# Disparities in Environmental Exposures to Endocrine-Disrupting Chemicals and Diabetes Risk in Vulnerable Populations

*Daniel Ruiz,[1] Marisol Becerra,[2] Jyotsna S. Jagai,[3] Kerry Ard,[2] and Robert M. Sargis[4]*

*Diabetes Care 2018;41:193–205 | https://doi.org/10.2337/dc16-2765*

**Burgeoning epidemiological, animal, and cellular data link environmental endocrine-disrupting chemicals (EDCs) to metabolic dysfunction. Disproportionate exposure to diabetes-associated EDCs may be an underappreciated contributor to disparities in metabolic disease risk. The burden of diabetes is not uniformly borne by American society; rather, this disease disproportionately affects certain populations, including African Americans, Latinos, and low-income individuals. The purpose of this study was to review the evidence linking unequal exposures to EDCs with racial, ethnic, and socioeconomic diabetes disparities in the U.S.; discuss social forces promoting these disparities; and explore potential interventions. Articles examining the links between chemical exposures and metabolic disease were extracted from the U.S. National Library of Medicine for the period of 1966 to 3 December 2016. EDCs associated with diabetes in the literature were then searched for evidence of racial, ethnic, and socioeconomic exposure disparities. Among Latinos, African Americans, and low-income individuals, numerous studies have reported significantly higher exposures to diabetogenic EDCs, including polychlorinated biphenyls, organochlorine pesticides, multiple chemical constituents of air pollution, bisphenol A, and phthalates. This review reveals that unequal exposure to EDCs may be a novel contributor to diabetes disparities. Efforts to reduce the individual and societal burden of diabetes should include educating clinicians on environmental exposures that may increase disease risk, strategies to reduce those exposures, and social policies to address environmental inequality as a novel source of diabetes disparities.**

Diabetes is a complex and devastating metabolic disease that arises from impairments in insulin production and/or action with consequential derangements in global energy metabolism. In the U.S., diabetes is the leading cause of adult blindness, kidney failure, and nontraumatic amputations; moreover, it is a central driver of cardiovascular disease, the leading cause of death among people with diabetes. Diabetes disproportionately afflicts African Americans, Latinos, and low-income individuals. Compared with non-Hispanic whites, the risk of developing diabetes is estimated to be 66% higher for Hispanics and 77% higher for African Americans (1). Indeed, 17.9% of African Americans and 20.5% of Mexican Americans have diabetes compared with only 9.1% of non-Hispanic whites, and these disparities in diabetes prevalence have been amplified over the past decade (2). Furthermore, age-adjusted diabetes mortality rates are significantly higher among Hispanics and non-Hispanic blacks than non-Hispanic whites (3). Understanding the complete array of factors that contribute to racial and ethnic differences in the pathogenesis of metabolic disease is critical for addressing the disproportionate burden of diabetes in communities of color.

REVIEW

[1]*Committee on Molecular Metabolism and Nutrition, University of Chicago, Chicago, IL*
[2]*College of Food, Agricultural, and Environmental Sciences, School of Environment and Natural Resources, Ohio State University, Columbus, OH*
[3]*Environmental and Occupational Health Sciences Division, School of Public Health, University of Illinois at Chicago, Chicago, IL*
[4]*Division of Endocrinology, Diabetes, and Metabolism, Department of Medicine, University of Illinois at Chicago, Chicago, IL*

*Corresponding author: Robert M. Sargis, rsargis@uic.edu.*

*Received 27 December 2016 and accepted 23 September 2017.*

*This article contains Supplementary Data online at http://care.diabetesjournals.org/lookup/suppl/doi:10.2337/dc16-2765/-/DC1.*

Although physical inactivity and caloric excess undoubtedly are risk factors, emerging evidence implicates environmental endocrine-disrupting chemicals (EDCs) as contributors to the diabetes epidemic. The Endocrine Society defines an EDC as an exogenous chemical or mixture of chemicals that interferes with any aspect of hormone action (4). Of note, the dramatic rise in U.S. diabetes rates correlates closely with synthetic chemical production (5), and these associations are now supported by epidemiological, animal, and cellular data that demonstrate that EDCs can interfere with insulin secretion and action as well as with other pathways that regulate glucose homeostasis. Despite a history of environmental pollution disproportionately affecting communities of color in the U.S. (6), the potential contribution of environmental toxicants to racial and ethnic differences in diabetes risk is underappreciated.

The issue of environmental injustice first entered widespread consciousness in 1982 when residents of the predominantly African American community of Warren County, North Carolina, made national news by laying themselves across a rural road to prevent encroaching trucks from dumping dirt laden with polychlorinated biphenyls (PCBs) in their community (6). This media attention prompted empirical examination of the community's claim that toxic waste facilities were being disproportionately sited in low-income communities and communities of color. This research has grown substantially since the 1980s, with the majority of evidence showing racial and socioeconomic disparities in exposures to myriad environmental hazards (6). In addition to higher exposure to air pollution nationwide (7), unequal exposures among people of color are also rooted in patterns of occupation, housing conditions, and neighborhood infrastructure (8,9). This article reviews the state of the evidence linking ethnic, racial, and socioeconomic disparities in pollutant exposure in the U.S. to EDCs linked to diabetes.

## UNEQUAL ENVIRONMENTAL EXPOSURES AND DIABETES RISK

Scientific evidence linking EDCs with the development of diabetes and other metabolic disorders continues to grow. Of note, exposures to several toxicants have been prospectively linked to diabetes risk, including PCBs, organochlorine (OC) pesticides, various chemical constituents of air pollution, bisphenol A (BPA), and phthalates (Table 1); moreover, exposure to these EDCs is higher among African Americans, Latinos, and low-income individuals (Supplementary Table 1). These unequal exposures raise the possibility that EDCs are underappreciated contributors to diabetes disparities.

### PCBs

Introduced in the U.S. in the 1930s for a variety of industrial purposes, PCBs are a class of synthetic compounds where various combinations of hydrogen atoms on the biphenyl ($C_{12}H_{10}$) structure are substituted with chlorine, resulting in 209 congeners designated by a unique number reflecting the extent and position of their chlorination (e.g., PCB 153). Although banned by the U.S. Environmental Protection Agency in 1977, PCBs remain detectable in human tissues as a result of their environmental and biological persistence (10). Higher PCB exposures among African Americans have been documented since the 1960s (11) (Supplementary Table 1). Ongoing human exposure to PCBs is due to the legacy of contamination in food, including certain fish (12); however, additional exposure sources include leaching from contaminated industrial sites and indoor construction materials (13,14). PCB waste is found in Superfund and toxic waste sites that are concentrated in neighborhoods of color (6). Although catfish consumption has been suggested as the main contributor to increased PCB levels in African Americans (15), the historical siting of PCB production and disposal sites in predominantly black communities is likely a significant additional contributor to increased contamination of locally sourced foods. One example of this phenomenon is Anniston, Alabama, a PCB manufacturing city from 1929 to 1971. African Americans not only lived closer to a former Monsanto PCB manufacturing plant but also had PCB levels three times higher than whites living in Anniston (16). Consumption of local fish and livestock were the strongest predictors of higher serum PCB levels among African Americans (17), whereas consumption of local dairy products and dredging near another PCB-contaminated Superfund site also predicted higher cord blood PCB levels in infants (18).

A large body of evidence, including prospective epidemiological studies, supports the hypothesis that PCBs are metabolic disease risk factors. For example, residential proximity to PCB-contaminated waste sites is associated with higher diabetes hospitalization rates (19). Among female residents of Anniston, serum PCB levels were significantly associated with diabetes (20), whereas in a separate study with 25 years of follow-up, women with higher PCB levels exhibited increased diabetes incidence (incidence density ratio 2.33 [95% CI 1.25–4.34]) (21). Similarly, women exposed to PCB-laced rice bran oil during the Yucheng poisoning event in Taiwan also had an increased risk of developing diabetes (odds ratio [OR] 2.1 [95% CI 1.1–4.5]), with markedly higher risk among those who developed chloracne, a cutaneous manifestation of dioxin-like PCB exposure (OR 5.5 [95% CI 2.1–13.4]) (22). A meta-analysis that pooled data from the Nurses' Health Study (NHS) with six prospective studies showed that total PCBs were associated with incident diabetes (OR 1.70 [95% CI 1.28–2.27]) (23). Further supporting these prospective links between PCB exposure and diabetes are data from cohort studies, including the Prospective Investigation of the Vasculature in Uppsala Seniors (PIVUS) (24) and a group followed for nearly 20 years (25). Finally, although not reaching statistical significance, a study of Swedish women suggested that higher levels of PCB 153 were similarly associated with increased rates of type 2 diabetes diagnosed after $>$6 years of follow-up (OR 1.6 [95% CI 0.61–4.0]) (26). Collectively, these data suggest an association between PCBs and diabetes risk, especially among women; however, some discrepant findings exist in the literature. In a study of Great Lakes sport fish consumers, PCB 118 and total PCBs were not associated with diabetes (27), and in a Flemish study that adjusted for correlated exposures, PCBs showed a negative association with self-reported diabetes (28). Despite these discrepancies, a meta-analysis of both cross-sectional and prospective studies published before March 2014 showed that in aggregate, total PCBs are associated with increased diabetes risk (relative risk [RR] 2.39 [95% CI 1.86–3.08]) (29). Taken within the context of animal and cellular data demonstrating that PCBs alter metabolic function (Supplementary Table 2), this evidence collectively suggests that PCBs contribute to diabetes risk and disparities.

**Table 1—Prospective studies documenting associations between EDC exposure and diabetes risk**

| Reference | Population | Outcome and comparison | Effect estimate (95% CI) |
|---|---|---|---|
| PCBs | | | |
| Vasiliu et al., 2006 (21) | 1,384 subjects without diabetes in the Michigan polybrominated biphenyls cohort followed for 25 years | Incident diabetes in women with the highest vs. lowest serum PCB levels | IDR: 2.33 (1.25–4.34)* |
| Wang et al., 2008 (22) | 378 subjects and 370 matched referents from the Yucheng poisoning in Taiwan in the 1970s | Incident diabetes in women who consumed rice bran oil laced with PCBs as well as a subgroup who developed chloracne, a manifestation of dioxin-like PCB exposure | OR: 2.1 (1.1–4.5)*; Chloracne OR: 5.5 (2.1–13.4)* |
| Turyk et al., 2009 (27) | 471 Great Lakes sport fish consumers without diabetes followed from 1994/1995 to 2005 | Incident diabetes among the highest vs. lowest tertile of PCB levels | Total PCBs IRR: 1.8 (0.6–5.0); PCB 118 IRR: 1.3 (0.5–3.0) |
| Wu et al., 2013 (23) | Two case-control studies of women without diabetes from the NHS and a meta-analysis of pooled data with six additional prospective studies | Incident diabetes after pooling of data and comparing highest PCB exposure group with the referent | Pooled OR: 1.70 (1.28–2.27)* |
| Rignell-Hydbom et al., 2009 (26) | Case-control study of women age 50–59 years in southern Sweden | Incident diabetes in 39 patients and matched control subjects after ≥6 years of follow-up comparing the highest quartile of PCB levels with the referent | OR: 1.6 (0.61–4.0) |
| Lee et al., 2010 (25) | 90 patients and control subjects in a nested case-control study followed for ~18 years | Incident diabetes comparing second sextile or quartile with the referent for a summary measure of 16 POPs, including 12 PCBs as well as individual PCBs | PCB sum OR: 5.3*; PCB 187 OR: 2.8 (1.1–7.4)* |
| Lee et al., 2011 (24) | 725 participants from the PIVUS study | Incident diabetes comparing a summary measure of 14 PCBs across quintiles with the referent | Quintile 2 OR: 4.5 (0.9–23.5); Quintile 3 OR: 5.1 (1.0–26.0); Quintile 4 OR: 8.8 (1.8–42.7)*; Quintile 5 OR: 7.5 (1.4–38.8)*; $P_{trend} < 0.01$ |
| Song et al., 2016 (29) | Meta-analysis of 13 cross-sectional and 8 prospective studies published before 8 March 2014 examining links between PCBs and diabetes risk | Pooled diabetes risk in the highest vs. lowest exposure groups for PCBs | RR: 2.39 (1.86–3.08)* |
| OC pesticides | | | |
| Wu et al., 2013 (23) | Two case-control studies of women without diabetes from the NHS and a meta-analysis of pooled data with six additional prospective studies | Incident diabetes comparing highest tertile of plasma HCB levels in NHS and highest to lowest exposure group in pooled prospective studies | NHS OR: 3.14 (1.28–7.67)*; Pooled OR: 2.00 (1.13–3.53)* |
| Turyk et al., 2009 (27) | 471 Great Lakes sport fish consumers without diabetes followed from 1994/1995 to 2005 | Incident diabetes comparing tertiles of serum DDE levels with the referent | Tertile 2 IRR: 5.5 (1.2–25.1)*; Tertile 3 IRR: 7.1 (1.6–31.9)* |
| Rignell-Hydbom et al., 2009 (26) | Case-control study of women age 50–59 years in southern Sweden | Incident diabetes in 39 patients and matched control subjects after ≥6 years of follow-up comparing the highest quartile of DDE levels with the referent | OR: 5.5 (1.2–25)* |
| Lee et al., 2010 (25) | 90 patients and control subjects in a nested case-control study followed for ~18 years | Incident diabetes comparing second sextile with the referent for summary measure of 16 POPs (including 3 OC pesticides) or second quartile with the referent for *trans*-nonachlor | Sum OR: 5.4 (1.6–18.4)*; *Trans*-nonachlor OR: 4.3 (1.5–12.6)* |
| Lee et al., 2011 (24) | 725 participants from the PIVUS study | Incident diabetes comparing quintiles of OC pesticides or summary measure of three OC pesticides with the referent | Quintile 5 sum OC pesticides OR: 3.4 (1.0–11.7); $P_{trend} = 0.03$; Quintile 4 *trans*-nonachlor OR: 4.2 (1.3–13.3)*; $P_{trend} = 0.03$ |
| Van Larebeke et al., 2015 (28) | 973 participants of the Flemish Environment and Health Survey | Risk of incident diabetes calculated for a doubling of serum or comparing 90th percentile with 10th percentile of levels for HCB (men and women) or DDE (men only) | Doubled HCB OR: 1.61 (1.07–2.42)*; 90th vs. 10th percentile HCB OR: 6.27*; Doubled DDE OR: 1.66 (1.09–2.53)*; 90th vs. 10th percentile DDE OR: 5.39* |

*Continued on p. 196*

**Table 1—Continued**

| Reference | Population | Outcome and comparison | Effect estimate (95% CI) |
|---|---|---|---|
| Starling et al., 2014 (35) | 13,637 women from the Agricultural Health Study | Incident diabetes for ever use of the OC pesticide dieldrin | HR: 1.99 (1.12–3.54)* |
| Song et al., 2016 (29) | Meta-analysis of 11 cross-sectional and 6 prospective studies published before 8 March 2014 examining links among various pesticides and diabetes risk | Pooled diabetes risk in the highest vs. lowest exposure groups for pesticides | RR: 2.30 (1.81–2.93)* |
| Chemical constituents of air pollution | | | |
| Brook et al., 2016 (41) | 65 adults with metabolic syndrome and insulin resistance from the Air Pollution and Cardiometabolic Diseases China Study | Change in HOMA-IR per SD increase in personal-level black carbon or $PM_{2.5}$ exposure during the fourth and fifth days of assessment | Day 4 black carbon: 0.18 (0.01–0.36)*; Day 5 black carbon: 0.22 (0.04–0.39)*; Day 4 $PM_{2.5}$: 0.18 (0.02–0.34)*; Day 5 $PM_{2.5}$: 0.22 (0.08–0.36)* |
| Weinmayr et al., 2015 (43) | 3,607 individuals from the Heinz Nixdorf Recall Study in Germany followed for an average of 5.1 years | Incident diabetes relative IQR increase in $PM_{10}$, $PM_{2.5}$, traffic-specific $PM_{10}$, and traffic-specific $PM_{2.5}$ as well as comparison of living <100 m vs. 200 m from a busy road | $PM_{10}$ RR: 1.20 (1.01–1.42)*; $PM_{2.5}$ RR: 1.08 (0.89–1.29); Traffic $PM_{10}$ RR: 1.11 (0.99–1.23); Traffic $PM_{2.5}$ RR: 1.10 (0.99–1.23); <100 m RR: 1.37 (1.04–1.81)* |
| To et al., 2015 (93) | 29,549 women from the Canadian National Breast Screening Study | Change in diabetes prevalence per 10 $\mu g/m^3$ increase in $PM_{2.5}$ exposure | PRR: 1.28 (1.16–1.41)* |
| Park et al., 2015 (46) | 5,839 subjects in the Multi-Ethnic Study of Atherosclerosis cohort | Prevalent and incident diabetes risk per IQR increase in residential concentrations of $PM_{2.5}$ or $NO_x$ | Prevalent DM $PM_{2.5}$ OR: 1.09 (1.00–1.17)*; Prevalent DM $NO_x$ OR: 1.18 (1.01–1.38)*; Incident DM $PM_{2.5}$ HR: 1.02 (0.95–1.10); Incident DM $NO_x$ HR: 1.00 (0.86–1.16) |
| Pope et al., 2015 (48) | 669,046 participants from the American Cancer Society Cancer Prevention Study II | Risk of diabetes-associated death on death certificates per 10 $\mu g/m^3$ increase in $PM_{2.5}$ | HR: 1.13 (1.02–1.26)* |
| Brook et al., 2013 (49) | 2.1 million adults from the 1991 Canadian Census Mortality Follow-up Study | Diabetes-associated mortality per 10 $\mu/m^3$ increase in $PM_{2.5}$ | HR: 1.49 (1.37–1.62)* |
| Thiering et al., 2013 (42) | Fasting blood from 397 10-year-old children in two prospective German birth cohort studies | Change in HOMA-IR per 2-SD increase in ambient $NO_2$ and $PM_{10}$ and for every 500 m to nearest major road | $NO_2$: 17.0% (5.0–30.3%)*; $PM_{10}$: 18.7% (2.9–36.9%)*; Road proximity: 7.2% (0.8–14.0%)* |
| Coogan et al., 2012 (44) | 3,992 black women living in Los Angeles followed for 10 years | Incident diabetes per IQR increase in $NO_x$ or 10 $\mu g/m^3$ increase in $PM_{2.5}$ | $NO_x$ IRR: 1.25 (1.07–1.46)*; $PM_{2.5}$ IRR: 1.63 (0.78–3.44) |
| Coogan et al., 2016 (47) | 43,003 participants in the Black Women's Health Study followed from 1995 to 2011 | Incident diabetes per IQR increase in $NO_2$ by using both land use repression and dispersion models | Land use HR: 0.96 (0.88–1.06); Dispersion HR: 0.94 (0.80–1.10) |
| Krämer et al., 2010 (45) | 1,775 women without diabetes age 54–55 followed for 16 years in West Germany | Incident diabetes per IQR increase in exposure on the basis of data from monitoring stations, emission inventories, or land use regression models as well as distance from busy road (<100 m) relative to education status | Monitored $PM_{10}$ HR: 1.16 (0.81–1.65); Monitored $NO_2$ HR: 1.34 (1.02–1.76)*; Inventory traffic PM HR: 1.15 (1.04–1.27)*; Inventory traffic $NO_2$ HR: 1.15 (1.04–1.27)*; Land use soot HR: 1.27 (1.09–1.48)*; Land use $NO_2$ HR: 1.42 (1.16–1.73)*; <100 m/low education HR: 2.54 (1.31–4.91)*; <100 m/high education HR: 0.92 (0.58–1.47) |
| Schneider et al., 2008 (50) | 22 people with type 2 diabetes living in North Carolina | Changes in vascular parameters per 10 $\mu/m^3$ increase in $PM_{2.5}$ accounting for lag period (in days) | Lag 0 FMD: −17.3 (−34.6 to 0.0)*; Lag 1 SAEI: −17.0 (−27.5 to −6.4)*; Lag 3 SAEI: −15.1 (−29.3 to −0.9)* |
| O'Donnell et al., 2011 (51) | 9,202 patients hospitalized with ischemic stroke | Risk of ischemic stroke among patients with diabetes per 10 $\mu g/m^3$ increase in $PM_{2.5}$ | 11% (1–22%)* |
| Brook et al., 2013 (40) | 25 healthy adults from rural Michigan brought to an urban location for 5 consecutive days | Change in HOMA-IR per 10 $\mu g/m^3$ increase in $PM_{2.5}$ | 0.7 (0.1–1.3)* |

*Continued on p. 197*

**Table 1—Continued**

| Reference | Population | Outcome and comparison | Effect estimate (95% CI) |
|---|---|---|---|
| BPA | | | |
| Sun et al., 2014 (60) | 971 incident type 2 diabetes case-control pairs from the NHS and NHS II | Incident diabetes after adjusting for BMI comparing highest with the referent quartile of urinary BPA levels | NHS OR: 0.81 (0.48–1.38); NHS II OR: 2.08 (1.17–3.69)* |
| Bi et al., 2016 (61) | 2,209 middle-aged and elderly subjects without diabetes followed for 4 years | Incident diabetes risk in highest quartile vs. lowest quartile of urinary BPA level for each 10-point increase in a diabetes genetic risk score | OR: 1.89 (1.31–2.72)* |
| Hu et al., 2015 (62) | 121 patients with type 2 diabetes followed for 6 years | Incident chronic kidney disease in patients with diabetes comparing highest with referent tertile of urinary BPA level | OR: 6.65 (1.47–30.04)* |
| Song et al., 2016 (29) | Meta-analysis of five cross-sectional and prospective studies published before 8 March 2014 examining links between BPA and diabetes risk | Pooled diabetes risk in the highest vs. lowest exposure groups for BPA | RR: 1.45 (1.13–1.87)* |
| Phthalates | | | |
| Sun et al., 2014 (60) | 971 incident type 2 diabetes case-control pairs from the NHS and NHS II | Incident diabetes after adjusting for BMI comparing highest with the referent quartile of urinary phthalate levels | NHS DEHP OR: 1.34 (0.77–2.30); NHS butyl phthalates OR: 0.91 (0.50–1.68); NHS total phthalates OR: 0.87 (0.49–1.53); NHS II DEHP OR: 1.91 (1.04–3.49)*; NHS II butyl phthalates OR: 3.16 (1.68–5.95)*; NHS II total phthalates OR: 2.14 (1.19–3.85)* |
| Watkins et al., 2016 (70) | 250 children of women enrolled in the Early Life Exposure in Mexico to Environmental Toxicants cohort | Change in insulin secretion as assessed by a C-peptide index per IQR increase in either in utero MEP levels for pubertal boys or peripubertal DEHP for prepubertal girls | Pubertal boys: −17% (−29 to −3.3%)*; Prepubertal girls: 20% (2.5–41%)* |
| Song et al., 2016 (29) | Meta-analysis of four cross-sectional and prospective studies published before 8 March 2014 examining links between phthalates and diabetes risk | Pooled diabetes risk in the highest vs. lowest exposure groups for BPA | RR: 1.48 (0.98–2.25) |

Data are from studies from around the world (Supplementary Fig. 1). DM, diabetes; FMD, flow-mediated dilatation; IDR, incidence density ratio; PRR, prevalence rate ratio; SAEI, small-artery elasticity index.
*$P < 0.05$.

### OC Pesticides

OC pesticides were extensively used in the U.S. until the 1970s when most were banned because of their environmental persistence and toxicity to humans and wildlife; however, several OC pesticides and their metabolites are still measurable in the U.S. population. Levels of these compounds are greater in Mexican Americans and African Americans compared with whites (Supplementary Table 1). The prolonged use of OC pesticides outside of the U.S. for agricultural purposes or vector control is believed to contribute to higher levels in Latino populations (10,30,31). Indeed, on the basis of National Health and Nutrition Examination Survey data, people born outside the U.S. are more likely to be exposed to OC pesticides (32). However, the overrepresentation of Mexican Americans in U.S. agriculture may also play a role in exposure disparities (33). In addition, direct exposures to OC pesticides before their phaseout may have been passed down to offspring through breast milk and cord blood (34), likely resulting in higher body burdens at the start of life that persist into adulthood.

In concordance with animal and cellular data demonstrating the capacity of OC pesticides to disrupt multiple aspects of cellular and systemic glucose regulation (Supplementary Table 2), epidemiological studies from various regions of the world have associated OC pesticide exposure with diabetes and the metabolic syndrome (Table 1). For example, plasma hexachlorobenzene (HCB) was positively associated with incident type 2 diabetes, an effect confirmed in an accompanying meta-analysis (OR 2.00 [95% CI 1.13–3.53]) (23). Among Great Lakes sport fish consumers, levels of dichlorodiphenyldichloroethylene (DDE), a metabolite of dichlordiphenyltrichloroethane (DDT), were associated with incident diabetes (27), whereas a study in Swedish women showed that being in the highest quartile of DDE levels relative to the lowest quartile was associated with incident diabetes (OR 5.5 [95% CI 1.2–25]) (26). In a nested case-control cohort of individuals followed for nearly 20 years, the OC pesticides *trans*-nonachlor, oxychlordane, and mirex were nonlinearly associated with new-onset diabetes (25). In the PIVUS study, *trans*-nonachlor and a summary index of three OC pesticides also were positively associated with diabetes at age

75 years (24). In a Flemish biomonitoring program, OC pesticide levels measured in 2004–2005 were associated with self-reported diabetes in 2011; this included HCB as well as DDE in men (28). Finally, in the Agricultural Health Study, a large prospective cohort of pesticide applicators and their spouses, the OC pesticide dieldrin was associated with incident diabetes (hazard ratio [HR] 1.99 [95% CI 1.12–3.54]) (35). By compiling data across studies, a meta-analysis comparing the highest to lowest exposure groups demonstrated a strong positive correlation between OC pesticide exposure and diabetes rates (RR 2.30 [95% CI 1.81–2.93]) (29).

### Traffic-Related Air Pollution and Particulate Matter

Traffic-related air pollution comprises various chemical components, including nitric oxides ($NO_x$), ozone, and particulate matter (PM), which is a mixture of particles and liquids classified by their diameter (e.g., $<$10 μm [$PM_{10}$] or $<$2.5 μm [$PM_{2.5}$]). Nationwide studies have shown that African Americans and Latinos are exposed to significantly more $PM_{2.5}$ (7,36), and ethnic and racial disparities in exposure to traffic-related air pollution exceed those between income groups (37) (Supplementary Table 1). $NO_2$ levels correlate closely with $PM_{2.5}$, ultrafine particles, and black carbon and thus serve as a proxy for traffic-related air pollution (38). Exposure to $NO_2$ is 38% higher for people of color than for non-Hispanic whites and 10% higher for people below the poverty line (37). Among nonwhite individuals living in poverty, children age $<$5 years are exposed to 23% higher $NO_2$ concentrations than the rest of the population (37). Of note, racial differences in $NO_2$ exposure are greater in large metropolitan centers compared with small-to-medium urban areas, likely reflecting racial and ethnic segregation around traffic corridors in major U.S. cities.

Increasing evidence implicates air pollution in glucose dysregulation, including insulin resistance (39) (Table 1). In a small, but elegant study of residents of rural Michigan, exposure to urban air for only 4–5 h daily for 5 consecutive days increased HOMA insulin resistance (HOMA-IR) for each 10 μg/$m^3$ increase in $PM_{2.5}$ (40). Similarly, in adults with the metabolic syndrome living in the Beijing metropolitan area, variations in black carbon and $PM_{2.5}$ have been associated with worsening insulin resistance (41). In Germany, long-term exposure to $PM_{10}$ and $NO_2$ was associated with greater insulin resistance in 10-year-old children (42). In addition, several studies have linked poor air quality with progression to diabetes. In one study of individuals without diabetes followed for 5.1 years, each interquartile range (IQR) increase in total $PM_{10}$ was associated with a 20% increased risk of developing type 2 diabetes (RR 1.20 [95% CI 1.01–1.42]) (43). Living $<$100 m (relative to $>$200 m) from a busy road was associated with a 37% increased risk of developing diabetes (RR 1.37 [95% CI 1.04–1.81]). Furthermore, higher levels of $PM_{2.5}$, traffic-specific $PM_{10}$, and traffic-specific $PM_{2.5}$ were associated with increased diabetes risk; however, these measures failed to reach statistical significance. In a study of black women living in Los Angeles, California, followed for 10 years, incident diabetes rates were increased for each IQR increase in $NO_x$ (incidence rate ratio [IRR] 1.25 [95% CI 1.07–1.46]), whereas $PM_{2.5}$ was associated with a nonsignificant increase in incident diabetes (IRR 1.63 [95% CI 0.78–3.44]) (44). Among woman without diabetes from the Study of the Influence of Air Pollution on Lung, Inflammation, and Aging cohort followed for 16 years, incident diabetes increased by 15–42% per IQR of $PM_{10}$ or traffic-related air pollution (45). The data from prospective studies are not, however, uniform. In the Multi-Ethnic Study of Atherosclerosis, $NO_x$ was associated with prevalent diabetes, and $PM_{2.5}$ trended toward an association (OR 1.09 [95% CI 1.00–1.17]), but no air pollution measure was associated with incident diabetes over 9 years of follow-up (46). In a long-term analysis of the Black Women's Health Study with adjustment for multiple metabolic stressors, $NO_2$ was not associated with diabetes incidence (47). Despite this heterogeneity, epidemiological studies linking various chemical constituents of air pollution to diabetes risk coupled with animal studies demonstrating that exposures to air pollutants such as $PM_{2.5}$ and polyaromatic hydrocarbons disrupt metabolism and promote inflammation (Supplementary Table 2) suggest that differential exposure to air pollution may augment diabetes risk in low-income communities of color.

In addition to effects on diabetes development per se, air pollutants may also promote adverse outcomes in those with the disease. For example, $PM_{2.5}$ levels modeled for home addresses were linked to diabetes on death certificates (48), whereas a prospective analysis of $>$2 million adults revealed that a 10 μg/$m^3$ increase in $PM_{2.5}$ was associated with increased diabetes-related mortality (49). These findings may be related to adverse vascular effects in individuals with diabetes. In 22 patients with type 2 diabetes living in North Carolina, daily measures of flow-mediated vasodilatation were decreased in association with $PM_{2.5}$ levels (50). The clinical significance of this finding may be reflected in data showing that each 10 μg/$m^3$ increase in $PM_{2.5}$ was associated with an 11% increased risk of ischemic stroke in individuals with diabetes (51).

### BPA

BPA is a ubiquitous synthetic chemical used in the manufacturing of polycarbonate and other plastics commonly used in consumer products; moreover, BPA is a component of sales receipts and epoxy resins lining food and beverage cans as well as water pipes. BPA exposure in the U.S. population is nearly universal (52). Although BPA is rapidly cleared from the body and single measurements may not reflect cumulative exposure (53), African Americans and people with lower incomes have higher BPA levels than the population at large (Supplementary Table 1). The reasons for these disparities are not clear, but reduced access to fresh food and consequential consumption of processed foods may partly explain these associations (54) because consuming foods packaged in plastic or cans increases BPA exposure (55). Moreover, among individuals with low food security, BPA levels are higher if they receive emergency food assistance, which includes canned foods (56). For example, 6–11-year-old children receiving emergency food assistance had BPA levels that were 54% higher than age-matched children from more affluent families (56).

Disparities in BPA exposure may contribute to metabolic disease burden because increasing evidence associates BPA with diabetes. Analyses that explore the association between urinary BPA levels and metabolic disease are complicated by BPA's rapid excretion (57); moreover, although no definitive evidence exists that urinary excretion of BPA is influenced by race/ethnicity, lack of adjustment for

renal function can complicate urinary assessments in population studies (58). Despite these caveats, the National Toxicology Program concluded that BPA could exert effects on glucose homeostasis and insulin release on the basis of animal and in vitro studies (59). Although some heterogeneity exists across studies, the literature that supports this conclusion demonstrates myriad BPA-induced metabolic disruptions across multiple animal and cellular model systems, including alterations in body weight regulation, insulin action, and insulin secretion as well as specific disruptions in β-cell, α-cell, hepatocyte, and adipocyte function and development (Supplementary Table 2). This conclusion is further supported by limited prospective human studies (Table 1). In data from the NHS, extremes of BPA quartiles were associated with incident diabetes after adjusting for BMI (OR 2.08 [95% CI 1.17–3.69]) in NHS II but not NHS (60), suggesting that age modifies BPA-associated diabetes risk because the mean age in NHS II was 45.6 years versus 65.6 years in NHS. Alternatively, these differences may have arisen from period-cohort effects in which the extent, diversity, or timing of exposures may have been greater or more deleterious in NHS II. Furthermore, evidence that the BPA-diabetes association is modified by a diabetes genetic risk score (61) suggests that some populations are more sensitive to the diabetogenic effects of BPA. Of note, BPA may exacerbate diabetes complications because high levels of BPA have been associated with a markedly increased rate of developing chronic kidney disease (OR 6.65 [95% CI 1.47–30.04]) (62). In one meta-analysis that aggregated cross-sectional and prospective studies, a comparison of the highest to lowest exposure groups demonstrated a positive association between BPA and diabetes (RR 1.45 [95% CI 1.13–1.87]) (29), a finding similar to a second, more recent meta-analysis of prevalent diabetes in three cross-sectional studies (OR 1.47 [95% CI 1.21–1.80]) (63). Thus, on the basis of reasonable evidence, differential BPA exposure may promote diabetes disparities.

### Phthalates

Phthalates are a diverse class of widely used synthetic compounds. High–molecular weight (HMW) phthalates are mainly used as plasticizers in food packaging, toys, and building materials, such as polyvinyl chloride (PVC); low–molecular weight phthalates are used in pharmaceuticals, personal care products, and solvents. Phthalates are not covalently bound within products and, thus, can volatilize or leach out, thereby facilitating absorption through dermal contact, ingestion, and inhalation. Higher phthalate exposures among people of color and people with low income have been documented in various studies (Supplementary Table 1), although the sources of these exposure differences are difficult to discern given the widespread commercial use of phthalates. Reduced access to fresh fruits and vegetables and increased consumption of fat-rich foods in low-income populations may augment exposure differences because certain high-fat foods are a major source of HMW phthalates (64). Weathering of older construction materials in low-income households may increase inhalational phthalate exposure (65). Furthermore, purchasing inexpensive products likely contributes to disproportionate phthalate exposures according to an evaluation of products at dollar stores that revealed that 32% of PVC-containing products exceed phthalate limits established for children's products by the Consumer Product Safety Commission (66). Of note, personal care products and cosmetics also contribute to phthalate exposure (67), especially in women, who typically have the highest concentrations of phthalates (68). Indeed, certain feminine hygiene products were found to be at least partially responsible for higher levels of monoethyl phthalate (MEP) in African American women (69). These data provide provocative evidence of racial, ethnic, and socioeconomic disparities in phthalate exposure; however, additional studies are needed to further illuminate the sources of these differences.

Several epidemiological studies have linked higher phthalate exposure with diabetes (Table 1). In data from NHS II, total urinary phthalate metabolites were associated with diabetes (60). In this analysis, metabolites of butyl phthalates and diethylhexyl phthalate (DEHP) were associated with diabetes (OR 3.16 [95% CI 1.68–5.95] and 1.91 [95% CI 1.04–3.49], respectively). Similar to BPA, these associations may be age-related or a consequence of period-cohort effects because similar findings were not observed with the older, original NHS. In the Early Life Exposures in Mexico to Environmental Toxicants cohort, in utero levels of MEP were associated with reduced insulin secretion in pubertal boys (70). In the meta-analysis of Song et al. (29), urinary concentrations of phthalates were nearly significantly associated with diabetes (RR 1.48 [95% CI 0.98–2.25]). With supportive cellular and animal data demonstrating that various phthalates have the capacity to promote dysfunction in multiple metabolic tissues (Supplementary Table 2), further prospective studies are justified to define the relationship between phthalate exposures and diabetes risk, particularly among vulnerable populations.

## LINKING ENVIRONMENTAL EXPOSURES TO DIABETES RISK IN VULNERABLE POPULATIONS

Most studies examining links between EDCs and diabetes have done so without consideration of race, ethnicity, or socioeconomic status; however, recent reports have begun to interrogate these important interactions. In a cross-sectional study investigating the associations between phthalates and insulin resistance, an interaction with race demonstrated that Mexican American ($P = 0.001$) and non-Hispanic black adolescents ($P = 0.002$) had significant increments in HOMA-IR with higher levels of HMW phthalates or DEHP that were not observed in non-Hispanic whites ($P \geq 0.74$) (71). Similarly, in stratified models, HMW phthalates and DEHP were more strongly associated with HOMA-IR in adolescents from households with lower income. In another cross-sectional study, phthalate levels were positively associated with fasting blood glucose, fasting insulin, or HOMA-IR; however, the dose-response relationship was stronger among African Americans and Mexican Americans than among whites (72). In the meta-analysis of Song et al. (29), the impact of PCBs on diabetes risk was higher in nonwhite populations (RR 2.91 [95% CI 1.60–5.30]) compared with their white counterparts (RR 1.94 [95% CI 1.42–2.62]); similarly, associations between OC pesticides and diabetes were stronger in nonwhites (RR 2.64 [95% CI 1.56–4.49]) than in whites (RR 1.95 [95% CI 1.40–2.71]). Although these associations are likely partially attributable to higher EDC exposures, these findings also suggest that African Americans and Latinos have heightened sensitivity to the diabetogenic effects of

**Table 2—Interventional studies that lowered levels of nonpersistent and persistent diabetogenic EDCs in humans**

| Reference | Population | Intervention and assessment | Results |
|---|---|---|---|
| Nonpersistent pollutants | | | |
| Harley et al., 2016 (83) | 100 Latina adolescents from the Health and Environmental Research on Makeup of Salinas Adolescents study | Mean percent change (95% CI) in urinary concentrations after 3-day intervention with personal care products devoid of chemicals under study | MEP: −27.4% (−39.3 to −13.2)*; Methylparaben: −43.9% (−61.3 to −18.8)*; Propylparaben: −45.4% (−63.7 to −17.9)*; Triclosan: −35.7% (−53.3 to −11.6)*; Benzophenone-3: −36.0% (−51.0 to −16.4)* |
| Rudel et al., 2011 (84) | 10 children and 10 adults from the San Francisco Bay Area, California | Mean urinary concentrations of BPA and phthalates before and during 3-day dietary intervention with fresh and organic foods that were not canned or packaged in plastic | BPA: 3.7 vs. 1.2 ng/mL; −66%*; MEHP: 7.1 vs. 3.4 ng/mL; −53%*; MEOHP: 27 vs. 12 ng/mL; −55%*; MEHHP: 57 vs. 25 ng/mL; −56%* |
| Chen et al., 2015 (85) | 30 Taiwanese girls with previously recorded high urinary phthalate metabolite concentrations | Mean urinary concentrations (μg/g) of creatinine (95% CI) of eight phthalate metabolites before and after 1 week of seven different interventions: hand washing, not using plastic containers, not eating food wrapped in plastic, not microwaving food, not taking nutritional supplements, reducing the use of cosmetics, and reducing the use of personal care products (results are for those who were compliant with the intervention) | MMP: 10.4 (3.49–29.7) vs. 4.54 (2.97–17.3)*; MEP: 58.6 (9.08–650) vs. 16.4 (4.66–200)*; MBP: 123 (57.9–482) vs. 84.7 (36.3–236)*; MBzP: 8.52 (1.87–58.2) vs. 4.67 (1.25–17.8)*; MEHP: 14.4 (4.34–38.3) vs. 6.95 (3.42–24.7)*; MEOHP: 55.2 (21.2–207) vs. 26.9 (15.5–85.6)*; MEHHP: 115 (40.3–398) vs. 61.2 (29.1–202)*; MECPP: 124 (34.7–320) vs. 52.9 (30.1–161)*; ΣDEHP: 0.98 (0.36–3.21) vs. 0.49 (0.27–1.57)* |
| Sathyanarayana et al., 2013 (86) | 21 individuals from Seattle, Washington, with high potential for BPA and phthalate exposures | Geometric mean urinary DEHP concentrations (nmol/g creatinine) (95% CI) before and at completion of 5-day intervention with complete dietary replacement with fresh and organic foods prepared without plastics | DEHP: 283.7 (154.6–520.8) vs. 7,027.5 (4,428.1–11,152.68)* |
| POPs | | | |
| Geusau et al., 1999 (87) | 2 female patients with chloracne | Fecal excretion of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin before and after a 38-day intervention of dietary supplementation with olestra chips by using five different dosing regimens (15–66 g olestra daily) | Patient 1: 134 vs. 1,350 ng/day; Patient 2: 29 vs. 240 ng/day |
| Jandacek et al., 2014 (88) | 23 participants from Anniston, Alabama, with PCB levels above the national 50th percentile | Elimination rate (ng/g lipid/year; mean ± SEM) of 37 serum PCBs before and after a 1-year double-blind placebo-controlled trial of 15 g/day dietary olestra vs. placebo (vegetable oil) | Olestra: −0.00864 ± 0.0116 vs. −0.0829 ± 0.0357/year*; Placebo: −0.0283 ± 0.0096 vs. −0.0413 ± 0.0408/year |
| Redgrave et al., 2005 (89) | 1 obese male patient with diabetes | Adipose levels of the PCB mixture aroclor 1254 before and after 2 years of dietary supplementation with olestra (16 g/day) | Aroclor 1254: 3,200 vs. 56 mg/kg; Body weight: 101 vs. 83 kg; BMI: 33.0 vs. 27.1 kg/m$^2$; Cholesterol: 8.6 vs. 3.7 mmol/L; Triglycerides : 11.8 vs. 1.4 mmol/L; Blood glucose: 17 vs. 5.3 mmol/L |
| Arguin et al., 2010 (90) | 37 obese men undergoing weight loss trial | Plasma concentrations (μg/L) of the OC pesticide β-HCH (mean ± SD) before and after a 3-month weight loss intervention; subjects randomized to standard treatment ($n$ = 13), fat-reduced diet ($n$ = 14), and olestra-substituted diet (33% of dietary fat) ($n$ = 10) | Standard treatment: 0.009 ± 0.019; Fat-reduced group: 0.015 ± 0.035; Olestra group: −0.009 ± 0.034* |

*Continued on p. 201*

**Table 2—Continued**

| Reference | Population | Intervention and assessment | Results |
|---|---|---|---|
| Guo et al., 2016 (92) | 15 healthy women from the San Francisco Bay Area, California | Blood levels of five PCBs and two OC pesticides (ng/g lipid) (mean ± SEM) before and after 2 months of supplementation with 1,000 mg/day ascorbic acid (vitamin C) | PCB 74: 4.04 ± 0.57 vs. 4.00 ± 0.62*; PCB 118: 6.87 ± 0.97 vs. 6.79 ± 1.01*; PCB 138: 10.85 ± 1.66 vs. 10.52 ± 1.65*; PCB 153: 21.16 ± 4.16 vs. 20.68 ± 4.01*; PCB 180: 20.47 ± 4.99 vs. 20.07 ± 4.85*; 4,4′-DDT: 8.31 ± 0.96 vs. 8.18 ± 1.11*; 4,4′-DDE: 344.06 ± 58.40 vs. 338.77 ± 57.65* |

β-HCH, β-hexachlorocyclohexane; MBP, monobutyl phthalate; MBzP, monobenzyl phthalate; MECPP, mono-2-ethyl-5-carboxypentyl phthalate; MEHHP, mono-2-ethyl-5-hydoxyhexyl phthalate; MEHP, mono-2-ethylhexyl phthalate; MEOHP, mono-2-ethyl-5-oxohexyl phthalate; MMP, monomethyl phthalate. *$P < 0.05$.

environmental contaminants because of potential synergy with other diabetes risk factors.

The current literature provides evidence that five classes of environmental toxicants are linked to diabetes risk in humans, and for each, vulnerable populations are disproportionately exposed. The strength of epidemiological evidence for these five classes varies, with the most consistent findings observed for the persistent pollutants (PCBs and OCs), likely reflecting their long biological half-lives, the stability of their quantitation, and the longer time they have been studied. Among all five classes, however, is provocative evidence of diabetes-promoting effects as well as disparities in exposure. Thus, although further study is required, the unequal burden of environmental risk factors in ethnically, racially, and economically segregated neighborhoods of color may contribute to interethnic differences in metabolic health.

## ORIGINS OF DIFFERENTIAL ENVIRONMENTAL EXPOSURES

Addressing disparities in environmental health necessitates understanding the sociological forces that shape society. Segregation profoundly influences individual socioeconomic status, reinforces unhealthy neighborhood environments, and modifies individual behaviors (73), all of which influence metabolic disease susceptibility. Reduced access to affordable healthy foods, as seen in many African American and Latino neighborhoods, promotes unhealthy eating habits (54), whereas lack of safety and reduced access to green space can limit physical activity (74). Thus, the built environment in many communities of color potentiates two key drivers of diabetes risk, namely diet and exercise.

In addition, historical economic and political racialization of residential areas and the labor force has promoted today's racial segregation and the codecline of environmental health in these neighborhoods (75). Indeed, living in highly segregated metropolitan areas is associated with a greater health risk from industrial air pollution, with African Americans at enhanced risk relative to non-Hispanic whites (76). Despite improvements in air quality over time, African Americans remain exposed to significantly more air pollution than non-Hispanic whites (77). Accounts of the industrial division of labor by race in major U.S. cities document how people of color were restricted to low-wage, hazardous occupations while simultaneously being confined to low-income housing near these industries (75). Similar labor divisions also occurred in agriculture (33). Grandfathering clauses allow older industrial facilities, often located in America's metropolitan centers, to opt out of the stricter environmental regulations required of newer facilities, thereby clustering industrial toxins within these urban cores (76). Suburbanization was accompanied by expansion and clustering of highways near and through neighborhoods of color (78), leading to higher traffic-related air pollution exposure among African Americans and Latinos (37). A shifted focus to suburban economic development with consequential disinvestment in inner city neighborhoods has perpetuated a legacy of environmental inequality (75). The cumulative effects of these cultural forces enhance exposure to environmental toxicants among African American, Latino, and low-income communities; addressing this history is essential to eliminating disparities in metabolic health.

## ENVIRONMENTAL HEALTH IN THE DIABETES CLINIC

With increasing evidence that pollutants promote metabolic dysfunction and likely contribute to diabetes disparities, environmental health will become an important component of clinical practice. As such, physicians need to be acquainted with these data to meaningfully address the concerns of their patients who are increasingly troubled about these links. In addition, as these data mature, policies to improve environmental quality should become components of comprehensive diabetes prevention and management strategies. Such efforts may have significant benefits. On the basis of recent intriguing analyses of the PIVUS study, 25% reductions in representative compounds from several chemical classes discussed herein (PCBs, OC pesticides, and phthalates) as well as perfluoroalkyl substances are predicted to reduce diabetes prevalence in Europe by 13% (95% CI 2–22%), with a projected cost savings of €4.51 billion/year (79). Thus, the identification of patient-specific exposures and implementation of exposure reduction strategies may reduce the burden of diabetes on both the individual and society at large.

### Identifying Patients With Unique Diabetes Phenotypes

Astute clinicians revolutionized diabetes care by recognizing unique disease phenotypes that were subsequently linked to specific genetic variants and targeted therapeutics (i.e., maturity onset diabetes of the young). Similarly, comprehensive occupational and environmental histories in patients without the classical clinical features of type 2 diabetes and without a genetic explanation may identify unique chemical exposures that promote disease development. Similarly, patients whose medication needs are greater than anticipated may have background exposures that exacerbate metabolic dysfunction. Aided by the development and implementation of validated clinical questionnaires to estimate contact with diabetogenic chemicals, informed clinicians may be able to identify glucose-disrupting exposures and offer patients targeted interventions to improve diabetes outcomes.

**Table 3—Sources of diabetes-promoting EDCs and exposure reduction strategies**

| Chemical | Source | Exposure reduction strategy |
|---|---|---|
| PCBs | Contaminated fish, meat, and dairy products, including bottom-feeding freshwater fish that consume PCB-laden sediment | Consult local guidelines regarding which sport fish are safe to consume; Trim fat from meat and skin from fish and cook on a rack that allows fat to drain away |
| | Dusts contaminated with low levels of PCBs can coat the surfaces of fruits and vegetables | Wash fruits and vegetables before consumption |
| | Contaminated drinking water arising from PCB leaching from toxic waste sites or old submersible pumps containing PCBs (development of an oily film or fuel odor in water wells) | Check submersible pumps for failure and, if so, replace pumps and clean the well |
| | Older fluorescent lights with transformers or ballasts containing PCBs | Replace old PCB-containing fluorescent bulbs |
| | Deterioration of old building materials, including some paints and caulking | Remove deteriorating building materials; Repair damaged areas with new, safer alternatives |
| OC pesticides | Some high-fat meats and dairy products as well as some fatty fish | Trim fat from meat and skin from fish and cook on a rack that allows fat to drain away |
| | Dust and soil contaminated from historical use | Regularly clean floors and remove dust with a damp cloth; Wash hands often, especially before eating or preparing food; Wash fruits and vegetables before consumption |
| Air pollutant | Burning of fossil fuels, including power plants, motorized vehicles, lawn care equipment, chemical plants, factories, refineries, and gas stations | Check local air pollution forecasts and avoid outdoor exercise when pollution levels are high; Avoid exercise near high-traffic areas; Use hand-powered or electric lawn care equipment; Encourage local schools and municipalities to reduce bus emissions by eliminating idling; Plant trees |
| | Gas appliances, paints, solvents, tobacco smoke, and household chemicals, including cleaning supplies | Choose electrical appliances and paints low in volatile organic compounds; Limit use of household chemicals; Avoid places that permit smoking |
| | Combustion of organic materials, including fireplaces, wood stoves, charcoal grills, and leaf burning | Do not burn wood, leaves, or trash |
| BPA | Polycarbonate plastics, including some water and baby bottles, compact discs, impact-resistant safety equipment, and medical devices | Avoid plastic containers designated #7 on the bottom; Do not microwave polycarbonate plastic food containers; Opt for infant formula bottles and toys that are labeled BPA-free; Opt for glass, porcelain, or stainless steel containers when possible, especially for hot foods and drinks |
| | Epoxy resins coating metal products, such as food cans, bottle tops, and water supply pipes | Eat fresh and frozen foods while reducing use of canned foods; Prepare more meals at home and emphasize fresh ingredients |
| | Thermal paper, including sales receipts | Minimize handling of receipts and thermal paper |
| | Some dental sealants and composites | Consult dentist about alternative options |
| Phthalates | Plastic food and beverage containers | Opt for glass, porcelain, or stainless steel containers when possible, especially for hot food and drinks |
| | Personal care products, such as perfumes, hair sprays, deodorants, nail polishes, insect repellants, and most consumer products containing fragrances, including shampoos, air fresheners, and laundry detergents | Read labels and avoid products containing phthalates; Choose products labeled phthalate-free; Avoid fragrances and opt for cosmetics labeled no synthetic fragrance, scented only with essential oils, or phthalate-free |
| | Contaminated food and water | Purchase, if possible, organic produce, meat, and dairy products; Avoid food known to be especially high in contaminants; Consider using a water filter |
| | Plastic toys; plastic coatings on wires, cables, and other equipment; plastic shower curtains; PVC-containing products; carpeting and vinyl flooring; and medical devices, including intravenous bags, tubing, and some extended-release medications | Choose nonplastic alternatives whenever possible, especially avoid plastics labeled #3 and #7; Avoid hand-me-down plastic toys |

### Reducing Exposures to Nonpersistent Pollutants

For patients exposed to nonpersistent diabetogenic pollutants, practices that increase exposure to diabetogenic toxicants offer insights into potential interventions. For example, fast food intake increases phthalate exposures (80), whereas consuming water from polycarbonate bottles (81) or soup from cans (82) increases urinary BPA levels. Built upon this knowledge, clinical trials have attempted to lower BPA and phthalate levels (Table 2). In an intervention focused on personal care products, attention to product contents reduced levels of various chemicals, including MEP (83). A trial focused on eating food with limited packaging reduced levels of DEHP and BPA (84), whereas hand washing and reduction of the use of plastic cups lowered phthalate levels in children (85). Although these studies are encouraging, challenges in advising patients remain. For example, avoiding packaged and fast foods may be impractical in individuals with low food security. Moreover, even careful efforts can be confounded by unexpected exposures as illustrated by a failed intervention during which DEHP levels rose because of unexpectedly high phthalate levels in milk and ground coriander (86). Collectively, these data suggest that limiting contact with plastics and packaging, encouraging hand washing, and increasing awareness of diabetogenic toxicants can reduce exposures; however, these efforts must be supported by regulatory action to ensure adequate labeling of consumer products. Finally, evidence that insulin sensitivity rapidly shifts with changes in air quality (40,41) suggests that advising patients to avoid exercise near busy streets or during peak traffic hours to limit contact with air pollutants may afford metabolic benefits, whereas community interventions to improve air quality (e.g., access to public transit, reduced wood and leaf burning, expanded use of clean energy sources, tree planting) may reduce diabetes risk.

### Clinical Strategies To Reduce the Body Burden of Persistent Pollutants

For people exposed to persistent organic pollutants (POPs), evidence suggests that interventions can reduce diabetogenic EDC levels (Table 2). In several small studies, the nonabsorbable fat olestra facilitated elimination of lipophilic toxicants, including the dioxin 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, in two patients with chloracne (87). Moreover, olestra was shown to accelerate the elimination of 37 noncoplanar PCBs in 11 individuals from Anniston, Alabama (88). With regard to the metabolic impact of these changes, one case study of OC toxicity showed that 2 years of olestra resulted in weight loss and improvements in glycemic control (89). Whether these metabolic improvements resulted from the elimination of POPs or were simply a consequence of weight loss requires further study. Olestra may not universally lower POP levels, however. In subjects who underwent a weight loss intervention, olestra decreased levels of β-hexachlorocyclohexane but did not attenuate the expected weight loss–induced rise in other OCs (90). Collectively, these findings raise the possibility that other agents that interrupt the enterohepatic circulation of lipophilic toxicants similarly lower the body burden of POPs and mitigate their diabetogenic effects. The glycemic benefits of the bile acid sequestrant colesevelam could partially reflect clearance of metabolism-disrupting chemicals, but this hypothesis requires formal testing. Other approaches to reduce the body burden of diabetogenic EDCs also have been tried. Supported by cross-sectional data suggesting that fruit and vegetable consumption attenuates the PCB-diabetes association (91), a study of 15 healthy women showed that 1,000 mg/day of ascorbic acid for 2 months reduced levels of six PCBs and two OC pesticides (92).

Although further work is needed, these small intervention trials provide clinicians and patients with intriguing evidence that therapeutic approaches may be devised to mitigate exposures to diabetogenic toxicants and potentially reverse their adverse effects. On the basis of these data and knowledge of common exposure sources, physicians can aid patients wishing to take a precautionary approach by providing guidance on exposure-reduction strategies (Table 3 and Healthcare Provider Guide in Supplementary Data).

## CONCLUSIONS

African Americans, Latinos, and the socioeconomically disadvantaged have long been recognized to bear a higher burden of diabetes, but the reasons for these disparities are not completely understood. We provide evidence that higher exposure to diabetogenic pollutants is an important contributor. Although further work is required to validate the EDC-diabetes link and better quantify exposure disparities, current evidence suggests that improvements in environmental health could reduce diabetes risk and disparities. As additional data accumulate and the field matures, the practicing diabetologist and endocrinologist will be uniquely positioned to address exposure to diabetogenic environmental toxicants as part of individualized diabetes care plans to reduce disease risk and to improve diabetes outcomes across the population.

**Acknowledgments.** The authors gratefully acknowledge the constructive feedback of Dr. Louis H. Philipson, Director, Kovler Diabetes Center, University of Chicago. The authors also recognize the insights and suggestions of Dr. Victoria Persky, University of Illinois at Chicago. Because of reference limits, the authors regret the omission of any other relevant studies.

**Funding.** This work was supported by the National Institute of Child Health and Human Development (T32-HD-007009 to D.R.) and the National Institute of Diabetes and Digestive and Kidney Diseases (P30-DK-092949 to J.S.J.) through the Chicago Center for Diabetes Translation Research, as well as by the American Diabetes Association (1-17-JDF-033 to R.M.S.).

**Duality of Interest.** No potential conflicts of interest relevant to this article were reported.

**Author Contributions.** D.R. researched and wrote the manuscript. M.B. researched and edited the manuscript. J.S.J. contributed to the discussion and edited the manuscript. K.A. contributed to the discussion and edited the manuscript. R.M.S. researched and wrote the manuscript. R.M.S. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

## References

1. Centers for Disease Control and Prevention. *National Diabetes Fact Sheet, 2011*. Atlanta, Centers for Disease Control and Prevention, 2011
2. Franco SJ. Age-adjusted percentage of adults aged ≥ 20 years with diabetes, by race and Hispanic ethnicity—National Health and Nutrition Examination Survey, United States, 1999-2002 and 2009-2012. MMWR 2015;64(21);599
3. Hunt BR, Whitman S, Henry CA. Age-adjusted diabetes mortality rates vary in local communities in a metropolitan area: racial and spatial disparities and correlates. Diabetes Care 2014;37:1279–1286
4. Zoeller RT, Brown TR, Doan LL, et al. Endocrine-disrupting chemicals and public health protection: a statement of principles from the Endocrine Society. Endocrinology 2012;153:4097–4110
5. Neel BA, Sargis RM. The paradox of progress: environmental disruption of metabolism and the diabetes epidemic. Diabetes 2011;60:1838–1848
6. Taylor D. *Toxic Communities: Environmental Racism, Industrial Pollution, and Residential Mobility*. New York, New York University Press, 2014

7. Bell ML, Ebisu K. Environmental inequality in exposures to airborne particulate matter components in the United States. Environ Health Perspect 2012;120:1699–1704
8. Rauh VA, Landrigan PJ, Claudio L. Housing and health: intersection of poverty and environmental exposures. Ann N Y Acad Sci 2008;1136:276–288
9. Murray LR. Sick and tired of being sick and tired: scientific evidence, methods, and research implications for racial and ethnic disparities in occupational health. Am J Public Health 2003;93:221–226
10. Sjödin A, Jones RS, Caudill SP, Wong LY, Turner WE, Calafat AM. Polybrominated diphenyl ethers, polychlorinated biphenyls, and persistent pesticides in serum from the National Health and Nutrition Examination Survey: 2003-2008. Environ Sci Technol 2014;48:753–760
11. James RA, Hertz-Picciotto I, Willman E, Keller JA, Charles MJ. Determinants of serum polychlorinated biphenyls and organochlorine pesticides measured in women from the Child Health and Development Study Cohort, 1963-1967. Environ Health Perspect 2002;110:617–624
12. Schafer KS, Kegley SE. Persistent toxic chemicals in the US food supply. J Epidemiol Community Health 2002;56:813–817
13. Herrick RF, McClean MD, Meeker JD, Baxter LK, Weymouth GA. An unrecognized source of PCB contamination in schools and other buildings. Environ Health Perspect 2004;112:1051–1053
14. Rudel RA, Seryak LM, Brody JG. PCB-containing wood floor finish is a likely source of elevated PCBs in residents' blood, household air and dust: a case study of exposure. Environ Health 2008;7:2
15. Weintraub M, Birnbaum LS. Catfish consumption as a contributor to elevated PCB levels in a non-Hispanic black subpopulation. Environ Res 2008;107:412–417
16. Aminov Z, Haase R, Olson JR, Pavuk M, Carpenter DO; Anniston Environmental Health Research Consortium. Racial differences in levels of serum lipids and effects of exposure to persistent organic pollutants on lipid levels in residents of Anniston, Alabama. Environ Int 2014;73:216–223
17. Pavuk M, Olson JR, Wattigney WA, et al.; Anniston Environmental Health Research Consortium. Predictors of serum polychlorinated biphenyl concentrations in Anniston residents. Sci Total Environ 2014;496:624–634
18. Choi AL, Levy JI, Dockery DW, et al. Does living near a Superfund site contribute to higher polychlorinated biphenyl (PCB) exposure? Environ Health Perspect 2006;114:1092–1098
19. Kouznetsova M, Huang X, Ma J, Lessner L, Carpenter DO. Increased rate of hospitalization for diabetes and residential proximity of hazardous waste sites. Environ Health Perspect 2007;115:75–79
20. Silverstone AE, Rosenbaum PF, Weinstock RS, et al. Polychlorinated biphenyl (PCB) exposure and diabetes: results from the Anniston Community Health Survey. Environ Health Perspect 2012;120:727–732
21. Vasiliu O, Cameron L, Gardiner J, Deguire P, Karmaus W. Polybrominated biphenyls, polychlorinated biphenyls, body weight, and incidence of adult-onset diabetes mellitus. Epidemiology 2006;17:352–359
22. Wang SL, Tsai PC, Yang CY, Guo YL. Increased risk of diabetes and polychlorinated biphenyls and dioxins: a 24-year follow-up study of the Yucheng cohort. Diabetes Care 2008;31:1574–1579
23. Wu H, Bertrand KA, Choi AL, et al. Persistent organic pollutants and type 2 diabetes: a prospective analysis in the nurses' health study and meta-analysis. Environ Health Perspect 2013;121:153–161
24. Lee DH, Lind PM, Jacobs DR Jr, Salihovic S, van Bavel B, Lind L. Polychlorinated biphenyls and organochlorine pesticides in plasma predict development of type 2 diabetes in the elderly: the Prospective Investigation of the Vasculature in Uppsala Seniors (PIVUS) study. Diabetes Care 2011;34:1778–1784
25. Lee DH, Steffes MW, Sjödin A, Jones RS, Needham LL, Jacobs DR Jr. Low dose of some persistent organic pollutants predicts type 2 diabetes: a nested case-control study. Environ Health Perspect 2010;118:1235–1242
26. Rignell-Hydbom A, Lidfeldt J, Kiviranta H, et al. Exposure to p,p′-DDE: a risk factor for type 2 diabetes. PLoS One 2009;4:e7503
27. Turyk M, Anderson H, Knobeloch L, Imm P, Persky V. Organochlorine exposure and incidence of diabetes in a cohort of Great Lakes sport fish consumers. Environ Health Perspect 2009;117:1076–1082
28. Van Larebeke N, Sioen I, Hond ED, et al. Internal exposure to organochlorine pollutants and cadmium and self-reported health status: a prospective study. Int J Hyg Environ Health 2015;218:232–245
29. Song Y, Chou EL, Baecker A, et al. Endocrine-disrupting chemicals, risk of type 2 diabetes, and diabetes-related metabolic traits: a systematic review and meta-analysis. J Diabetes 2016;8:516–532
30. Bradman AS, Schwartz JM, Fenster L, Barr DB, Holland NT, Eskenazi B. Factors predicting organochlorine pesticide levels in pregnant Latina women living in a United States agricultural area. J Expo Sci Environ Epidemiol 2007;17:388–399
31. Wang RY, Jain RB, Wolkin AF, Rubin CH, Needham LL. Serum concentrations of selected persistent organic pollutants in a sample of pregnant females and changes in their concentrations during gestation. Environ Health Perspect 2009;117:1244–1249
32. Muennig P, Song X, Payne-Sturges DC, Gee GC. Blood and urine levels of long half-life toxicants by nativity among immigrants to the United States. Sci Total Environ 2011;412-413:109–113
33. Canales AI. Inclusion and segregation: the incorporation of Latin American immigrants into the U.S. labor market. Lat Am Perspect 2007;34:73–82
34. Smith D. Worldwide trends in DDT levels in human breast milk. Int J Epidemiol 1999;28:179–188
35. Starling AP, Umbach DM, Kamel F, Long S, Sandler DP, Hoppin JA. Pesticide use and incident diabetes among wives of farmers in the Agricultural Health Study. Occup Environ Med 2014;71:629–635
36. Schweitzer L, Zhou J. Neighborhood air quality, respiratory health, and vulnerable populations in compact and sprawled regions. J Am Plann Assoc 2010;76:363–371
37. Clark LP, Millet DB, Marshall JD. National patterns in environmental injustice and inequality: outdoor $NO_2$ air pollution in the United States. PLoS One 2014;9:e94431
38. Beckerman B, Jerrett M, Brook JR, Verma DK, Arain MA, Finkelstein MM. Correlation of nitrogen dioxide with other traffic pollutants near a major expressway. Atmos Environ 2008;42:275–290
39. Rao X, Patel P, Puett R, Rajagopalan S. Air pollution as a risk factor for type 2 diabetes. Toxicol Sci 2015;143:231–241
40. Brook RD, Xu X, Bard RL, et al. Reduced metabolic insulin sensitivity following sub-acute exposures to low levels of ambient fine particulate matter air pollution. Sci Total Environ 2013;448:66–71
41. Brook RD, Sun Z, Brook JR, et al. Extreme air pollution conditions adversely affect blood pressure and insulin resistance: the Air Pollution and Cardiometabolic Disease Study. Hypertension 2016;67:77–85
42. Thiering E, Cyrys J, Kratzsch J, et al. Long-term exposure to traffic-related air pollution and insulin resistance in children: results from the GINIplus and LISAplus birth cohorts. Diabetologia 2013;56:1696–1704
43. Weinmayr G, Hennig F, Fuks K, et al.; Heinz Nixdorf Recall Investigator Group. Long-term exposure to fine particulate matter and incidence of type 2 diabetes mellitus in a cohort study: effects of total and traffic-specific air pollution. Environ Health 2015;14:53
44. Coogan PF, White LF, Jerrett M, et al. Air pollution and incidence of hypertension and diabetes mellitus in black women living in Los Angeles. Circulation 2012;125:767–772
45. Krämer U, Herder C, Sugiri D, et al. Traffic-related air pollution and incident type 2 diabetes: results from the SALIA cohort study. Environ Health Perspect 2010;118:1273–1279
46. Park SK, Adar SD, O'Neill MS, et al. Long-term exposure to air pollution and type 2 diabetes mellitus in a multiethnic cohort. Am J Epidemiol 2015;181:327–336
47. Coogan PF, White LF, Yu J, et al. Long term exposure to $NO_2$ and diabetes incidence in the Black Women's Health Study. Environ Res 2016;148:360–366
48. Pope CA 3rd, Turner MC, Burnett RT, et al. Relationships between fine particulate air pollution, cardiometabolic disorders, and cardiovascular mortality. Circ Res 2015;116:108–115
49. Brook RD, Cakmak S, Turner MC, et al. Long-term fine particulate matter exposure and mortality from diabetes in Canada. Diabetes Care 2013;36:3313–3320
50. Schneider A, Neas L, Herbst MC, et al. Endothelial dysfunction: associations with exposure to ambient fine particles in diabetic individuals. Environ Health Perspect 2008;116:1666–1674
51. O'Donnell MJ, Fang J, Mittleman MA, Kapral MK, Wellenius GA; Investigators of the Registry of Canadian Stroke Network. Fine particulate air pollution (PM2.5) and the risk of acute ischemic stroke. Epidemiology 2011;22:422–431
52. Ranjit N, Siefert K, Padmanabhan V. Bisphenol-A and disparities in birth outcomes: a review and directions for future research. J Perinatol 2010;30:2–9
53. Vandenberg LN, Hunt PA, Myers JP, Vom Saal FS. Human exposures to bisphenol A: mismatches between data and assumptions. Rev Environ Health 2013;28:37–58
54. Larson NI, Story MT, Nelson MC. Neighborhood environments: disparities in access to healthy foods in the U.S. Am J Prev Med 2009;36:74–81

55. von Goetz N, Wormuth M, Scheringer M, Hungerbühler K. Bisphenol A: how the most relevant exposure sources contribute to total consumer exposure. Risk Anal 2010;30:473–487
56. Nelson JW, Scammell MK, Hatch EE, Webster TF. Social disparities in exposures to bisphenol A and polyfluoroalkyl chemicals: a cross-sectional study within NHANES 2003-2006. Environ Health 2012;11:10
57. Lakind JS, Goodman M, Mattison DR. Bisphenol A and indicators of obesity, glucose metabolism/type 2 diabetes and cardiovascular disease: a systematic review of epidemiologic research. Crit Rev Toxicol 2014;44:121–150
58. Hays SM, Aylward LL, Blount BC. Variation in urinary flow rates according to demographic characteristics and body mass index in NHANES: potential confounding of associations between health outcomes and urinary biomarker concentrations. Environ Health Perspect 2015;123:293–300
59. Thayer KA, Heindel JJ, Bucher JR, Gallo MA. Role of environmental chemicals in diabetes and obesity: a National Toxicology Program workshop review. Environ Health Perspect 2012;120:779–789
60. Sun Q, Cornelis MC, Townsend MK, et al. Association of urinary concentrations of bisphenol A and phthalate metabolites with risk of type 2 diabetes: a prospective investigation in the Nurses' Health Study (NHS) and NHSII cohorts. Environ Health Perspect 2014;122:616–623
61. Bi Y, Wang W, Xu M, et al. Diabetes genetic risk score modifies effect of bisphenol A exposure on deterioration in glucose metabolism. J Clin Endocrinol Metab 2016;101:143–150
62. Hu J, Yang S, Wang Y, et al. Serum bisphenol A and progression of type 2 diabetic nephropathy: a 6-year prospective study. Acta Diabetol 2015;52:1135–1141
63. Rancière F, Lyons JG, Loh VH, et al. Bisphenol A and the risk of cardiometabolic disorders: a systematic review with meta-analysis of the epidemiological evidence. Environ Health 2015;14:46
64. Serrano SE, Braun J, Trasande L, Dills R, Sathyanarayana S. Phthalates and diet: a review of the food monitoring and epidemiology data. Environ Health 2014;13:43
65. Ait Bamai Y, Araki A, Kawai T, et al. Associations of phthalate concentrations in floor dust and multi-surface dust with the interior materials in Japanese dwellings. Sci Total Environ 2014;468-469:147–157
66. Campaign for Healthier Solutions. A Day Late and a Dollar Short: Discount Retailers are Falling Behind on Safer Chemicals [Internet], 2015. Available from: http://ej4all.org/assets/media/documents/Report_ADayLateAndADollarShort.pdf. Accessed 4 August 2017
67. Parlett LE, Calafat AM, Swan SH. Women's exposure to phthalates in relation to use of personal care products. J Expo Sci Environ Epidemiol 2013;23:197–206
68. Zota AR, Calafat AM, Woodruff TJ. Temporal trends in phthalate exposures: findings from the National Health and Nutrition Examination Survey, 2001-2010. Environ Health Perspect 2014;122:235–241
69. Branch F, Woodruff TJ, Mitro SD, Zota AR. Vaginal douching and racial/ethnic disparities in phthalates exposures among reproductive-aged women: National Health and Nutrition Examination Survey 2001-2004. Environ Health 2015;14:57
70. Watkins DJ, Peterson KE, Ferguson KK, et al. Relating phthalate and BPA exposure to metabolism in peripubescence: the role of exposure timing, sex, and puberty. J Clin Endocrinol Metab 2016;101:79–88
71. Trasande L, Spanier AJ, Sathyanarayana S, Attina TM, Blustein J. Urinary phthalates and increased insulin resistance in adolescents. Pediatrics 2013;132:e646–e655
72. Huang T, Saxena AR, Isganaitis E, James-Todd T. Gender and racial/ethnic differences in the associations of urinary phthalate metabolites with markers of diabetes risk: National Health and Nutrition Examination Survey 2001-2008. Environ Health 2014;13:6
73. Kramer MR, Hogue CR. Is segregation bad for your health? Epidemiol Rev 2009;31:178–194
74. Gordon-Larsen P, Nelson MC, Page P, Popkin BM. Inequality in the built environment underlies key health disparities in physical activity and obesity. Pediatrics 2006;117:417–424
75. Massey DS, Denton NA. *American Apartheid: Segregation and the Making of the Underclass*. Cambridge, MA, Harvard University Press, 1998
76. Ard K. By all measures: an examination of the relationship between segregation and health risk from air pollution. Popul Environ 2016;38:1–20
77. Ard K. Trends in exposure to industrial air toxins for different racial and socioeconomic groups: a spatial and temporal examination of environmental inequality in the U.S. from 1995 to 2004. Soc Sci Res 2015;53:375–390
78. Chi G, Parisi D. Highway Expansion effects on urban racial redistribution in the post–Civil Rights period. Public Works Manag Policy 2011;16:40–58
79. Trasande L, Lampa E, Lind L, Lind PM. Population attributable risks and costs of diabetogenic chemical exposures in the elderly. J Epidemiol Community Health 2017;71:111–114
80. Zota AR, Phillips CA, Mitro SD. Recent fast food consumption and bisphenol A and phthalates exposures among the U.S. population in NHANES, 2003-2010. Environ Health Perspect 2016;124:1521–1528
81. Makris KC, Andra SS, Jia A, et al. Association between water consumption from polycarbonate containers and bisphenol A intake during harsh environmental conditions in summer. Environ Sci Technol 2013;47:3333–3343
82. Carwile JL, Ye X, Zhou X, Calafat AM, Michels KB. Canned soup consumption and urinary bisphenol A: a randomized crossover trial. JAMA 2011;306:2218–2220
83. Harley KG, Kogut K, Madrigal DS, et al. Reducing phthalate, paraben, and phenol exposure from personal care products in adolescent girls: findings from the HERMOSA Intervention Study. Environ Health Perspect 2016;124:1600–1607
84. 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;119:914–920
85. Chen C-Y, Chou Y-Y, Lin S-J, Lee C-C. Developing an intervention strategy to reduce phthalate exposure in Taiwanese girls. Sci Total Environ 2015;517:125–131
86. Sathyanarayana S, Alcedo G, Saelens BE, et al. Unexpected results in a randomized dietary trial to reduce phthalate and bisphenol A exposures. J Expo Sci Environ Epidemiol 2013;23:378–384
87. Geusau A, Tschachler E, Meixner M, et al. Olestra increases faecal excretion of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. Lancet 1999;354:1266–1267
88. Jandacek RJ, Heubi JE, Buckley DD, et al. Reduction of the body burden of PCBs and DDE by dietary intervention in a randomized trial. J Nutr Biochem 2014;25:483–488
89. Redgrave TG, Wallace P, Jandacek RJ, Tso P. Treatment with a dietary fat substitute decreased Arochlor 1254 contamination in an obese diabetic male. J Nutr Biochem 2005;16:383–384
90. Arguin H, Sánchez M, Bray GA, et al. Impact of adopting a vegan diet or an olestra supplementation on plasma organochlorine concentrations: results from two pilot studies. Br J Nutr 2010;103:1433–1441
91. Hofe CR, Feng L, Zephyr D, Stromberg AJ, Hennig B, Gaetke LM. Fruit and vegetable intake, as reflected by serum carotenoid concentrations, predicts reduced probability of polychlorinated biphenyl-associated risk for type 2 diabetes: National Health and Nutrition Examination Survey 2003-2004. Nutr Res 2014;34:285–293
92. Guo W, Huen K, Park JS, et al. Vitamin C intervention may lower the levels of persistent organic pollutants in blood of healthy women—a pilot study. Food Chem Toxicol 2016;92:197–204
93. To T, Zhu J, Villeneuve PJ, et al. Chronic disease prevalence in women and air pollution—a 30-year longitudinal cohort study. Environ Int 2015;80:26–32