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Substances Migrating from Plastic Products into the Human Body and Their Effects on Human Health

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Abstract; This study examines the toxicological effects of substances migrating from commonly used plastic products into the human body, with particular emphasis on endocrine-disrupting chemicals (EDCs) such as bisphenol A (BPA) and phthalates. Based on a comprehensive review of international scientific literature published between 2002 and 2021, the research analyzes the sources of human exposure, metabolic pathways, and biological mechanisms through which these chemicals affect human health. The findings indicate that both BPA and phthalates can exert significant biological effects even at very low exposure levels, particularly during critical developmental periods such as pregnancy and early childhood. Evidence suggests that perinatal exposure to BPA may alter fetal epigenetic programming, increasing the risk of metabolic disorders, cardiovascular diseases, and developmental abnormalities later in life. Phthalates, on the other hand, are strongly associated with anti-androgenic effects and reproductive dysfunction. The study highlights ongoing regulatory challenges related to low-dose exposure and non-monotonic dose–response relationships, emphasizing the need for stricter control measures, increased public awareness, and effective strategies to reduce human exposure to these chemicals.
Keywords: endocrine-disrupting chemicals, bisphenol A, phthalates, plastic products, human health

1. INTRODUCTION

Plastic products have become essential in modern life due to their low cost, durability, and wide range of applications. They are commonly used in food packaging, water bottles, household containers, medical devices, and many daily consumer goods. Because of this constant and long-term contact with plastic materials, human exposure to plastic-related chemicals has become increasingly relevant from a public health perspective.

In recent decades, scientific attention has focused on endocrine-disrupting chemicals (EDCs) associated with plastics, especially bisphenol A (BPA) and phthalates. EDCs are substances that can interfere with the normal functioning of the hormonal system by mimicking natural hormones, blocking hormone receptors, or altering hormone synthesis and metabolism. Even low-level exposure may contribute to adverse outcomes, and concerns are stronger for vulnerable groups such as pregnant women, infants, and children. Research has linked EDC exposure to reproductive problems, metabolic disorders, immune changes, and developmental effects, which has increased public and regulatory concern worldwide.

The aim of this study is to analyze the toxicological effects of EDCs migrating from plastic products into the human body, with a focus on BPA and phthalates. The study reviews evidence on sources of exposure, mechanisms of action, metabolism, and possible clinical outcomes. It also discusses the challenges in risk assessment and regulatory decision-making, especially regarding low-dose exposure and long-term health impacts. Overall, the study provides an evidence-based overview intended to support public awareness and encourage strategies that reduce exposure to harmful plastic-related chemicals.

2. PLASTICS AND CHEMICAL ADDITIVES

Plastics are not single pure substances; they are manufactured materials that often require chemical additives to achieve specific functional properties. Additives are used to improve flexibility, durability, transparency, heat resistance, color, and stability. For example, phthalates are commonly added as plasticizers to make plastics softer and more flexible, while BPA is used in producing polycarbonate plastics and epoxy resins that provide strength and protective lining for food containers and cans. Other additives may include flame retardants, antioxidants, stabilizers, and pigments, depending on the intended use of the product.

Although additives improve product performance, they may also create health and environmental concerns because many of these chemicals are not permanently bound to the plastic matrix. Over time, they can be released into the surrounding environment through processes such as heating, mechanical wear, aging, or contact with fats and oils. This release can occur during production, daily use, storage, or disposal of plastic materials. As a result, additives can migrate into food and beverages from packaging, enter indoor air and dust, and ultimately reach the human body through ingestion, inhalation, or skin contact.

The migration of plastic additives is influenced by several factors, including temperature, duration of contact, the type of plastic, the chemical characteristics of the additive, and the nature of the contacted material (e.g., oily or acidic foods). Therefore, understanding how additives are used in plastics and how they migrate into the environment and the human body is essential for evaluating potential risks and developing effective prevention strategies.

3. ENDOCRINE-DISRUPTING CHEMICALS (EDCS)

Endocrine-disrupting chemicals (EDCs) are exogenous substances that can interfere with the normal functioning of the endocrine system. They may **mimic** natural hormones, **block** hormone receptors, or **alter** hormone synthesis, transport, metabolism, and elimination, thereby disturbing hormonal signaling and homeostasis (Rogers et al., 2013). In plastic-related exposure, EDCs are especially important because they can be released from consumer products and reach humans through multiple routes, including diet, inhalation of indoor air/dust, and dermal contact (Singh & Pal, 2018).

Definition and general mechanisms of action

EDCs can act through several biological mechanisms. A major pathway involves interaction with nuclear hormone receptors (e.g., estrogen, androgen, thyroid hormone receptors), leading to changes in gene expression and downstream physiological effects. Some EDCs also influence membrane-associated receptors and rapid signaling pathways, or disrupt endocrine function indirectly through oxidative stress and inflammatory pathways (Rogers et al., 2013). Importantly, endocrine systems regulate development, reproduction, metabolism, and immune function; therefore, disruption may produce effects across multiple organ systems rather than in a single target tissue (Rogers et al., 2013).

Health relevance of low-dose exposure

A central concern in EDC research is that **biological effects may occur at low exposure levels**, sometimes showing **non-monotonic dose–response** patterns (i.e., effects that do not increase linearly with dose). This complicates risk assessment and can create uncertainty in regulatory decisions, especially when exposure is chronic and occurs during sensitive life stages such as fetal and early childhood development (Vom Saal & Vandenberg, 2021). Evidence from both experimental and human studies has supported the need to evaluate real-world, long-term exposure scenarios rather than focusing only on high-dose toxicology models (Tsai, 2007; Vom Saal & Vandenberg, 2021).

4. BISPHENOL A (BPA)

Bisphenol A (BPA) is one of the most widely studied plastic-associated EDCs. It is primarily used in the production of **polycarbonate plastics** and **epoxy resins**, materials valued for durability and clarity and commonly applied in food-contact and household plastic-related materials (Tsai, 2007; Schug & Birnbaum, 2014). Because of its chemical structure, BPA can exhibit estrogen-like activity and may influence endocrine-regulated processes (Vom Saal & Vandenberg, 2021).

Sources of BPA in plastic products

BPA exposure is strongly linked to products and materials made with polycarbonate plastics and epoxy resin coatings, including plastic food-contact items and certain packaging-related applications (Schug & Birnbaum, 2014; Tsai, 2007). Migration tends to increase under conditions such as **heat**, prolonged contact time, and contact with foods or liquids that facilitate leaching, making dietary intake a major exposure route in everyday life (Tsai, 2007; Singh & Pal, 2018).

Metabolism and exposure pathways

After entering the body—most commonly through ingestion—BPA undergoes metabolic processing, including conjugation pathways (e.g., glucuronidation), and is then eliminated. However, even with metabolism, measurable exposure can still occur in population studies, and the timing of exposure may be critical for biological outcomes (Völkel et al., 2002; Tsai, 2007). In addition to dietary intake, exposure may also occur through contact with contaminated dust and through dermal pathways in certain contexts (Singh & Pal, 2018).

Endocrine, metabolic, and developmental effects

BPA is associated with endocrine-related outcomes because it can interact with estrogen signaling and other endocrine pathways (Vom Saal & Vandenberg, 2021). Research has discussed links between BPA exposure and **metabolic outcomes** (such as pathways contributing to obesity-related risk) and broader multi-system effects, particularly when exposure occurs during early development (Tsai, 2007; Sarathi et al., 2021). Experimental evidence has also reported endocrine-related changes in animal models consistent with hormonal disruption mechanisms (Vom Saal et al., 1998). Overall, the literature supports continued attention to BPA as a public health issue, with particular concern for **prenatal and early-life exposure windows** (Sarathi et al., 2021; Vom Saal & Vandenberg, 2021).

5. PHTHALATES

Phthalates are a large group of chemicals primarily used as **plasticizers**, added to plastics to increase flexibility, softness, and durability. They are widely used in many consumer and industrial plastic products, which contributes to widespread human exposure (Kamrin, 2009; Yıldıztekin et al., n.d.). A key issue is that phthalates are often **not chemically bound** to the plastic polymer matrix, making them more prone to release during use, aging, and disposal processes (Kamrin, 2009; Singh & Pal, 2018).

Use of phthalates as plasticizers

Phthalates are used to modify physical properties of plastics and are found in a variety of applications, including flexible plastic materials used in household items and certain product components. Their extensive use increases the probability of continuous low-level exposure over time (Kamrin, 2009; Yıldıztekin et al., n.d.).

Routes of human exposure

Human exposure to phthalates occurs through multiple pathways. **Ingestion** can occur via food and beverages contaminated through contact with phthalate-containing materials, while **inhalation** and **dust ingestion** are relevant in indoor environments. **Dermal exposure** may also occur through contact with certain consumer products and materials (Singh & Pal, 2018; Kamrin, 2009). Because these exposures can be frequent and chronic, population-level exposure is a significant public health concern (Kamrin, 2009).

Reproductive and endocrine toxicity

Phthalates are strongly discussed in the literature for their **endocrine-disrupting potential**, particularly anti-androgenic effects and impacts on reproductive development and function. Research has emphasized risks related to developmental exposure and possible reproductive outcomes, making sensitive periods (prenatal and early childhood) a major focus of concern (Kamrin, 2009; Yıldıztekin et al., n.d.). These findings have supported calls for stronger exposure reduction strategies and more cautious regulatory assumptions in risk assessment (Kamrin, 2009).

6. ROUTES OF HUMAN EXPOSURE

Human exposure to BPA and phthalates occurs through **multiple everyday pathways**, which makes these chemicals a continuous public health concern. Because plastics are used in food systems, household products, and medical settings, exposure is often **chronic** and may affect all age groups, including vulnerable populations (Singh & Pal, 2018; Kamrin, 2009).

Food packaging and containers

Dietary intake is considered a major exposure route, especially when plastic materials come into contact with food and beverages. BPA migration is strongly associated with food-contact materials that use polycarbonate plastics and epoxy resin coatings. Conditions such as **heating, long storage time, and contact with fatty foods** can increase the release of additives into food, raising the likelihood of ingestion (Tsai, 2007; Singh & Pal, 2018). For phthalates, migration can occur from flexible plastic packaging and processing materials, making food-related exposure an ongoing concern in daily life (Kamrin, 2009).

Infant and child products

Infants and children represent a **high-risk group** due to developmental sensitivity and relatively higher exposure per body weight. Plastic feeding items, toys, and other child-related products can contribute to exposure through **hand-to-mouth behavior**, chewing, and prolonged contact. Even when products are marketed as safer, real-life exposure can still occur via household plastics and packaging used around infants (Singh & Pal, 2018). This is particularly important because early-life exposure windows are often considered critical for endocrine-related outcomes (Vom Saal & Vandenberg, 2021).

Cosmetics, medical devices, and household items

In addition to diet, exposure may occur via **indoor environments** and product contact. Phthalates have been widely discussed in relation to flexible plastics used in household materials; exposure may occur through **inhalation and ingestion of indoor dust** as well as dermal contact (Kamrin, 2009; Singh & Pal, 2018). Medical contexts are also relevant because plastic-based devices and tubing can contain additives, potentially contributing to exposure in clinical settings (Singh & Pal, 2018). Overall, these routes demonstrate that exposure is not limited to a single source, which complicates risk reduction and regulation (Kamrin, 2009).

7. HEALTH EFFECTS OF BPA AND PHTHALATES

The health relevance of BPA and phthalates is linked to their classification as endocrine-disrupting chemicals and their potential to influence **reproductive, immune, and metabolic systems**. Evidence summarized in major reviews suggests that effects may occur even at low exposure levels, and outcomes may depend strongly on timing and duration of exposure (Tsai, 2007; Vom Saal & Vandenberg, 2021).

Reproductive and endocrine disorders

Both BPA and phthalates have been associated with endocrine-related effects due to their ability to interfere with hormone signaling pathways. BPA is often discussed for estrogen-like activity and broader endocrine interactions, while phthalates are widely recognized for anti-androgenic concerns in reproductive development (Kamrin, 2009; Vom Saal & Vandenberg, 2021). Because endocrine systems regulate fertility, puberty timing, and reproductive tissue development, even subtle disruptions may have clinically relevant consequences, particularly when exposure occurs during sensitive developmental periods (Vom Saal & Vandenberg, 2021).

Immune system modulation

EDCs may also influence immune function. Mechanistic and review-level evidence has emphasized that BPA can modulate immune responses through endocrine-immune interactions and changes in immune signaling pathways (Rogers et al., 2013). Such modulation may contribute to altered inflammatory responses or immune balance, although the exact clinical implications may vary depending on exposure levels and individual susceptibility (Rogers et al., 2013). Concerns about children's vulnerability are also reflected in pediatric-focused discussions of BPA's multi-system relevance (Sarathi et al., 2021).

Metabolic effects (obesity, diabetes)

Metabolic outcomes are another major area of concern. Reviews have discussed links between BPA exposure and metabolic disruption, including pathways relevant to weight regulation and cardiometabolic risk (Tsai, 2007; Vom Saal & Vandenberg, 2021). Phthalates have similarly been discussed in public health literature due to widespread exposure and potential endocrine-related impacts that may contribute to metabolic dysregulation (Kamrin, 2009). These findings support the importance of evaluating long-term, real-world exposure patterns rather than focusing only on acute toxicity (Tsai, 2007).

8. PRENATAL AND EPIGENETIC EFFECTS

Prenatal and early-life exposure is repeatedly highlighted as a critical concern in the EDC literature, because fetal and infant development depends on precise endocrine signaling. Disruptions during these periods may have **long-lasting consequences**, potentially influencing disease risk later in life (Vom Saal & Vandenberg, 2021).

Perinatal exposure and fetal programming

Perinatal exposure refers to exposure during pregnancy and early postnatal life. Reviews emphasize that BPA exposure during developmental windows may affect biological programming processes that shape endocrine and metabolic trajectories (Tsai, 2007; Vom Saal & Vandenberg, 2021). In addition, immune-related pathways may be affected during development, which is relevant because immune maturation and endocrine regulation are closely connected (Rogers et al., 2013). Although research continues to refine mechanisms, developmental timing is consistently treated as a key factor in interpreting risk (Vom Saal & Vandenberg, 2021).

Long-term health risks in childhood and adulthood

Long-term outcomes discussed in the literature include increased vulnerability to endocrine and metabolic disorders across the lifespan, with particular attention to childhood outcomes because early exposures may manifest as developmental and systemic changes (Sarathi et al., 2021; Vom Saal & Vandenberg, 2021). These concerns reinforce the need for prevention strategies that prioritize exposure reduction in pregnant women, infants, and children, while also supporting broader population-level risk reduction given the widespread nature of plastic-related exposure (Singh & Pal, 2018; Kamrin, 2009).

9. REGULATORY ISSUES AND SCIENTIFIC CONTROVERSIES

Regulating BPA and phthalates remains challenging because endocrine-disrupting chemicals may not follow the classic toxicology principle that "the dose makes the poison" in a simple linear way. A major scientific controversy concerns **low-dose effects** and **non-monotonic dose–response** relationships, meaning that measurable biological effects can occur at low exposure levels and may not increase consistently as dose increases (Vom Saal & Vandenberg, 2021; Tsai, 2007). This pattern complicates standard risk assessment models that often rely on higher-dose testing and assume predictable dose–response trends.

Another area of debate involves differences between **scientific evidence** and **regulatory assumptions**. Some regulatory frameworks may place greater emphasis on traditional toxicity endpoints and thresholds, while many researchers argue that endocrine endpoints, developmental timing, and chronic exposure scenarios require a more precautionary approach (Vom Saal & Vandenberg, 2021). In addition, because exposure occurs from multiple sources simultaneously, assessing "real-life" cumulative risk is difficult, which can lead to gaps between laboratory findings and regulatory decisions (Kamrin, 2009; Singh & Pal, 2018). These issues help explain why different institutions and countries may adopt different limits, restrictions, or labeling requirements for the same chemical groups.

10. PUBLIC HEALTH IMPLICATIONS

The public health impact of BPA and phthalates is amplified by their **widespread presence** in consumer products and the resulting **continuous exposure** in the general population (Singh & Pal, 2018; Kamrin, 2009). Because exposure can occur through food packaging, household dust, consumer products, and medical settings, complete avoidance is difficult, making prevention strategies a public health priority rather than only an individual responsibility (Singh & Pal, 2018).

Vulnerable populations

Vulnerability is strongly influenced by developmental and physiological factors. **Pregnant women, fetuses, infants, and children** are often highlighted as higher-risk groups because endocrine signaling plays a critical role in growth and development, and exposure per body weight may be higher in early life (Vom Saal & Vandenberg, 2021; Sarathi et al., 2021). Individuals with pre-existing endocrine or immune conditions may also be more sensitive to disruption, although susceptibility can vary across populations (Rogers et al., 2013).

Need for risk reduction strategies

Given the broad exposure pathways, effective risk reduction requires coordinated action across consumers, manufacturers, and regulators. Public health strategies should address exposure sources at the population level, especially in food-contact materials and child-related products, where everyday contact is frequent and the potential consequences may be long-term (Kamrin, 2009; Singh & Pal, 2018).

11. RECOMMENDATIONS

Reducing consumer exposure

Practical steps can help lower exposure to BPA and phthalates in daily life. Consumers can reduce risk by limiting heating of food in plastic containers, avoiding prolonged storage of hot or fatty foods in plastics, preferring glass or stainless-steel alternatives when possible, and paying attention to product safety labeling—especially for infant and child products (Singh & Pal, 2018; Tsai, 2007). Reducing indoor dust exposure through regular cleaning and ventilation may also be beneficial, as indoor environments can contribute to chronic exposure pathways (Singh & Pal, 2018).

Policy and regulatory improvements

Regulatory bodies should consider the evolving evidence on endocrine disruption, developmental timing, and low-dose effects. Updating risk assessment methods to better reflect non-monotonic dose–response patterns and cumulative exposure would strengthen protection (Vom Saal & Vandenberg, 2021). Stronger regulation of food-contact materials, improved safety standards for child-related products, and clear disclosure requirements for plastic additives can also reduce population-level exposure (Kamrin, 2009; Singh & Pal, 2018).

Public awareness and education

Public education is essential for translating scientific findings into safer everyday practices. Awareness campaigns and health communication can help consumers understand exposure routes and safer alternatives without creating misinformation or panic. Educational efforts are especially important for families, pregnant women, and caregivers, where risk reduction may have long-term benefits for children's health outcomes (Sarathi et al., 2021; Singh & Pal, 2018).

12. CONCLUSION

This literature-based analysis demonstrates that endocrine-disrupting chemicals migrating from plastic products—particularly BPA and phthalates—represent a significant and complex health concern. The reviewed evidence indicates that these substances may exert biological effects at low exposure levels, influence endocrine regulation, and contribute to reproductive, immune, and metabolic outcomes, especially when exposure occurs during sensitive developmental periods (Rogers et al., 2013; Tsai, 2007; Vom Saal & Vandenberg, 2021). Exposure is widespread and occurs through multiple routes, including food packaging, household environments, and consumer products, which increases the relevance of the issue for public health (Singh & Pal, 2018; Kamrin, 2009).

Preventive measures are therefore essential. Reducing exposure requires a combined approach: informed consumer behavior, safer product design and substitution of harmful additives, and regulatory frameworks that reflect modern evidence on endocrine disruption and real-world exposure patterns (Vom Saal & Vandenberg, 2021; Singh & Pal, 2018). Future research should continue improving understanding of chronic low-dose exposure, mixture effects, and developmental vulnerability, while regulatory systems should adapt to scientific advances to ensure more effective long-term protection of human health.

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