Exposure to Environmental Endocrine Disruptors and Child Development

John D. Meeker, ScD

E xposure to exogenous chemicals can affect endocrine function at multiple sites and through numerous specific modes of action, which may have far-reaching effects on human health and development. Widespread human exposure to known or suspected endocrine disrupting chemicals (EDCs) has been documented in the United States and worldwide, as have trends for increased rates of endocrine-related diseases and disorders among children. While human epidemiology studies of exposure to EDCs and children's health remain extremely limited, a growing body of evidence shows that exposure to a number of chemicals commonly found in consumer goods, personal care products, food, drinking water, and other sources may adversely affect child development through altered endocrine function. This narrative review provides a brief introduction to several common EDCs (with a specific focus on persistent organic pollutants, phthalates, bisphenol A, and contemporary-use pesticides, which represent only a small number of all known or suspected EDCs), an overview of the state of the human evidence for adverse effects of EDCs on child development (fetal growth, early reproductive tract development, pubertal development, neurodevelopment, and obesity), guidance for health care providers based on current knowledge, and recommendations for future research.

Arch Pediatr Adolesc Med. Published online June 4, 2012.
doi:10.1001/archpediatrics.2012.241

The development and use of synthetic chemicals have grown exponentially since the 1940s, and there are now more than 84 000 different chemicals in commerce.[1] While many of these chemicals have allowed for modern conveniences (eg, plastics) or were developed to address safety (eg, flame retardants) and other societal needs (eg, pesticides) to improve our quality of life, recent advances in the fields of exposure science and analytical chemistry have documented widespread exposure to hundreds of these chemicals among men, women, and children throughout the world. Depending on the chemical, exposure can occur through food, drinking water, air, soil, house dust, and direct contact with various household materials or consumer products. Exposures among children are especially of concern because children have contact with potentially contaminated soil and dust; have frequent hand-to-mouth or object-to-mouth activity; eat, drink and breathe more per body weight compared with adults; and undergo many rapid changes that are susceptible to even minute doses of environmental stressors.[2] Fetal and infant exposures are also of concern because many chemicals have been shown to pass through the placenta and/or from mother to infant through breast milk.

Numerous high-production-volume chemicals—those produced or imported in the United States in quantities of 1 million pounds or more per year (currently numbering approximately 3000)—are known or suspected endocrine disrupting chemicals (EDCs). Once inside the body, EDCs can affect the endocrine system through a multitude of specific mechanisms that can target different levels of the

Author Affiliation: Department of Environmental Health Sciences, University of Michigan School of Public Health, Ann Arbor.

hypothalamic-pituitary-gonad, thyroid, and adrenal axes, ranging from effects on hormone receptors to effects on hormone synthesis, secretion, or metabolism; therefore, they can have far-reaching health implications throughout the life course.[3,4] Transgenerational effects are also possible, as is now being observed in offspring of women who had been exposed to diethylstilbestrol in utero decades ago.[5] The realization that exposure to many environmental EDCs is now ubiquitous, coupled with proven or suggested trends for increased rates of certain endocrine-related diseases and disorders among children, has resulted in growing concern regarding potential links between the two among scientists, governments, physicians, and patients. Several scientific bodies, including the Endocrine Society, now support that EDCs can affect human health.[3] However, human studies investigating possible adverse health effects of EDCs, especially among children, are surprisingly deficient for most EDCs.

This review provides a brief introduction to several common EDCs, an overview of the state of the human evidence for adverse effects of EDCs on child development, guidance for health care providers based on current knowledge, and recommendations for future research. As an overview, it does not provide in-depth information on any of the individual exposures or outcomes introduced and discusses only a small portion of all known or suspected EDCs. Seminal studies, select examples, and previous review articles focusing on various subtopics are referenced here, and the interested reader is directed toward those for additional detail.

ENDOCRINE DISRUPTING CHEMICALS

Persistent Organic Pollutants

Persistent organic pollutants (POPs) are lipophilic chemicals with long half-lives that bioaccumulate up the food chain and include polychlorinated biphenyls (PCBs), organochlorine pesticides (eg, dichlorodiphenyltrichloroethane [DDT], chlordane, and hexachlorobenzene), polybrominated diphenyl ethers (PBDEs), other brominated flame retardants, and others. The PCBs are a class of chemicals widely used as transformer and hydraulic fluids and as additives in paints, oils, and building materials.[6] Both DDT and other organochlorine pesticides were widely used after World War II and were regarded at the time as safe and effective alternatives to arsenic-based pesticides. In response to reports of high concentrations in the environment owing to their persistence, effects on wildlife, and the potential to harm human health, PCBs and some of the more heavily used organochlorine pesticides were banned in industrialized nations in the 1970s. The use of DDT still occurs in some developing countries as an effective and affordable method to combat malaria and other vector-borne illnesses. The PBDEs and other flame retardants are found in furniture, carpet backing, electronics, and many other consumer products.[6] The use of PBDEs has recently been banned or is currently being phased out in the United States and other countries. Owing to the environmental ubiquity and persistence of POPs, human exposure to them can continue for decades after their use ceases. Continued exposures to PCBs and DDT in countries that have banned their use occur primarily through the diet (dairy, meat, and higher-trophic-level fish), although PCB exposure from building materials used in the mid-20th century is also possible. Exposures to PBDEs can occur through the same dietary sources, although exposure to some congeners may occur to a greater extent through contact with house dust after they have leached from products in the home or other indoor environments.

The POPs have been associated with a wide range of adverse health effects in studies of adults, including male and female reproductive problems, thyroid effects, obesity, diabetes, and endocrine-related cancers.[7-9] Most of this evidence comes from research on PCBs and organochlorine pesticides, although a growing number of studies are now investigating health effects related to PBDE exposures.

Phthalates

Phthalates are a diverse class of widely used industrial chemicals. They are used as plasticizers to make plastics more flexible and are also used as solubilizing or stabilizing agents. Phthalates can be found in an extensive array of products. Low-molecular-weight phthalates are found in personal care products, certain dietary supplements and medications, and other consumer goods. High-molecular-weight phthalates are found in flexible polyvinyl chloride commonly found in consumer products, food packaging, home furnishings, and other building materials. Medical equipment can also contain phthalates, and elevated exposures have been documented among infants in the neonatal intensive care unit.[10] Owing to this widespread use, urinary phthalate metabolites can be measured in virtually everyone.[6] Several phthalates are antiandrogenic, and in rodents they have demonstrated significant adverse effects on male reproductive development and numerous other end points at high doses.[11] In human studies of adults, phthalates have been related to decreases in sex steroid and thyroid hormone levels, poor sperm quality, endometriosis, insulin resistance, obesity, and possibly breast cancer.[12,13]

Bisphenol A

Bisphenol A (BPA) is a high-production chemical used in the manufacture of polycarbonate plastics, epoxy resins, and thermal paper. Polycarbonate is a clear, rigid plastic that has been used for water bottles and other items, while epoxy resins are found in the lining of many canned foods and in certain construction materials. As with phthalates, medical equipment may also contain BPA, as infants in the neonatal intensive care unit have been shown to have elevated exposure levels.[14] For most people, exposure to BPA occurs primarily through the diet, and measurable levels of BPA can be found in most people.[6] It has been known to be weakly estrogenic for 75 years, and recent animal studies have reported a diverse variety of developmental problems following early life exposure such as altered reproductive organ development and neurobehavioral effects.[15] Human studies of BPA remain limited, although in adults there have been suggestive rela-

tionships with male and female reproductive end points, altered thyroid hormone levels and liver function, cardiovascular disease, and diabetes.[16]

Contemporary-Use Pesticides

Owing to the long-lasting environmental issues related to the persistent organochlorine pesticides described earlier, nearly all pesticides used today are nonpersistent. While they are designed to break down in a matter of hours or days, it has been shown that many nonpersistent pesticides can remain for years after application in homes and other indoor environments where they are protected from moisture, sunlight, and other degradation mechanisms. Exposure is multimedia, multipathway, and multiroute and can depend on the chemical, scenario, and population. Pesticides are known neurotoxins, especially in high-dose situations. Many commonly used pesticides are also known or suspected EDCs, although studies of potential endocrine effects have greatly lagged behind research focused on their designed mode of action (eg, cholinesterase inhibition). Among all the types of pesticides (insecticides, herbicides, fungicides, rodenticides, etc), most research in humans has been conducted for insecticides. The most common classes of insecticides are organophosphates, carbamates, and pyrethroids. Of these, the organophosphates, some of which have been banned or restricted for residential but not agricultural use in the United States, have been studied the most.

Other Chemicals

There are many other types of known or suspected EDCs for which widespread human exposure has been documented. A large body of evidence shows that a number of heavy metals such as lead, cadmium, and mercury may affect endocrine function in addition to their other modes of toxic effects. There is also a growing list of emerging EDCs of concern, including parabens, triclosan, perchlorate, alternative brominated and chlorinated flame retardants, and fluorinated organic compounds such as perfluoro-octane octanoate and perfluoro-octane sulfonate. Several studies suggest that many of these emerging compounds may be associated with endocrine-related end points in animals and humans. However, the number of human studies that have been conducted for any one chemical or class of chemicals is sparse. Thus, the remainder of this article will focus on developmental end points associated with those EDCs that have been introduced here.

DEVELOPMENTAL END POINTS RELATED TO EDCS

Fetal Growth and Gestation Duration

Low birth weight and preterm birth are the leading causes of infant mortality and precursors to future morbidity, and both have increased significantly in the United States since 1990.[17] Numerous studies have assessed relationships between chemical exposures and birth weight, which

have been extensively reviewed.[18,19] Studies among EDCs are more limited compared with those of agents related to ambient air pollution such as particulate matter, carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide. There is some inconsistent evidence for reduced birth weight in association with exposure to POPs, organophosphate insecticides, and triazine herbicides. A meta-analysis of nearly 8000 women from 12 European birth cohorts dating back to 1990 reported significant declines in birth weight in relation to markers of low-level exposure to PCBs but not DDT.[20] More recently, evidence for reduced birth weight in relation to phthalates,[21] BPA,[22] and PBDE[23] has been reported, although several studies have reported no associations. Because study designs and results have varied across studies, for most EDCs it is currently difficult to conclude whether a relationship exists between exposure and birth weight.

Few studies have investigated the potential relationship between EDC exposure and preterm birth, and most have focused on PCBs and organochlorine pesticides.[18,19] Since these exhaustive literature reviews were published, a small nested case-control study (n=60) taking place in Mexico City, Mexico, reported higher concentrations of phthalates and BPA in third-trimester urine of women who delivered preterm compared with women who delivered at term.[24,25] For phthalates, this was consistent with 2 studies reporting inverse relationships between phthalates and gestation duration.[26,27] On the other hand, 2 studies have reported null or even positive associations between phthalates and gestation duration.[28,29] Future studies are needed on the relationship between EDCs and preterm birth and should account for the heterogeneous etiologies of preterm birth to enhance study precision.

Male Reproductive Tract Development

There is evidence that birth anomalies of the male reproductive tract (cryptorchidism, hypospadias) may have increased in some countries in recent decades.[30] A leading hypothesis for a collection of linked conditions in human males exposed to EDCs in utero is termed *testicular dysgenesis syndrome*. Testicular dysgenesis syndrome represents a number of reproductive disorders of varying severity that are associated with disturbed gonadal development including cryptorchidism, hypospadias, and smaller reproductive organs.[31] Later in life, the effects of testicular dysgenesis syndrome are hypothesized to manifest as a reduction in semen quality and infertility as well as an increased risk of testicular cancer. The evidence for widespread endocrine disruption among males is thus further fueled by reports of significant secular declines in semen quality[32] and testosterone[33] as well as increased rates of testicular cancer[34] in men during the past 50 years or so. Several studies have assessed relationships between EDCs, particularly POPs, and male genital birth defects, with inconsistent findings that have been reviewed previously.[19,30] More recently, a large case-control study (471 cases and 490 control subjects) of maternal occupation reported a significantly increased risk of hypospadias associated with exposure to hairspray and phthalates, some of which are antiandrogenic.[35] An-

other recent case-control study reported an increased risk of hypospadias and cryptorchidism in relation to parental occupational exposure to pesticides, although the number of cases in the study was relatively small (14 with hypospadia, 18 with cryptorchidism).[36] A relationship between PBDE measured in breast milk, but not placenta, and the risk of cryptorchidism was also reported in a Danish case-control study of 95 boys with cryptorchidism.[37]

More subtle measures of reproductive tract development have been studied in relation to EDCs in recent years. A landmark US study reported reduced anogenital distance (a marker for insufficient fetal androgenization), penis size, and incomplete testicular descent in 106 boys aged 2 to 24 months in relation to several urinary phthalate metabolites measured in third-trimester maternal urine.[38] A newer Japanese study that measured phthalate metabolites in 111 pregnant women also reported inverse associations with anogenital distance in male infants.[39] Finally, a Danish study reported significant decreases in serum measures of free testosterone and Leydig cell function in 3-month-old boys in relation to phthalates in maternal breast milk.[40] Thus, there is evidence that phthalates and possibly other EDCs disrupt early male reproductive development, but additional studies are needed.

Pubertal Development

A secular decline in the age at onset of puberty and an increased frequency of precocious puberty have been observed during the past couple decades in the United States and other countries.[41,42] These trends are considered to be a significant public health concern because precocious puberty is a risk factor for endocrine-related diseases in adulthood. The trends cannot be fully explained by known predictors (eg, living conditions, body mass index [BMI; calculated as weight in kilograms divided by height in meters squared]), and exposure to EDCs has been hypothesized to be a significant contributor.[43,44] Several studies have reported an association between exposure to POPs and precocious puberty or earlier menarche in girls and delayed puberty in boys; however, a number of studies have not observed these relationships.[45]

There has been a lack of research on nonpersistent EDCs and pubertal development. Levels of several phthalates were found to be elevated in serum of girls with premature thelarche compared with control subjects in a small study in Puerto Rico.[46] However, the study has been criticized on several aspects of the study design, including the potential for sample contamination when measuring phthalate levels in serum. A more recent US study of pubertal development among 1151 girls aged 6 to 8 years at enrollment reported subtle but statistically suggestive positive associations between urinary low-molecular-weight phthalate metabolites and breast and pubic hair development.[47] The authors also reported a weak inverse relationship between high-molecular-weight phthalate levels and pubic hair stage but no associations between BPA levels and pubertal development. Among boys, a small study conducted in Turkey reported that plasma concentrations of high-molecular-weight phthalates were significantly higher in 11- to 15-year-olds with pubertal gynecomastia compared with a control group.[48] Additional studies on EDC exposure and pubertal development are greatly needed owing to the current lack of human data.

Neurodevelopment

Neurodevelopmental disorders are prevalent in the United States and worldwide, with evidence that rates of certain disorders such as attention-deficit/hyperactivity disorder and autism spectrum disorders have been increasing in recent years.[49-52] While it is likely that these trends are attributable to numerous factors including changes in diagnostic practices, there is growing evidence that exposure to EDCs may play a significant role. Sex steroid hormones are vital to central nervous system development. Thus, developing neuroendocrine systems may be particularly sensitive to EDC exposure.[53] Longitudinal and/or cross-sectional human studies have related exposure to EDCs, both in utero and during early childhood, with neurodevelopmental disorders such as decreased IQ, poorer memory, autism spectrum disorders, attention-deficit/hyperactivity disorder, and other behavioral problems.[54] These data are most robust for PCBs[55] and pesticides.[56] However, there is recent evidence that certain phthalates may be associated with each of these end points[13,54] as well as reduced masculine play in boys,[57] that gestational BPA exposure may be associated with poorer executive function and behavior in 3-year-old girls,[58] and that gestational exposure to PBDEs could be related to lower scores on tests of mental development in the first few years of life.[59]

Thyroid hormones also play an essential role in neurodevelopment in addition to many other functions related to growth and metabolism. Rates of thyroid dysfunction, including congenital hypothyroidism, have been on the rise during the past several decades.[60] There is a growing list of EDCs that have been found capable of disrupting thyroid function. Both human and animal studies suggest that PCBs, PBDEs, pesticides, phthalates, BPA, and numerous other EDCs may disrupt thyroid signaling through diverse mechanisms.[61,62] More research is needed to establish dose-response relationships between EDCs and adverse neurodevelopment as well as to determine the most sensitive stages and precise biological mechanisms involved.

Obesity

The prevalence of overweight and obesity is rapidly increasing in the United States and worldwide.[63,64] In addition to diet, physical activity, and genetics, environmental "obesogens" may play a role in these trends. *Obesogens* are defined as chemicals that inappropriately alter lipid homeostasis to promote adipogenesis and lipid accumulation, and experimental evidence showing that numerous chemicals may impart these effects is growing.[64,65] Human studies of environmental exposures in relation to obesity among children are lacking. They are primarily limited to studies of POPs, and results have been

inconsistent.[64,66] Cord blood PCB and dichlorodiphenyl-dichloroethylene (a persistent lipophilic metabolite of DDT) concentrations were associated with increased BMI or change in BMI from ages 1 to 3 years in a Belgian prospective study.[67] In a cross-sectional study of adolescents, 3 serum PCB congeners (138, 153, and 180) were associated with decreased BMI but a fourth (118) was positively associated with BMI among 14- and 15-year-olds.[68] Several studies have reported null results as well.[64] For nonpersistent EDCs, research has been limited to 2 cross-sectional studies that have reported suggestive positive associations between certain phthalates and BMI in girls.[66,69] More research is needed to more adequately assess whether EDC exposure is associated with childhood obesity and related conditions (metabolic syndrome, diabetes, and future cardiovascular disease).

Clinical Perspectives

Based on the available data, it is currently impossible to determine individual-level risk and whether there are safe levels of exposure to EDCs. Although the effect estimates or expected changes in developmental markers reported in individual studies may seem subtle, a seemingly small shift in the population distribution for these measures in relation to exposure is of great public health concern because exposure is ubiquitous. Given the range of potential serious developmental effects described here, efforts to reduce EDC exposure as a precaution among pregnant women and children are warranted. The first level of concern is for those highly exposed, and physicians should obtain occupational and environmental exposure history information. Occupational exposure history for the parents may shed light on potentially important in utero exposures. Current "take-home" exposures may also occur for some children, wherein the parent's clothing or other articles contaminated from the workplace can lead to exposures in the home or car. Patient or parent accounts of product overuse, hobbies, home-based businesses, or contaminated locations where children spend time are some examples of potentially useful environmental history information.[70]

Because exposure to the chemicals described here occurs among virtually everyone as they go about their normal activities, all patients could be advised to take certain steps in an attempt to reduce exposure. They can purchase consumer goods or personal care products labeled "phthalate free" or "BPA free," which are becoming more commonly available. However, this trend has been primarily due to marketing purposes, and products containing these chemicals are generally not required to be labeled as such.[71] For BPA and high-molecular-weight phthalates, replacing foods in the diet that involve plastic food packaging with fresh alternatives may reduce exposure by more than 50%.[72] Among fresh foods, replacing a diet of conventional produce with organic produce may significantly reduce exposure to organophosphate pesticides for children who are exposed primarily through residues in food.[73] For legacy POPs like PCBs and DDT that are no longer used in most countries as well as for more contemporary POPs such as PBDEs, consuming a diet lower in animal fats may reduce exposure. Individuals who live near polluted waters should also adhere to local fishing advisories. Because homes, offices, daycares, and cars still have many products that contain PBDEs and because other flame retardants are being used in new products, careful product selection and cleaning practices to reduce indoor dust exposure (eg, cleaning carpets and dusty surfaces regularly, using a vacuum cleaner with a high-efficiency particulate air filter) may help reduce exposure.[74]

Health care providers are encouraged to practice primary prevention by learning about EDC exposure sources and potential health effects. Several resources are available for health care professionals and patients, including handouts designed by university-based Pediatric Environmental Health Specialty Units (http://www.aoec.org/PEHSU/facts.html), a pediatric environmental health toolkit from the Physicians for Social Responsibility (http://www.psr.org/resources/pediatric-toolkit.html), the "green book" *Pediatric Environmental Health* from the American Academy of Pediatrics (http://ebooks.aap.org/product/pediatric-environmental-health-3rd-edition), and guidance on collecting pediatric exposure history from the National Environmental Education Foundation (http://www.neefusa.org/health/PEHI/index.htm).[16] Hospitals may help prevent exposures among sensitive populations through their purchasing practices such as seeking out polyvinyl chloride–free products for use in the neonatal intensive care unit.[75] Finally, clinicians are encouraged to consult with physicians or other professionals trained in environmental and occupational health as needed to address specific exposures or potential environment-related health conditions. A resource for clinician referrals is the Pediatric Environmental Health Specialty Units network of pediatric environmental health care providers (http://www.aoec.org/pehsu.htm).

Regulatory Perspectives

While the steps listed here may help reduce exposure to some extent, exposure to most EDCs is multisource, multipathway, and multiroute. Individual exposure scenarios depend on many factors, many of which are not modifiable through personal choices and activities. Thus, the most effective way to reduce risk is at the regulatory level. The regulatory framework for controlling chemical risks in the United States is considered outdated and ineffective.[76] An extremely small proportion of chemicals in current use have been thoroughly tested for endocrine disrupting potential, and there has been little motivation for chemical producers to assess this during product development and registration. In 1996, the US Environmental Protection Agency enacted legislation requiring that special considerations be given to child susceptibility in the risk assessment of pesticides but not other industrial or consumer chemicals.[1] The 1996 legislation also mandated that pesticides and certain drinking water contaminants be screened for endocrine disrupting activity, which resulted in implementation of the Environmental Protection Agency Endocrine Disrupting Screening Program.[77] In 2009, the Environmental Protection Agency finally ordered producers to conduct the first set of endocrine screening tests for a truncated list

of chemicals, but at the time this article was written, data from these new tests were still not available.[78] In addition to data on health risks, data on exposure sources and pathways are also needed to inform the most effective and cost-efficient regulations. For example, several phthalates have been banned from use in children's toys in the United States. However, the most sensitive exposure period may be in the developing fetus, and this would likely not be reduced with legislation geared only toward children's toys. Finally, there must be caution when replacing chemicals deemed high risk with new chemicals for which we know less about the potential toxic effects.

CONCLUSIONS AND FUTURE RESEARCH NEEDS

A growing body of evidence shows that exposure to a number of chemicals may adversely affect child development through altered endocrine function. However, many of the potential exposure-response relationships described here have not been adequately explored. For those that have been investigated in multiple studies, results have been inconsistent across studies. There are many possible explanations for variability in study findings, including differences in sample size, study design, study populations, life stage, data analysis approaches, and strategies for attaining data on exposures, end points, and important covariates. Many studies on EDCs to date among both children and adults are cross-sectional; there is a great need for well-designed longitudinal studies that measure both exposure and developmental end points at multiple potentially sensitive times. For nonpersistent EDCs, it is especially important for studies to consider intraindividual variability in exposure levels over time. Future research aimed at explaining sexually dimorphic effects of EDCs on development is also needed, as are studies capable of exploring health effects resulting from exposure to multiple EDCs simultaneously to more closely reflect the reality of being exposed to chemical mixtures. Research that combines molecular epidemiology and toxicology approaches should be conducted to establish causality and to elucidate specific biological mechanisms of EDCs in humans, individual susceptibility factors, and the stages of development most sensitive to exposure. Finally, more research is needed in the area of exposure science to enable more precise effect estimates in epidemiology studies used for risk assessment as well as to provide solid data on important exposure sources and pathways for risk management. The National Children's Study (http://www.nationalchildrensstudy.gov) and the Centers for Children's Environmental Health and Disease Prevention Research (http://www.niehs.nih.gov/research/supported/centers/prevention/) are important sources of cutting-edge research for developing new information on these topics.

Correspondence: John D. Meeker, ScD, Department of Environmental Health Sciences, University of Michigan School of Public Health, 6635 SPH Tower, 109 S Observatory St, Ann Arbor, MI 48109 (meekerj@umich.edu).

REFERENCES

1. Landrigan PJ, Goldman LR. Children's vulnerability to toxic chemicals: a challenge and opportunity to strengthen health and environmental policy. *Health Aff (Millwood)*. 2011;30(5):842-850.
2. Landrigan PJ, Miodovnik A. Children's health and the environment: an overview. *Mt Sinai J Med*. 2011;78(1):1-10.
3. Diamanti-Kandarakis E, Bourguignon JP, Giudice LC, et al. Endocrine-disrupting chemicals: an Endocrine Society scientific statement. *Endocr Rev*. 2009;30(4):293-342.
4. Schug TT, Janesick A, Blumberg B, Heindel JJ. Endocrine disrupting chemicals and disease susceptibility. *J Steroid Biochem Mol Biol*. 2011;127(3-5):204-215.
5. Titus-Ernstoff L, Troisi R, Hatch EE, et al. Birth defects in the sons and daughters of women who were exposed in utero to diethylstilbestrol (DES). *Int J Androl*. 2010;33(2):377-384.
6. Centers for Disease Control and Prevention. *Fourth National Report on Human Exposure to Environmental Chemicals.* Atlanta, GA: Centers for Disease Control & Prevention; 2010.
7. Caserta D, Mantovani A, Marci R, et al. Environment and women's reproductive health. *Hum Reprod Update*. 2011;17(3):418-433.
8. Eskenazi B, Chevrier J, Rosas LG, et al. The Pine River statement: human health consequences of DDT use. *Environ Health Perspect*. 2009;117(9):1359-1367.
9. Meeker JD. Exposure to environmental endocrine disrupting compounds and men's health. *Maturitas*. 2010;66(3):236-241.
10. Green R, Hauser R, Calafat AM, et al. Use of di(2-ethylhexyl) phthalate-containing medical products and urinary levels of mono(2-ethylhexyl) phthalate in neonatal intensive care unit infants. *Environ Health Perspect*. 2005;113(9):1222-1225.
11. Foster PM. Disruption of reproductive development in male rat offspring following in utero exposure to phthalate esters. *Int J Androl*. 2006;29(1):140-147, discussion 181-185.
12. Meeker JD, Sathyanarayana S, Swan SH. Phthalates and other additives in plastics: human exposure and associated health outcomes. *Philos Trans R Soc Lond B Biol Sci*. 2009;364(1526):2097-2113.
13. Meeker JD, Ferguson KK. Phthalates: human exposure and related health effects. In: Schecter A, ed. *Dioxins and Health*. 3rd ed. Hoboken, NJ: John Wiley & Sons; 2012.
14. Calafat AM, Weuve J, Ye X, et al. Exposure to bisphenol A and other phenols in neonatal intensive care unit premature infants. *Environ Health Perspect*. 2009;117(4):639-644.
15. vom Saal FS, Akingbemi BT, Belcher SM, et al. Chapel Hill bisphenol A expert panel consensus statement: integration of mechanisms, effects in animals and potential to impact human health at current levels of exposure. *Reprod Toxicol*. 2007;24(2):131-138.
16. Braun JM, Hauser R. Bisphenol A and children's health. *Curr Opin Pediatr*. 2011;23(2):233-239.
17. Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Mathews TJ, Osterman MJ. Births: final data for 2008. *Natl Vital Stat Rep*. 2010;59(1):1, 3-71.
18. Stillerman KP, Mattison DR, Giudice LC, Woodruff TJ. Environmental exposures and adverse pregnancy outcomes: a review of the science. *Reprod Sci*. 2008;15(7):631-650.
19. Wigle DT, Arbuckle TE, Turner MC, et al. Epidemiologic evidence of relationships between reproductive and child health outcomes and environmental chemical contaminants. *J Toxicol Environ Health B Crit Rev*. 2008;11(5-6):373-517.
20. Govarts E, Nieuwenhuijsen M, Schoeters G, et al; OBELIX; ENRIECO. Birth weight and prenatal exposure to polychlorinated biphenyls (PCBs) and dichlorodiphenyldichloroethylene (DDE): a meta-analysis within 12 European birth cohorts. *Environ Health Perspect*. 2012;120(2):162-170.
21. Zhang Y, Lin L, Cao Y, Chen B, Zheng L, Ge RS. Phthalate levels and low birth weight: a nested case-control study of Chinese newborns. *J Pediatr*. 2009;155(4):500-504.

22. Miao M, Yuan W, Zhu G, He X, Li DK. In utero exposure to bisphenol-A and its effect on birth weight of offspring. *Reprod Toxicol*. 2011;32(1):64-68.

23. Harley KG, Chevrier J, Schall RA, Sjödin A, Bradman A, Eskenazi B. Association of prenatal exposure to polybrominated diphenyl ethers and infant birth weight. *Am J Epidemiol*. 2011;174(8):885-892.

24. Meeker JD, Hu H, Cantonwine DE, et al. Urinary phthalate metabolites in relation to preterm birth in Mexico city. *Environ Health Perspect*. 2009;117(10):1587-1592.

25. Cantonwine D, Meeker JD, Hu H, et al. Bisphenol a exposure in Mexico City and risk of prematurity: a pilot nested case control study. *Environ Health*. 2010;9:62.

26. Whyatt RM, Adibi JJ, Calafat AM, et al. Prenatal di(2-ethylhexyl)phthalate exposure and length of gestation among an inner-city cohort. *Pediatrics*. 2009;124 (6):e1213-e1220.

27. Latini G, De Felice C, Presta G, et al. In utero exposure to di-(2-ethylhexyl) phthalate and duration of human pregnancy. *Environ Health Perspect*. 2003; 111(14):1783-1785.

28. Adibi JJ, Hauser R, Williams PL, et al. Maternal urinary metabolites of di-(2-ethylhexyl) phthalate in relation to the timing of labor in a US multicenter pregnancy cohort study. *Am J Epidemiol*. 2009;169(8):1015-1024.

29. Wolff MS, Engel SM, Berkowitz GS, et al. Prenatal phenol and phthalate exposures and birth outcomes. *Environ Health Perspect*. 2008;116(8):1092-1097.

30. Main KM, Skakkebaek NE, Virtanen HE, Toppari J. Genital anomalies in boys and the environment. *Best Pract Res Clin Endocrinol Metab*. 2010;24(2):279-289.

31. Skakkebaek NE, Rajpert-De Meyts E, Main KM. Testicular dysgenesis syndrome: an increasingly common developmental disorder with environmental aspects. *Hum Reprod*. 2001;16(5):972-978.

32. Swan SH, Elkin EP, Fenster L. The question of declining sperm density revisited: an analysis of 101 studies published 1934-1996. *Environ Health Perspect*. 2000; 108(10):961-966.

33. Travison TG, Araujo AB, O'Donnell AB, Kupelian V, McKinlay JB. A population-level decline in serum testosterone levels in American men. *J Clin Endocrinol Metab*. 2007;92(1):196-202.

34. Huyghe E, Matsuda T, Thonneau P. Increasing incidence of testicular cancer worldwide: a review. *J Urol*. 2003;170(1):5-11.

35. Ormond G, Nieuwenhuijsen MJ, Nelson P, et al. Endocrine disruptors in the workplace, hair spray, folate supplementation, and risk of hypospadias: case-control study. *Environ Health Perspect*. 2009;117(2):303-307.

36. Gaspari L, Paris F, Jandel C, et al. Prenatal environmental risk factors for genital malformations in a population of 1442 French male newborns: a nested case-control study. *Hum Reprod*. 2011;26(11):3155-3162.

37. Main KM, Kiviranta H, Virtanen HE, et al. Flame retardants in placenta and breast milk and cryptorchidism in newborn boys. *Environ Health Perspect*. 2007;115 (10):1519-1526.

38. Swan SH. Environmental phthalate exposure in relation to reproductive outcomes and other health endpoints in humans. *Environ Res*. 2008;108(2):177-184.

39. Suzuki Y, Yoshinaga J, Mizumoto Y, Serizawa S, Shiraishi H. Foetal exposure to phthalate esters and anogenital distance in male newborns [published online June 22, 2011]. *Int J Androl*. doi:10.1111/j.1365-2605.2011.01190.x.

40. Main KM, Mortensen GK, Kaleva MM, et al. Human breast milk contamination with phthalates and alterations of endogenous reproductive hormones in infants three months of age. *Environ Health Perspect*. 2006;114(2):270-276.

41. Euling SY, Herman-Giddens ME, Lee PA, et al. Examination of US puberty-timing data from 1940 to 1994 for secular trends: panel findings. *Pediatrics*. 2008; 121(suppl 3):S172-S191.

42. Aksglaede L, Sørensen K, Petersen JH, Skakkebaek NE, Juul A. Recent decline in age at breast development: the Copenhagen Puberty Study. *Pediatrics*. 2009; 123(5):e932-e939.

43. Mouritsen A, Aksglaede L, Sørensen K, et al. Hypothesis: exposure to endocrine-disrupting chemicals may interfere with timing of puberty. *Int J Androl*. 2010; 33(2):346-359.

44. Schoeters G, Den Hond E, Dhooge W, van Larebeke N, Leijs M. Endocrine disruptors and abnormalities of pubertal development. *Basic Clin Pharmacol Toxicol*. 2008;102(2):168-175.

45. Buck Louis GM, Gray LE Jr, Marcus M, et al. Environmental factors and puberty timing: expert panel research needs. *Pediatrics*. 2008;121(suppl 3):S192-S207.

46. Colón I, Caro D, Bourdony CJ, Rosario O. Identification of phthalate esters in the serum of young Puerto Rican girls with premature breast development. *Environ Health Perspect*. 2000;108(9):895-900.

47. Wolff MS, Teitelbaum SL, Pinney SM, et al; Breast Cancer and Environment Research Centers. Investigation of relationships between urinary biomarkers of phytoestrogens, phthalates, and phenols and pubertal stages in girls. *Environ Health Perspect*. 2010;118(7):1039-1046.

48. Durmaz E, Ozmert EN, Erkekoglu P, et al. Plasma phthalate levels in pubertal gynecomastia. *Pediatrics*. 2010;125(1):e122-e129.

49. Boyle CA, Boulet S, Schieve LA, et al. Trends in the prevalence of developmental disabilities in US children, 1997-2008. *Pediatrics*. 2011;127(6):1034-1042.

50. Kim YS, Leventhal BL, Koh YJ, et al. Prevalence of autism spectrum disorders in a total population sample. *Am J Psychiatry*. 2011;168(9):904-912.

51. Hertz-Picciotto I, Delwiche L. The rise in autism and the role of age at diagnosis. *Epidemiology*. 2009;20(1):84-90.

52. Aguiar A, Eubig PA, Schantz SL. Attention deficit/hyperactivity disorder: a focused overview for children's environmental health researchers. *Environ Health Perspect*. 2010;118(12):1646-1653.

53. Parent AS, Naveau E, Gerard A, Bourguignon JP, Westbrook GL. Early developmental actions of endocrine disruptors on the hypothalamus, hippocampus, and cerebral cortex. *J Toxicol Environ Health B Crit Rev*. 2011;14(5-7):328-345.

54. Miodovnik A. Environmental neurotoxicants and developing brain. *Mt Sinai J Med*. 2011;78(1):58-77.

55. Korrick SA, Sagiv SK. Polychlorinated biphenyls, organochlorine pesticides and neurodevelopment. *Curr Opin Pediatr*. 2008;20(2):198-204.

56. Rosas LG, Eskenazi B. Pesticides and child neurodevelopment. *Curr Opin Pediatr*. 2008;20(2):191-197.

57. Swan SH, Liu F, Hines M, et al. Prenatal phthalate exposure and reduced masculine play in boys. *Int J Androl*. 2010;33(2):259-269.

58. Braun JM, Kalkbrenner AE, Calafat AM, et al. Impact of early-life bisphenol A exposure on behavior and executive function in children. *Pediatrics*. 2011;128 (5):873-882.

59. Herbstman JB, Sjödin A, Kurzon M, et al. Prenatal exposure to PBDEs and neurodevelopment. *Environ Health Perspect*. 2010;118(5):712-719.

60. Harris KB, Pass KA. Increase in congenital hypothyroidism in New York State and in the United States. *Mol Genet Metab*. 2007;91(3):268-277.

61. Boas M, Feldt-Rasmussen U, Main KM. Thyroid effects of endocrine disrupting chemicals [published online September 10, 2011]. *Mol Cell Endocrinol*. doi:10.1016/j.mce.2011.09.005.

62. Miller MD, Crofton KM, Rice DC, Zoeller RT. Thyroid-disrupting chemicals: interpreting upstream biomarkers of adverse outcomes. *Environ Health Perspect*. 2009;117(7):1033-1041.

63. Wang Y, Lobstein T. Worldwide trends in childhood overweight and obesity. *Int J Pediatr Obes*. 2006;1(1):11-25.

64. La Merrill M, Birnbaum LS. Childhood obesity and environmental chemicals. *Mt Sinai J Med*. 2011;78(1):22-48.

65. Grün F, Blumberg B. Minireview: the case for obesogens. *Mol Endocrinol*. 2009; 23(8):1127-1134.

66. Hatch EE, Nelson JW, Stahlhut RW, Webster TF. Association of endocrine disruptors and obesity: perspectives from epidemiological studies. *Int J Androl*. 2010; 33(2):324-332.

67. Verhulst SL, Nelen V, Hond ED, et al. Intrauterine exposure to environmental pollutants and body mass index during the first 3 years of life. *Environ Health Perspect*. 2009;117(1):122-126.

68. Dhooge W, Den Hond E, Koppen G, et al. Internal exposure to pollutants and body size in Flemish adolescents and adults: associations and dose-response relationships. *Environ Int*. 2010;36(4):330-337.

69. Wolff MS, Teitelbaum SL, Windham G, et al. Pilot study of urinary biomarkers of phytoestrogens, phthalates, and phenols in girls. *Environ Health Perspect*. 2007; 115(1):116-121.

70. Paulson JA, Gordon L. Clinical services in environmental pediatrics. *Mt Sinai J Med*. 2011;78(1):11-21.

71. Dunagan SC, Dodson RE, Rudel RA, Brody JG. Toxics use reduction in the home: lessons learned from household exposure studies. *J Clean Prod*. 2011;19(5): 438-444.

72. Rudel RA, Gray JM, Engel CL, et al. Food packaging and bisphenol A and bis(2-ethyhexyl) phthalate exposure: findings from a dietary intervention. *Environ Health Perspect*. 2011;119(7):914-920.

73. Lu C, Toepel K, Irish R, Fenske RA, Barr DB, Bravo R. Organic diets significantly lower children's dietary exposure to organophosphorus pesticides. *Environ Health Perspect*. 2006;114(2):260-263.

74. Environmental Working Group. Reducing your exposure to PBDEs in your home. http://www.ewg.org/pbdefree. Accessed December 31, 2011.

75. Van Vliet ED, Reitano EM, Chhabra JS, Bergen GP, Whyatt RM. A review of alternatives to di (2-ethylhexyl) phthalate-containing medical devices in the neonatal intensive care unit. *J Perinatol*. 2011;31(8):551-560.

76. Vogel SA, Roberts JA. Why the toxic substances control act needs an overhaul, and how to strengthen oversight of chemicals in the interim. *Health Aff (Millwood)*. 2011;30(5):898-905.

77. Harding AK, Daston GP, Boyd GR, et al. Endocrine disrupting chemicals research program of the US Environmental Protection Agency: summary of a peer-review report. *Environ Health Perspect*. 2006;114(8):1276-1282.

78. US Environmental Protection Agency. Endocrine Disruptor Screening Program (EDSP). http://www.epa.gov/endo/. Accessed December 31, 2011.