.<sup>46</sup> An excellent review of these studies has just been published.<sup>47</sup>

Interestingly, rats exposed to PCBs while *in utero* experience reduced hearing ability.<sup>48</sup> Hearing was assessed when the rats were 200 days old; the rats exhibited permanent hearing defects of cochlear origin that were not present in control rats.

Children with gestational exposure to the chlorinated pesticides DDT and DDE also showed differences from non-exposed children. Those with higher levels of DDT/DDE exposure had poorer mental development.<sup>49</sup> Those exposed to hexachlorobenzene (HCB) during pregnancy did not show cognitive or psychomotor defects, but by age four showed poorer social competence and had a far higher odds ratio (2.71) for having attention deficit hyperactivity disorder.<sup>50</sup>

### ***Effects of Organophosphate Pesticides***

Children with *in utero* exposure to organophosphate pesticides have more abnormal reflexes at birth than children without such exposure.<sup>51,52</sup> Reflexes are checked on newborns because they are important markers of neurological integrity. One would surmise from these studies that as these children age, they would begin to exhibit other neurological problems, an assumption that turns out to be correct. As these children age they begin to have difficulties performing tasks that require short-term memory, and they also tend to exhibit slower reaction time, impaired mental development, and some may have pervasive developmental delays.<sup>53</sup>

### ***Effects of Solvents***

Solvents are neurotoxic by nature and can also lead to infertility. Less is known about the persistent neurologic damage from gestational exposure. In rat models, xylene (present in gasoline, cigarette smoke, and some household cleaners) causes severe neurotoxicity. Levels of xylene that are not toxic to the adult animal induce a range of problems in the offspring, including decreased brain weight and difficulty with neuromotor abilities, learning, and memory, which persist as they age.<sup>54,55</sup>

## Adverse Effects on Endocrinological Development and Function

Since proper thyroid function is critical for proper neurological development, researchers have studied the potential problems that gestational exposure to xenobiotics can cause. Because adult exposure to PCBs and other chlorinated compounds has been associated with a variety of thyroid problems, it is reasonable to examine whether gestational exposure can cause similar issues. *In utero* exposure to PCBs has been positively associated with increased levels of thyroid stimulating hormone (TSH) in children, although there are not many current studies of this issue.<sup>56</sup> The effect of perchlorate in the water supply on the developing thyroid gland also poses concern. Perchlorate is a competitive inhibitor of iodine and decreases the active transport of this halogen molecule into the thyroid gland. It was actually used as an anti-thyroid drug in the 1950s and 1960s but was discontinued because of some incidence of aplastic anemia. It is now found in some water supplies as an industrial waste product and a large number of children are being exposed to it *in utero* and neonatally. Fortunately, water pollution with this potent anti-thyroid compound does not appear to cause adverse thyroid effects in exposed children.<sup>57</sup>

While there are undoubtedly many factors associated with childhood obesity, including a decrease in physical activity and a high sugar intake, environmental toxic burden may impact it as well. In adults the presence of chlorinated pesticides (a class with multiple compounds found in all individuals tested) has been documented to adversely affect the rate of thermogenesis.<sup>58</sup> The higher the blood levels of these pesticides, the lower the resting metabolic rate, which accounts for the majority of calories burned in a day. This finding was mirrored in a study that examined mitochondrial markers for fatty acid metabolism. These markers, reflective of fat being broken down in adipose tissue, showed that the higher the blood levels of pesticides and PCBs, the lower the level of these markers, indicating inhibition of fat metabolism.<sup>59</sup>

Another common toxin, benzo(a)pyrene (BAP) from cigarettes, tailpipes, and other combustion sources, can also lead to weight gain. The presence of BAP inhibits fat breakdown and has been shown to cause weight gain in animal models.<sup>60</sup> In children, *in*

*utero* exposure to the chlorinated pesticide HCB predisposed them to being overweight by the time they reached age six. Children with gestational exposure to HCB were 2.5-3.0 times more likely to be overweight than children without this exposure, no matter what their dietary intake or activity level.<sup>61</sup> In animal models, adult mice exposed to cigarette smoke *in utero* were given a high-fat diet for two weeks. During that time, mice with prenatal tobacco smoke exposure gained substantially more weight and had far higher levels of total cholesterol than non-gestationally exposed controls.<sup>62</sup>

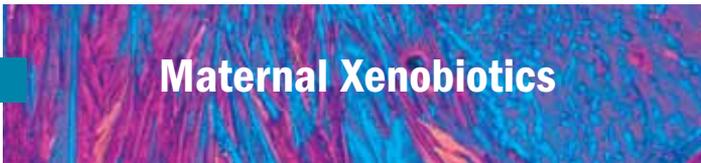
Sex hormone levels can also be affected by gestational xenobiotic exposure. German children whose mothers had higher levels of polychlorinated dibenzo dioxins (PCDD) and furans (PCDF) had lower cord blood levels of estrogens (more so in male babies) and testosterone (more so in female babies) than controls.<sup>63</sup> Taiwanese girls ages 13-19, whose mothers were exposed to PCBs when pregnant, were more likely to have irregular menses and higher estradiol and follicle stimulating hormone (FSH) levels during their follicular phase than control girls the same age.<sup>64</sup> Male Taiwanese children also showed sex hormone differences, with those exposed *in utero* to PCBs and PCDFs having higher serum estradiol and FSH levels at puberty along with lower testosterone.<sup>65</sup>

In animal models, maternal exposure to polybrominated diphenyl ether (PBDE), a common flame retardant found in high concentrations in farmed Atlantic salmon, had profound long-term effects for both male and female offspring.<sup>66</sup> Females had fewer primary and secondary follicles and experienced delayed puberty. Male animals had dramatic decreases in circulating sex hormones at weaning, which persisted into adulthood. Another study showed males with a history of PBDE exposure also had reduced spermatogenesis.<sup>67</sup>

## Conclusion and Recommendations

Table 4 shows the health effects on children from gestational exposure to compounds documented in cord blood and meconium studies. Children are increasingly under assault before they are born and the major targets include immune and neurological functioning.

In an effort to help obtain this information, Colburn has developed a website that summarizes the



critical windows of exposure for these chemical compounds. The website is: <http://www.endocrinedisruption.com/prenatal.criticalwindows.overview.php>

Fortunately, fairly simple approaches exist to reduce exposure to some of these compounds. The organophosphate pesticides are easily avoided by not consuming commercial varieties of the 12 most toxic fruits and vegetables (list available at [www.foodnews.org](http://www.foodnews.org)). Avoidance of a strikingly similar list of foods resulted in a dramatic decrease in organophosphate pesticide metabolites from the urine of preschoolers in Seattle.<sup>68</sup> By avoiding farmed salmon and catfish one can also avoid the greatest source of current exposures to PCBs, PBDEs, and other chlorinated pesticides.<sup>69</sup> Other common dietary sources of lower levels of PCBs and dioxins include dairy products and fish oils.<sup>70</sup>

In addition to avoiding consumption, a prospective mother (any sexually active menstruating female) can be tested to find out if she is carrying a sizeable burden of any of these compounds. The heavy metals, chlorinated pesticides, and PCBs can be measured in either the serum or urine. Chelation can reduce the heavy metal burden but will not lower the levels of persistent chemicals. To reduce those levels one needs to increase

the fecal excretion of those compounds through the following dietary supplementation as well as with sauna therapy and colonic irrigations.

Pregnant women who consumed high-chlorella supplements during pregnancy were able to reduce the amount of dioxin in their babies' cord blood by 26 percent and levels in breast milk by 30 percent.<sup>71</sup> The active ingredient in chlorella is chlorophyll. Several other research projects have been conducted in animals to examine the effect of chlorophyll and chlorophyll-containing compounds on removal of dioxins and PCBs via the stool. The higher the content of chlorophyll in the diet, the greater the excretion of these fat-soluble

**Table 4. Summary of Xenobiotics from Cord Blood or Meconium and Effects on Children**

Compound	Location	Adverse Effects in Offspring
Mercury	Meconium/Cord blood	Reduced cognition and altered mood
Lead	Meconium	Neurological and immune dysfunction
Polycyclic aromatic hydrocarbons (PAH)	Meconium/Cord blood	Allergies, asthma, recurrent infections
Polybrominated dioxins and furans (PBDD/F)	Cord blood	No studies to date
Polychlorinated dioxins and furans (PCDD/F)	Cord blood	Cognitive and behavioral problems, sex hormone differences
Perfluorinated chemicals (PFCs)	Cord blood	No studies to date
Chlorinated pesticides	Meconium/Cord blood	Recurrent infections, allergies, reduced cognition and memory, childhood obesity, attention deficit disorder
Polybrominated diphenyl ethers (PBDE)	Cord blood	Endocrine disorders in animal models
Polychlorinated naphthalenes	Cord blood	No studies to date
Polychlorinated biphenyls (PCBs)	Meconium/Cord blood	Reduced infection fighting, recurrent infections, diminished IQ points, activity disorders, thyroid dysfunction, sexual changes, hearing loss
Organophosphate pesticides	Meconium	Reduced cognition and mental development

persistent toxins in the feces. The ranges of chlorophyll went from a low of 0.1 percent to a high of 0.5 percent in the diet. A diet with 0.1-percent chlorophyll is roughly equivalent to consuming 10 percent of the diet as spinach or 20 percent as seaweed. In the 0.1-percent group the fecal excretion of the various toxins ranged from 40- to 80-percent greater than the control group. At the end of the study the animals given chlorophyll had lower total body burden of persistent toxins than their counterparts.<sup>72</sup>

In a laboratory setting, rice bran fiber (RBF) was shown to have a high binding affinity for PCBs and other toxins, including the combustion by-product benzo(a)pyrene.<sup>73</sup> When measured against other fibers, RBF demonstrated the ability to dramatically reduce the reabsorption (termed “hepatic recycling”) of PCBs from the intestines in animals.<sup>74</sup> Hepatic recycling occurs after the liver dumps some of these toxins into the intestines with bile; however, when these compounds reach the small intestine they are reabsorbed into the bloodstream and sent back to the liver. This recycling pattern is the primary reason a minute amount of these toxins are actually excreted from the body. While RBF helps prevent recycling, wheat bran showed no benefit.<sup>75</sup> A study using either spinach fiber or RBF in animals exposed to PCBs showed RBF increased fecal PCB excretion 6.6 times and spinach fiber 4.1 times.<sup>76</sup> Therefore, simply increasing the amount of brown rice and dark green vegetables in the diet will reduce the exposure to and increase the excretion of these fat-soluble persistent compounds. It may take up to 12 months to significantly reduce toxin levels.

## References

- Colborn TE, Davidson A, Green SN, et al. Great Lakes, Great Legacy? Washington, DC: Conservation Foundation; 1990.
- Myllynen P, Pasanen M, Pelkonen O. Human placenta: a human organ for developmental toxicology research and biomonitoring. *Placenta* 2005;26:361-371.
- Body burden – the pollution in newborns. <http://www.ewg.org/reports/bodyburden2/> [Accessed July 29, 2009]
- Barr DB, Wang RY, Needham LL. Biologic monitoring of exposure to environmental chemicals throughout the life stages: requirements and issues for consideration for the National Children's Study. *Environ Health Perspect* 2005;113:1083-1091.
- Barr DB, Bishop A, Needham LL. Concentrations of xenobiotic chemicals in the maternal-fetal unit. *Reprod Toxicol* 2007;23:260-266.
- Leonardi-Bee J, Smyth A, Britton J, Coleman T. Environmental tobacco smoke and fetal health: systematic review and meta-analysis. *Arch Dis Child Fetal Neonatal Ed* 2008;93:F351-F361.
- Choi H, Jedrychowski W, Spengler J, et al. International studies of prenatal exposure to polycyclic aromatic hydrocarbons and fetal growth. *Environ Health Perspect* 2006;114:1744-1750.
- Choi H, Rauh V, Garfinkel R, et al. Prenatal exposure to airborne polycyclic aromatic hydrocarbons and risk of intrauterine growth restriction. *Environ Health Perspect* 2008;116:658-665.
- Perera FP, Rauh V, Tsai WY, et al. Effects of transplacental exposure to environmental pollutants on birth outcomes in a multiethnic population. *Environ Health Perspect* 2003;111:201-205.
- Wolff MS, Engel S, Berkowitz G, et al. Prenatal pesticide and PCB exposures and birth outcomes. *Pediatr Res* 2007;61:243-250.
- Villanueva CM, Durand G, Coutte MB, et al. Atrazine in municipal drinking water and risk of low birth weight, preterm delivery, and small-for-gestational-age status. *Occup Environ Med* 2005;62:400-405.
- Sherman JD. Chlorpyrifos (Dursban)-associated birth defects: report of four cases. *Arch Environ Health* 1996;51:5-8.
- Holmberg PC. Central-nervous-system defects in children born to mothers exposed to organic solvents during pregnancy. *Lancet* 1979;28:177-179.
- Holmberg PC, Hernberg S, Kurppa K, et al. Oral clefts and organic solvent exposure during pregnancy. *Int Arch Occup Environ Health* 1982;50:371-376.
- McDonald JC, Lavoie J, Cote R, McDonald AD. Chemical exposures at work in early pregnancy and congenital defect: a case-referent study. *Br J Ind Med* 1987;44:527-533.
- Dietert RR, Lee JE, Hussain I, Peipenbrink M. Developmental immunotoxicology of lead. *Toxicol Appl Pharmacol* 2004;198:86-94.
- Dietert RR, Zelikoff JT. Early-life environment, developmental immunotoxicology, and the risk of pediatric allergic disease including asthma. *Birth Defects Res B Dev Reprod Toxicol* 2008;83:547-560.
- Gogal RM Jr, Holladay SD. Perinatal TCDD exposure and the adult onset of autoimmune disease. *J Immunotoxicol* 2008;5:413-418.
- DiFranza JR, Aligne CA, Weitzman M. Prenatal and postnatal environmental tobacco smoke exposure and children's health. *Pediatrics* 2004;113:1007-1015.
- Hertz-Picciotto I, Park HY, Dostal M, et al. Prenatal exposures to persistent and non-persistent organic compounds and effects on immune system development. *Basic Clin Pharmacol Toxicol* 2008;102:146-154.

21. Allen JR, Barsotti DA. The effects of transplacental and mammary movement of PCBs on infant rhesus monkeys. *Toxicology* 1976;6:331-340.
22. Vos JG, van Driel-Grootenhuis J. PCB-induced suppression of the humoral and cell-mediated immunity in guinea pigs. *Sci Total Environ* 1972;1:289-302.
23. Weisglas-Kuperus N, Patandin S, Berbers GA, et al. Immunologic effects of background exposure to polychlorinated biphenyls and dioxins in Dutch preschool children. *Environ Health Perspect* 2000;108:1203-1207.
24. Glynn A, Thuvander A, Aune M, et al. Immune cell counts and risks of respiratory infections among infants exposed pre- and postnatally to organochlorine compounds: a prospective study. *Environ Health* 2008;7:62. (<http://www.ehjournal.net/content/7/1/62>).
25. Dallaire F, Dewailly E, Vezina C, et al. Effect of prenatal exposure to polychlorinated biphenyls on incidence of acute respiratory infections in preschool Inuit children. *Environ Health Perspect* 2006;114:1301-1305.
26. Dietert RR. Developmental immunotoxicity (DIT), postnatal immune dysfunction and childhood leukemia. *Blood Cells Mol Dis* 2009;42:108-112.
27. Dietert RR, Dietert JM. Potential for early-life immune insult including developmental immunotoxicity in autism and autism spectrum disorders: focus on critical windows of immune vulnerability. *J Toxicol Environ Health B Crit Rev* 2008;11:660-680.
28. Oken E, Wright RO, Kleinman KP, et al. Maternal fish consumption, hair mercury, and infant cognition in a U.S. cohort. *Environ Health Perspect* 2005;113:1376-1380.
29. Oken E, Radesky JS, Wright RO, et al. Maternal fish intake during pregnancy, blood mercury levels, and child cognition at age 3 years in a US cohort. *Am J Epidemiol* 2008;167:1171-1181.
30. Davidson PW, Strain JJ, Myers GJ, et al. Neurodevelopmental effects of maternal nutritional status and exposure to methylmercury from eating fish during pregnancy. *Neurotoxicology* 2008;29:767-775.
31. Jett DA, Kuhlmann AC, Farmer SJ, Guilarte TR. Age-dependent effects of developmental lead exposure on performance in the Morris water maze. *Pharmacol Biochem Behav* 1997;57:271-279.
32. Gomaa A, Hu H, Bellinger D, et al. Maternal bone lead as an independent risk factor for fetal neurotoxicity: a prospective study. *Pediatrics* 2002;110:110-118.
33. Eriksson P, Fredriksson A. Neurotoxic effects in adult mice neonatally exposed to 3,3',4,4'-pentachlorobiphenyl or 2,3,3',4,4'-pentachlorobiphenyl. Changes in brain nicotinic receptors and behaviour. *Environ Toxicol Pharmacol* 1998;5:17-27.
34. Jacobson SW, Fein GG, Jacobson JL, et al. The effect of intrauterine PCB exposure on visual recognition memory. *Child Dev* 1985;56:853-860.
35. Hsu ST, Ma CI, Hsu SK, et al. Discovery and epidemiology of PCB poisoning in Taiwan: a four-year followup. *Environ Health Perspect* 1985;59:5-10.
36. Chen YC, Guo YL, Hsu CC, Rogan WJ. Cognitive development of Yu-Cheng ('Oil disease') children prenatally exposed to heat-degraded PCBs. *JAMA* 1992;268:3213-3218.
37. Chen YC, Yu ML, Rogan WJ, et al. A 6-year follow-up of behavior and activity disorders in the Taiwan Yu-Cheng children. *Am J Public Health* 1994;84:415-421.
38. Lai TJ, Liu X, Guo YL, et al. A cohort study of behavioral problems and intelligence in children with high prenatal polychlorinated biphenyl exposure. *Arch Gen Psychiatry* 2002;59:1061-1066.
39. Gladen BC, Rogan WJ, Ragan NB, Spierto FW. Urinary porphyrins in children exposed transplacentally to polyhalogenated aromatics in Taiwan. *Arch Environ Health* 1988;43:54-58.
40. Li MH, Hansen LG. Enzyme induction and acute endocrine effects in prepubertal female rats receiving environmental PCB/PCDF/PCDD mixtures. *Environ Health Perspect* 1996;104:712-722.
41. Jacobson SW, Fein GG, Jacobson JL, et al. The effect of intrauterine PCB exposure on visual recognition memory. *Child Dev* 1985;56:853-860.
42. Jacobson JL, Jacobson SW. Intellectual impairment in children exposed to polychlorinated biphenyls in utero. *N Engl J Med* 1996;335:783-789.
43. Rogan WJ, Gladen BC, McKinney JD, et al. Neonatal effects of transplacental exposure to PCBs and DDE. *J Pediatr* 1986;109:335-341.
44. Gladen BC, Rogan WJ, Hardy P, et al. Development after exposure to polychlorinated biphenyls and dichlorodiphenyl dichloroethene transplacentally and through human milk. *J Pediatr* 1988;113:991-995.
45. Gladen BC, Rogan WJ. Effects of perinatal polychlorinated biphenyls and dichlorodiphenyl dichloroethene on later development. *J Pediatr* 1991;119:58-63.
46. Jacobson JL, Jacobson SW. Prenatal exposure to polychlorinated biphenyls and attention at school age. *J Pediatr* 2003;143:780-788.
47. Schantz SL, Widholm JJ, Rice DC. Effects of PCB exposure on neuropsychological function in children. *Environ Health Perspect* 2003;111:357-376.
48. Powers BE, Poon E, Sable HJK, Schantz SL. Developmental exposure to PCBs, MeHg, or both: long-term effects on auditory function. *Environ Health Perspect* 2009;117:1101-1107.
49. Eskenazi B, Rosas LG, Marks AR, et al. Pesticide toxicity and the developing brain. *Basic Clin Pharmacol Toxicol* 2008;102:228-236.
50. Ribas-Fito N, Torrent M, Carrizo D, et al. Exposure to hexachlorobenzene during pregnancy and children's social behavior at 4 years of age. *Environ Health Perspect* 2007;115:447-450.

51. Young JG, Eskenazi B, Gladstone EA, et al. Association between *in utero* organophosphate pesticide exposure and abnormal reflexes in neonates. *Neurotoxicology* 2005;26:199-209.
52. Engel SM, Berkowitz GS, Barr DB, et al. Prenatal organophosphate metabolite and organochlorine levels and performance on the Brazelton Neonatal Behavioral Assessment Scale in a multiethnic pregnancy cohort. *Am J Epidemiol* 2007;165:1397-1404.
53. Jurewicz J, Hanke W. Prenatal and childhood exposure to pesticides and neurobehavioral development: review of epidemiological studies. *Int J Occup Med Environ Health* 2008;21:121-132.
54. Hass U, Lund SP, Simonsen L, Fries AS. Effects of prenatal exposure to xylene on postnatal development and behavior in rats. *Neurotoxicol Teratol* 1995;17:341-349.
55. Hass U, Lund SP, Simonsen L. Long-lasting neurobehavioral effects of prenatal exposure to xylene in rats. *Neurotoxicology* 1997;18:547-551.
56. Chevrier J, Eskenazi B, Bradman A, et al. Associations between prenatal exposure to polychlorinated biphenyls and neonatal thyroid-stimulating hormone levels in a Mexican-American population, Salinas Valley, California. *Environ Health Perspect* 2007;115:1490-1496.
57. Tellez Tellez R, Michaud Chacon P, Reyes Abarca C, et al. Long-term environmental exposure to perchlorate through drinking water and thyroid function during pregnancy and the neonatal period. *Thyroid* 2005;15:963-975.
58. Tremblay A, Pelletier C, Doucet E, Imbeault P. Thermogenesis and weight loss in obese individuals: a primary association with organochlorine pollution. *Int J Obes Relat Metab Disord* 2004;28:936-939.
59. Imbeault P, Tremblay A, Simoneau JA, Joanisse DR. Weight loss-induced rise in plasma pollutant is associated with reduced skeletal muscle oxidative capacity. *Am J Physiol Endocrinol Metab* 2002;282:E574-E579.
60. Irigaray P, Ogier V, Jacquenet S, et al. Benzo[a]pyrene impairs beta-adrenergic stimulation of adipose tissue lipolysis and causes weight gain in mice. A novel molecular mechanism of toxicity for a common food pollutant. *FEBS J* 2006 273:1362-1372.
61. Smink A, Ribas-Fita N, Garcia R, et al. Exposure to hexachlorobenzene during pregnancy increases the risk of overweight in children aged 6 years. *Acta Paediatr* 2008;97:1465-1469.
62. Ng SP, Conklin DJ, Bhatnagar A, et al. Prenatal exposure to cigarette smoke induces diet- and sex-dependent dyslipidemia and weight gain in adult murine offspring. *Environ Health Perspect* 2009;117:1042-1048.
63. Cao Y, Winneke G, Wilhelm M, et al. Environmental exposure to dioxins and polychlorinated biphenyls reduce levels of gonadal hormones in newborns: results from the Duisburg cohort study. *Int J Hyg Environ Health* 2008;211:30-39.
64. Yang CY, Yu ML, Guo HR, et al. The endocrine and reproductive function of the female Yucheng adolescents prenatally exposed to PCBs/PCDFs. *Chemosphere* 2005;61:355-360.
65. Hsu PC, Lai TJ, Guo NW, et al. Serum hormones in boys prenatally exposed to polychlorinated biphenyls and dibenzofurans. *J Toxicol Environ Health A* 2005;68:1447-1456.
66. Lilienthal H, Hack A, Roth-Harer A, et al. Effects of developmental exposure to 2,2',4,4',5-pentabromodiphenyl ether (PBDE-99) on sex steroids, sexual development, and sexually dimorphic behavior in rats. *Environ Health Perspect* 2006;114:194-201.
67. Kuriyama SN, Talsness CE, Grote K, Chahoud I. Developmental exposure to low-dose PBDE-99: effects on male fertility and neurobehavior in rat offspring. *Environ Health Perspect* 2005;113:149-154.
68. Lu C, Toepel K, Irish R, et al. Organic diets significantly lower children's dietary exposure to organophosphorous pesticides. *Environ Health Perspect* 2006;114:260-263.
69. Hites RA, Foran JA, Carpenter DO, et al. Global assessment of organic contaminants in farmed salmon. *Science* 2004;303:226-229.
70. Huisman M, Eerenstein SE, Koopman-Elseboom C, et al. Perinatal exposure to polychlorinated biphenyls and dioxins through dietary intake. *Chemosphere* 1995;31:4273-4287.
71. Nakano S, Noguchi T, Takekoshi H, et al. Maternal-fetal distribution and transfer of dioxins in pregnant women in Japan, and attempts to reduce maternal transfer with *Chlorella (Chlorella pyrenoidosa)* supplements. *Chemosphere* 2005;61:1244-1255.
72. Morita K, Ogata M, Hasegawa T. Chlorophyll derived from *Chlorella* inhibits dioxin absorption from the gastrointestinal tract and accelerates dioxin excretion in rats. *Environ Health Perspect* 2001;109:289-294.
73. Sera N, Morita K, Nagasoe M, et al. Binding effect of polychlorinated compounds and environmental carcinogens on rice bran fiber. *J Nutr Biochem* 2005;16:50-58.
74. Kimura Y, Nagata Y, Buddington RK. Some dietary fibers increase elimination of orally administered polychlorinated biphenyls but not that of retinol in mice. *J Nutr* 2004;134:135-142.
75. De Vos S, De Schrijver R. Polychlorinated biphenyl distribution and faecal excretion in rats fed wheat bran. *Chemosphere* 2005;61:374-382.
76. Morita K, Hamamura K, Iida T. Binding of PCB by several types of dietary fiber *in vivo* and *in vitro*. *Fukuoka Igaku Zasshi* 1995;86:212-217. [Article in Japanese]