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Review Article

Endocrine-Disrupting Chemicals in Personal Care Products: Exposure Pathways and Health Effects

Obiageri Ihuarulam Okeoma[1], Mariam Iyabo Adeoba[2], Vivian Ukamaka Nwokedi[3],

[1]*Department of Medical Laboratory Science, Trinity University, Yaba, Lagos, Nigeria*
[2]*Department of Mechanical, Bioresources and Biomedical Engineering, University of South Africa, Pretoria, South Africa*
[3]*Department of Clinical Pharmacy, Faculty of Pharmacy, University of Benin, Benin City, Nigeria*

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Corresponding author's email:
viviannwokedi250@gmail.com

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ABSTRACT

Background:

Endocrine-disrupting chemicals (EDCs) are exogenous substances that interfere with the normal functioning of the endocrine system, leading to adverse effects on human health, particularly in relation to reproductive, developmental, and metabolic processes. Recent research has increasingly identified personal care products (PCPs) as a major source of EDC exposure. These often contain chemicals such as parabens, phthalates, and triclosan, which retain endocrine activity even at low concentrations.

This narrative review aimed to consolidate current research on the exposure pathways, health effects, and regulatory frameworks associated with EDCs in PCPs.

A narrative review approach was adopted, focusing on studies published between 2021 and the literature search date (January 3rd, 2026). A comprehensive literature search was conducted in PubMed and ScienceDirect.

The review found that EDCs are widely present in personal care products and dermal absorption, oral ingestion, and inhalation are the primary pathways through which EDCs enter the body. EDCs pose significant risks to human health, including reproductive dysfunction, developmental delays, metabolic disorders, and cancer risks with cumulative exposure exacerbating these risks. Regulatory frameworks vary globally, with many regions lagging in addressing the long-term impacts of EDC exposure.

Ultimately, the findings emphasize the urgent need to address the public health implications of EDC exposure from PCPs, which contribute to chronic diseases across multiple systems. Effective policy recommendations include stricter regulations on EDCs in consumer products, better monitoring systems, and enhanced consumer awareness. These findings will be of significant value to public health officials, regulatory bodies, industry stakeholders, and health professionals who can influence and implement strategies for reducing EDC exposure to protect human health.

Keywords: Endocrine-Disrupting Chemicals; Personal Care Products; Exposure Pathways; Health Effects; Regulatory Frameworks

Introduction

Endocrine-disrupting chemicals (EDCs) are exogenous substances that interfere with hormonal signalling, synthesis, metabolism, or receptor interactions within the endocrine system, leading to adverse effects on growth, development, reproduction, and metabolism [1]. Although originally investigated in industrial and agricultural contexts, modern evidence increasingly identifies everyday consumer goods, especially personal care products (PCPs), as significant contributors to human EDC exposure [2, 3]. PCPs encompass a vast range of formulations — including cosmetics, fragrances, lotions, deodorants, and shampoos — many of which contain chemicals such as phthalates, parabens, bisphenols, and per- and polyfluoroalkyl substances (PFAS) that retain endocrine activity even at low concentrations [4, 5].

The pervasive use of PCPs in contemporary societies has made human exposure to EDCs nearly ubiquitous. This is exemplified by biomonitoring studies demonstrating detectable levels of EDC metabolites in the urine of children and adults heavily using PCPs [3]. In addition to dermal uptake during routine application, inhalation of aerosolised product particles and incidental oral ingestion further contribute to internal chemical burdens [3]. Importantly, EDC exposure is not limited to products themselves — packaging and product containers may leach additional compounds like phthalates and PFAS into formulations, as highlighted in recent environmental health research [6, 7]. This multifaceted exposure profile underscores the complexity of assessing risk, especially when chronic and aggregate exposures occur over long periods.

In response to mounting scientific concern, regulatory bodies in several jurisdictions have taken steps to address endocrine disruption linked to consumer chemicals, including those in PCPs. Within the European Union (EU), updates to the Classification, Labelling and Packaging Regulation now incorporate hazard categories explicitly for EDCs, and changes to cosmetic product legislation have identified and restricted numerous potential endocrine disruptors [8, 9]. These measures reflect an evolving regulatory paradigm aimed at harmonising safety assessment with emerging mechanistic evidence of endocrine activity. However, regulatory divergence persists. For example, chemical substances banned in the EU due to reproductive toxicity and endocrine concerns may still be permitted in United States personal care formulations under current FDA standards, revealing gaps in consumer protection and risk management [10, 11]. Moreover, identification and classification of EDCs remain technically and logistically challenging because of the diverse modes of action and low-dose effects characteristic of these chemicals [9].

Beyond regulation, global scientific and public awareness of EDC risks continues to grow. Narrative reviews and empirical studies alike have documented associations between EDC exposures and a range of health outcomes — from reproductive dysfunction and altered pubertal timing to metabolic disorders and immune disruption [3, 4]. Meta-analyses within European cohorts have further elucidated complex exposure-health relationships, highlighting regional variations in exposure burdens and vulnerability [12]. Importantly, these studies emphasise that EDC impacts are not confined to isolated biological endpoints; rather, they span multiple physiological systems and may involve intricate interactions with genetic, nutritional, and socioeconomic contexts [1, 5].

Despite significant advances, critical gaps persist in the scientific literature, especially regarding the cumulative and mixture effects of PCP-related EDC exposures over the lifespan of individuals. Most epidemiological studies focus on single chemicals or limited endpoints, and there is a need for more integrative frameworks that account for real-world exposure scenarios involving concurrent use of multiple products. Furthermore, current knowledge of how PCP-associated EDC exposures contribute to chronic disease trajectories — including metabolic, neuroendocrine, and oncologic processes — remains incomplete [13]. These limitations underscore the impetus for convening and synthesising existing research to identify knowledge gaps, inform public health strategies, and guide regulatory policy.

The purpose of this narrative review is therefore to consolidate and critically analyse contemporary evidence on EDCs in personal care products, with explicit emphasis on the exposure pathways through which these chemicals enter the human body, and the health effects associated with their use. By integrating mechanistic insights, epidemiological findings, and regulatory developments from recent literature, this review aims to provide an authoritative overview for researchers, clinicians, policy-makers, and consumer advocates. The scope encompasses chemical characterisation of EDCs in PCPs, modes of human exposure, documented effects on reproductive, developmental, metabolic, and endocrine systems, and an appraisal of regulatory frameworks shaping risk mitigation globally.

Methodology

Study Design

This study utilized a narrative review approach, which was selected for its flexibility in synthesizing diverse literature on complex topics like endocrine-disrupting chemicals (EDCs) in personal care products (PCPs). The narrative review method is particularly suited for consolidating findings from both qualitative and quantitative studies [14], allowing for a broader understanding of the exposure pathways and health effects of EDCs in consumer products. It facilitates the integration of varied study designs and methodologies, providing an overarching perspective of the current state of research on EDCs.

Literature Search Strategy

The literature search was performed on January 3rd, 2026, using PubMed and ScienceDirect. The search focused on publications from 2021 to the search date. In the search string for ScienceDirect, title and abstract keywords were used while for PubMed title and abstract keywords were combined with MeSH terms [15]. Boolean operators ("AND," "OR") were used in both databases to ensure comprehensive retrieval of relevant studies [16]. The compiled search string for each of the databases were as presented in Table 1. A grey literature search was conducted to retrieve policy documents by searching directly in google search engine and reference list of articles were also screened. The inclusion of grey literature was intended to capture valuable insights from reports that may not be published in peer-reviewed journals but which still inform our understanding of EDCs in consumer products and their regulatory frameworks.

Table 1: Search Strategy

Database	Search Strings
PubMed	((((("Endocrine Disruptors"OR "Endocrine Disrupting Chemicals" OR "EDCs"[MeSH Terms]) AND ("Endocrine Disruptors"OR "Endocrine Disrupting Chemicals"[Title/Abstract] OR "EDCs"[Title/Abstract])) AND (("Personal Care Products" OR "Cosmetics"[MeSH Terms]) AND ("Personal Care Products"[Title/Abstract] OR "Cosmetics"[Title/Abstract]))) AND (("Environmental Exposure" OR "Exposure"[MeSH Terms]) AND ("Environmental Exposure"[Title/Abstract] OR "Exposure"[Title/Abstract]))) AND (("Health Effects" OR "Toxicity" OR "Adverse Effects"[MeSH Terms]) AND ("Health Effects"[Title/Abstract] OR "Toxicity"[Title/Abstract] OR "Adverse Effects"[Title/Abstract]))
ScienceDirect	("Endocrine Disruptors"OR "Endocrine Disrupting Chemicals") AND ("Personal Care Products" OR "Cosmetics") AND ("Exposure") AND ("Health Effects" OR "Toxicity" OR "Adverse Effects")

Eligibility Criteria

Studies included in the review were published between 2021 and search date (January 3rd, 2026), peer-reviewed, and examined the role of EDCs in PCPs or their health effects. Articles were excluded if they focused on non-human subjects, were not available in full text, or did not directly address the impact of EDCs in personal care products.

Study Selection

This occurred in two phases. First the retrieved articles were screened based on titles and abstracts, followed by full-text reviews to assess relevance. Duplicate articles were removed in Zotero. This screening was handled by two independent reviewers and discrepancies resolved by consensus. A total of 37 publications were included in the narrative synthesis. The literature selection process was documented as in Figure 1. It should be noted that a formal quality assessment of the included studies was not conducted. This is because, in a narrative review, the focus is on synthesizing the breadth of available literature rather than evaluating individual study quality. Unlike systematic reviews, narrative reviews do not typically include quality assessments, which is consistent with the review's goal of providing an integrative overview of diverse studies. However, we acknowledge that the absence of a formal quality assessment could influence the strength of the evidence, particularly when dealing with studies of varying methodological rigor.

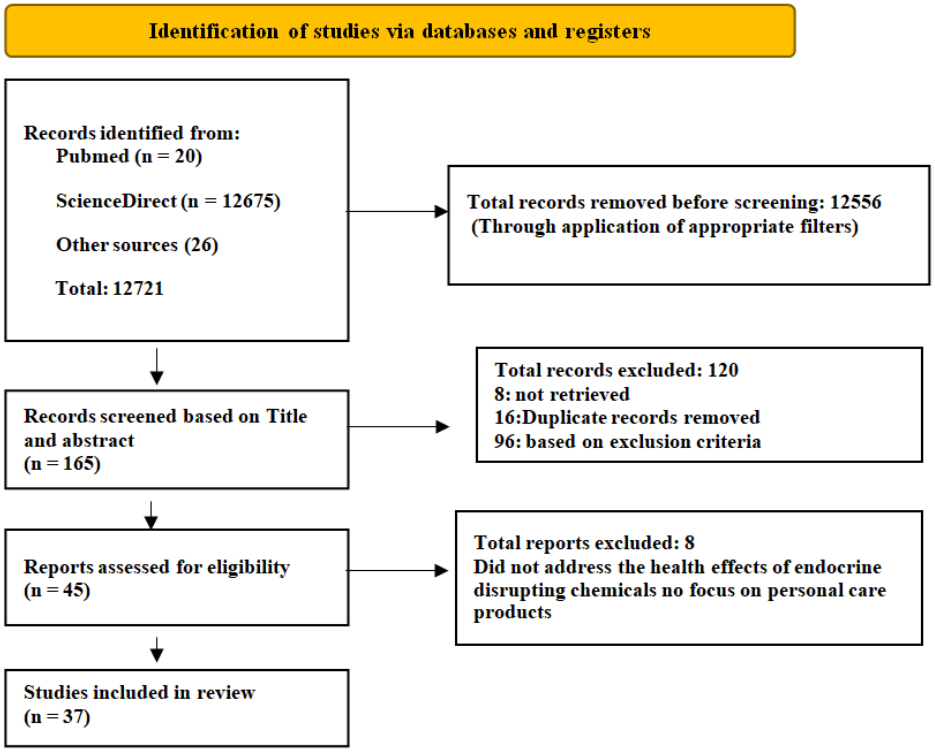

Figure 1: PRISMA Flow diagram

Data Extraction and Synthesis

Data were extracted based on exposure pathways and health effects. The studies were synthesized qualitatively, identifying common trends and gaps in the literature.

Results and Discussion

Types of EDCs in Personal Care Products

Personal care products (PCPs) are complex mixtures of chemicals designed to cleanse, moisturize, scent, or otherwise enhance the appearance and feel of the body. Within these products are numerous compounds that have been identified as endocrine-disrupting chemicals (EDCs) — substances capable of interfering with the endocrine system by mimicking, blocking, or altering hormone synthesis, transport, or action. Such disruptions may lead to adverse effects on reproductive, developmental, and metabolic systems [17].

The classification of EDCs in PCPs generally follows their functional roles in product formulation. For example, preservatives such as parabens are added to prevent microbial growth; plasticizers like phthalates enhance texture or fix fragrance; and antimicrobial agents such as triclosan are incorporated to reduce bacterial contamination. Beyond these, other categories include UV filters (e.g., oxybenzone) and phenolic compounds, all of which may possess hormone-modulating properties [17]. These chemicals have been shown to interact with estrogen, androgen, or thyroid hormone pathways, raising concern regarding their widespread use and human exposure.

Among the most studied EDCs in PCPs are parabens, a class of alkyl esters of p-hydroxybenzoic acid used extensively as preservatives. Parabens such as methylparaben, ethylparaben, and propylparaben are frequently detected in lotions, deodorants, shampoos, and makeup products, where they inhibit microbial growth and prolong shelf life [18]. These compounds are highly soluble in oils and have been measured in human biological samples such as hair and urine, indicating widespread exposure [18]. Although individual parabens exhibit relatively weak estrogenic activity, their ubiquitous presence and potential cumulative effects have been associated with endocrine perturbations, including reproductive outcomes and early pubertal timing in epidemiological studies [19].

Phthalates represent another common category of EDCs in PCPs, often used as plasticizers or fragrance carriers. Typical phthalates detected in products include diethyl phthalate (DEP) and di-n-butyl phthalate (DnBP), which are found in perfumes, deodorants, and hair sprays [3]. Phthalate exposure is commonly observed, and associations with altered hormone levels, reduced antral follicle growth, and early puberty have been reported, particularly among female populations [3]. These compounds are also

known to interact with androgen receptors and disrupt male reproductive hormone pathways, which complicates risk assessment [3].

Triclosan, an antimicrobial agent historically used in antibacterial soaps, toothpaste, and deodorants, has also been scrutinized for endocrine activity. While newer studies are emerging, triclosan's ability to disrupt hormone metabolism and its widespread detection in consumer products raise concerns regarding potential thyroid and reproductive effects [20]. Recent literature emphasizes triclosan's interference with hormone–receptor binding and steroidogenic enzymes, which can perturb normal endocrine signalling if exposure is chronic [20].

In addition to parabens, phthalates, and triclosan, PCPs may contain other EDCs such as benzophenones (UV-filter chemicals), bisphenols (plasticizers), and phenolic compounds, which have been detected in various cosmetic products and are linked to hormonal disruption and adverse health effects [21]. Consumer behaviour research has found that many PCP ingredient lists include chemicals associated with cancer, reproductive, or developmental harm, with some products containing undisclosed fragrance components that elude consumer detection [22].

For clarity, Table 1 below synthesizes current knowledge on commonly encountered EDCs in PCPs, outlining their typical uses, estimated concentration ranges in products, and associated health concerns. This table is anchored in available biomonitoring and analytical chemistry data and is intended to provide an empirical foundation for understanding how these chemicals are incorporated into products with which consumers interact daily.

Table 1: Common Endocrine-disrupting chemicals (EDCs) in Personal Care Products, Their Uses, Concentrations, and Health Concerns

EDC	Use in PCPs	Typical Concentration Range in Products	Health Concerns	Reference
Parabens (MeP, EtP, PrP, BuP)	Preservatives used to prevent microbial growth in cosmetics, lotions, shampoos, sunscreen, and makeup	Parabens are commonly detected at up to ~0.01–0.3 % of formulation in many leave-on and rinse-off products (typical levels observed in surveys of PCPs)	Potential endocrine activity (weak estrogenic effects), associations with reproductive hormone disruption and developmental endpoints in human biomonitoring studies (linked to urinary paraben metabolites)	[19]
Phthalates (e.g., DEP, DBP)	Used as solvents and fragrance carriers in perfumes, deodorants, hair sprays, nail polish, and soaps	Phthalates are frequently detected in products; DEP and DBP have median concentrations detected up to ~1000 µg/g in some surveys of PCPs (highest levels among certain product categories)	Anti-androgenic effects, endocrine disruption, associations with urinary metabolites reflecting PCP use and potential reproductive health impacts (higher levels in frequent users)	[3]
Triclosan (TCS)	Antimicrobial agent historically used in antibacterial soaps, deodorants, toothpaste, and some cosmetics	Historically present in antibacterial products at up to ~0.1–0.3 % before regulatory phase-outs and bans in some regions	Disrupts thyroid and reproductive hormone signalling; potential links to altered endocrine outcomes in toxicological studies (frequent detection in biomonitoring)	[20]
Benzophenone-3 (BP-3)	UV filter added to sunscreens, lip balms, sunscreen cosmetics	Occurs in a wide range of products; biomonitoring studies show high detection rates, though specific product percentage varies	Acts with weak estrogenic potential, implicated in hormone disruption and developmental effects (detected with parabens and other phenols in PCP use)	[21]
Bisphenols (BPA analogs)	Used in packaging resins and sometimes in cosmetic containers/formulations; can leach into products	Not intentionally added but detected via leaching; typically ppb level in formulations	Mimics estrogen and thyroid hormones; associated with metabolic disruption, reproductive effects, and developmental impacts	[21]

Exposure Pathways

Exposure to endocrine-disrupting chemicals (EDCs) from personal care products (PCPs) occurs through multiple interconnected pathways, each contributing to the total body burden of these biologically active compounds. A comprehensive understanding of these exposure pathways is essential for interpreting epidemiological evidence, estimating internal dose, and developing effective public health strategies. Personal care products such as lotions, deodorants, cosmetics, and sprays serve as vectors for EDCs to enter the human body through dermal absorption, oral ingestion, and inhalation, with cumulative exposure arising from the combined use of multiple products across daily routines. These pathways are not independent; instead, their contributions vary with product type, usage frequency, formulation characteristics, and individual behaviours.

Dermal exposure represents a significant route of EDC uptake due to the intimate and prolonged contact between PCPs and the skin. The human skin, although an effective barrier to many environmental agents, is permeable to lipophilic and low-molecular-weight chemicals commonly found in personal products. EDCs such as parabens and phthalates, which are used as preservatives and plasticizers, readily partition into the stratum corneum and diffuse into deeper tissue layers [2]. The capacity for dermal uptake is influenced by formulation factors including the solvent composition, presence of surfactants and emulsifiers, and occlusive properties of the product, all of which can enhance permeability and facilitate the entry of EDCs into systemic circulation [4, 23]. Studies have shown that dermal absorption can be a predominant pathway for chemicals like parabens and UV filters, especially for "leave-on" products such as moisturizers and sunscreens that remain on the skin for extended periods [22].

Oral exposure occurs when EDC-containing products are ingested, either intentionally or inadvertently. This pathway is particularly relevant for products applied near or around the mouth — such as lipsticks, lip balms, toothpastes, and hand-to-mouth contact following application of lotions or creams. EDCs like triclosan and bisphenols may be ingested in small amounts during routine use or through transfer from hands to food following product application [22]. Oral uptake is compounded by habits such as habitual biting of nails or lips, or by infants and young children who frequently explore objects and surfaces with their mouths. Dietary intake could also contribute to PCP-related exposure when residues from products contaminate food handling surfaces or are transferred via utensils.

Inhalation is an often overlooked but important exposure pathway, especially for volatile or aerosolized EDCs present in sprays, mists, and airborne particles from perfumes, deodorants, hair sprays, and room fragrances. Volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) associated with fragrance components or solvents can be inhaled into the lungs, where thin alveolar membranes facilitate rapid entry into the bloodstream. Although research on inhalation of PCP-related EDCs is still emerging, several studies describe inhalational uptake as a meaningful contributor to internal chemical burdens [24]. In addition, particles from sprays can settle on indoor surfaces, increasing dermal contact and oral ingestion through dust transmission, which underscores how pathways may overlap and reinforce one another over time.

These individual pathways do not act in isolation; instead, daily real-world use of multiple personal care products creates cumulative exposure to EDCs. Users apply combinations of lotions, deodorants, makeup, and other products, each containing different EDCs that may be absorbed through varied routes. The additive effect of repeated exposure across pathways increases the internal dose, regardless of concentration in any single product. Emerging research supports this concept of aggregate exposure: individuals with higher self-reported PCP use exhibit elevated biomarkers of parabens, phthalates, and other endocrine disruptors, reflecting combined dermal, oral, and inhalation uptake [22].

To aid conceptualisation, Figure 1 presents a schematic diagram of EDC exposure pathways from personal care products. The figure illustrates the three primary routes — dermal, oral, and inhalation — showing how chemicals applied to the skin, inhaled as aerosols, or ingested unintentionally can enter the human body and contribute to total endocrine disruptor load.

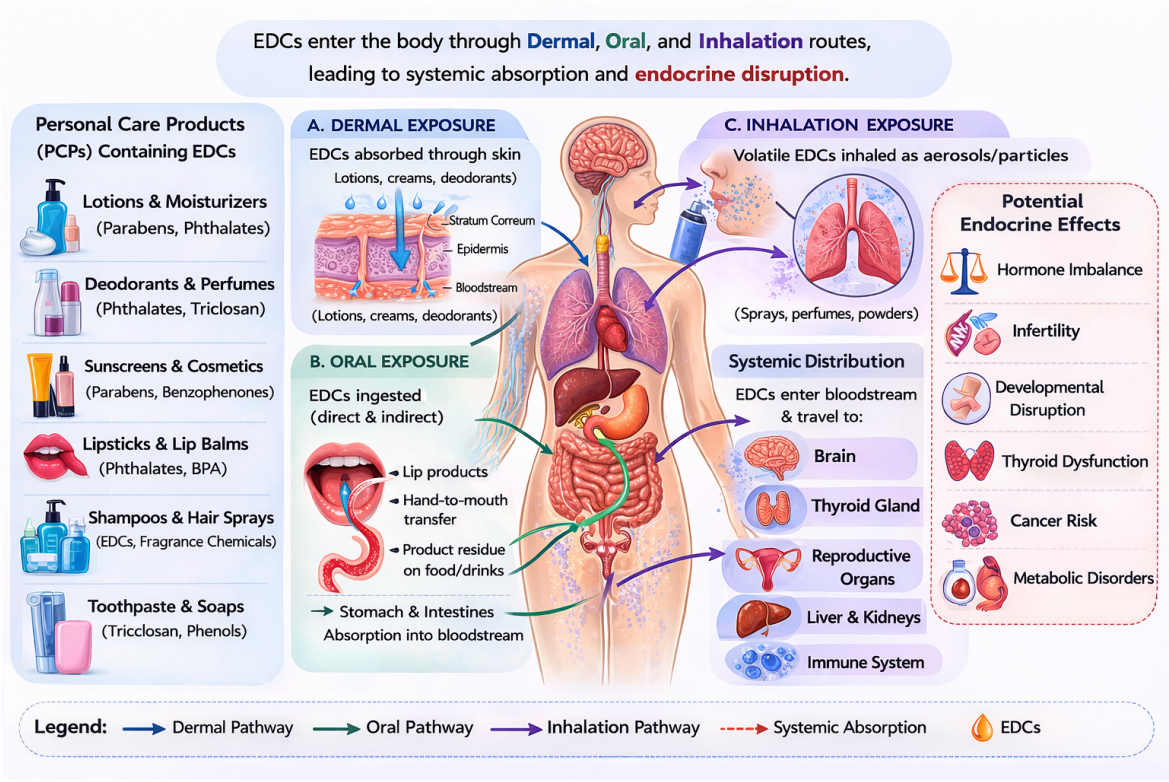

Figure 2: Schematic Diagram of EDC Exposure Pathways in Humans from Personal Care Products (PCPs)

Health Effects of EDCs

Endocrine-disrupting chemicals (EDCs) present a multifaceted potential threat to human health because they can interfere with hormone signalling, synthesis, and regulation at extremely low doses that overlap with normal physiological hormone levels. EDCs may mimic, block, or alter the actions of endogenous hormones, leading to disturbances in reproductive, developmental, metabolic, and neurological systems throughout life [25, 26].

A major domain of concern is the possible impact of EDCs on reproductive health. Because the reproductive system is highly sensitive to hormonal cues, chemicals that disrupt sex hormone receptors or synthesis may affect fertility and reproductive outcomes. Recent systematic reviews of epidemiological evidence consistently link exposure to EDCs — including bisphenols, phthalates, and persistent organic pollutants — with adverse reproductive outcomes in both males and females of reproductive age [27]. These associations include reduced sperm quality, hormonal dysregulation, impaired ovulatory function, and an increased risk of conditions such as polycystic ovarian syndrome (PCOS) and diminished ovarian reserve. Furthermore, prenatal and perinatal exposure to EDCs has been associated with altered reproductive development in offspring, raising concerns about potential transgenerational reproductive effects [25]. Human reproductive tissues appear particularly vulnerable because EDCs can bind to estrogen and androgen receptors, subtly but chronically altering endocrine signalling pathways that regulate gametogenesis, menstrual cycling, and fertility [28].

Closely linked to reproductive consequences are the developmental effects of EDC exposure, which may begin in utero and extend through childhood. EDCs can cross the placental barrier, exposing the developing fetus during critical windows when hormonal signals orchestrate organogenesis and differentiation. Prenatal exposure to mixtures of suspected endocrine disruptors has been associated with lower cognitive scores among children and altered neurodevelopmental trajectories by age seven [29]. These effects are likely to arise from EDC interference with thyroid hormone signalling during fetal neurodevelopment, a period when maternal thyroid hormones are crucial for brain maturation. Disrupted thyroid function early in life may lead to persistent consequences, including attention deficits, learning difficulties, and behavioural abnormalities [30, 31]. Importantly, epidemiological and clinical evidence also associates early life EDC exposure with reduced birth weight, altered body composition in children, and an increased risk of childhood obesity — effects that seem to endure into later life [26]. These findings highlight how early exposure to EDCs may imprint on growth and development long after initial exposure windows.

The carcinogenic potential of EDCs has drawn increasing scientific scrutiny, especially for

hormone-dependent cancers such as breast, prostate, and thyroid cancer. Although mechanisms linking EDCs to carcinogenesis remain complex and not fully resolved, research suggests that EDCs may influence cell proliferation, modulate epigenetic states, and alter hormone receptor expression in ways that could promote neoplastic transformation [32]. For example, certain flame retardants, polychlorinated biphenyls (PCBs), and pesticides have been associated with increased risks of thyroid and breast cancers in observational studies, with effects likely mediated through disrupted thyroid and estrogenic signalling [33]. Experimental evidence shows that EDCs can influence tumour microenvironments and cell cycle regulation, thereby exacerbating cancer progression through non-genotoxic pathways [34]. Although causality in humans remains a subject of ongoing investigation, the weight of evidence suggests that EDC exposure may contribute to hormone-sensitive cancers across the lifespan.

Beyond reproductive and carcinogenic outcomes, thyroid disruption and metabolic disorders are emerging as major health concerns associated with EDC exposure. The thyroid gland is central to regulating metabolism, growth, and energy balance, and EDCs such as bisphenol analogues, per- and polyfluoroalkyl substances (PFAS), and phthalates can disturb thyroid hormone homeostasis. A study examining multiple chemicals in adults found significant associations between EDC mixtures and altered thyroid hormone levels, implicating compounds like bisphenol F in thyroid disruption [35]. Disrupted thyroid hormone balance may lead to hypothyroidism or hyperthyroidism, with downstream effects on metabolism and weight regulation. Furthermore, there is accumulating evidence linking EDC exposure to metabolic disorders including obesity and type 2 diabetes. EDCs may augment adipogenesis, alter lipid metabolism, and impair glucose tolerance, contributing to an obesogenic environment and insulin resistance [26, 31]. These metabolic alterations, which can begin in childhood or even prenatally, underscore the pervasive influence of EDCs on endocrine regulation beyond classical hormone systems.

Other health concerns associated with EDC exposure span neurological impacts, immune modulation, and long-term cognitive declines. Emerging research suggests that chronic EDC exposure may lead to neuroinflammation, oxidative stress, and disruptions in neural signalling pathways, potentially contributing to neurodegenerative conditions and mood disorders [25, 36]. Although this area is still evolving, the consistent detection of EDCs in brain tissue and their association with altered neurotransmitter functioning suggests broad disruptions beyond traditional endocrine targets.

Finally, there is growing awareness of the long-term health effects of EDC exposure across the life course. Effects that originate from early life exposures — such as altered reproductive development or thyroid function — may predispose individuals to chronic diseases in adulthood, including infertility, metabolic syndrome, and hormone-related cancers. The concept of "developmental origins of health and disease" provides a framework for understanding how EDCs may set trajectories for disease well before clinical symptoms appear. This life course perspective emphasizes that exposure during sensitive windows such as fetal growth, infancy, and puberty can have implications that extend decades later, amplifying the burden of chronic disease in populations [25].

Factors Influencing EDC Exposure

The degree to which individuals are exposed to endocrine-disrupting chemicals (EDCs) is shaped by an interplay of sociodemographic, lifestyle, environmental, and geographic factors that determine not only the magnitude of exposure but also the susceptibility and potential health effects of these chemicals. Age, sex, and ethnicity play significant roles in shaping exposure patterns and internal doses because they influence both behaviour and physiological vulnerability. Younger individuals, particularly children and adolescents, may experience higher effective doses relative to body weight due to rapid growth and development, while hormonal differences between sexes can modify metabolic processing of EDCs, leading to sex-dependent disparities in both internal doses and health outcomes [37]. Ethnicity and socioeconomic status also correlate with distinct patterns of personal care product use — for example, differing categories and frequencies of product use among racial/ethnic groups — which can lead to systematically higher exposure to certain EDCs in specific populations [38]. Such disparities are not only a matter of product habits but reflect underlying structural inequalities that influence access to safe products, health information, and environmental conditions.

Lifestyle factors further modulate EDC exposure thresholds. Personal behaviours such as the frequency and type of personal care product usage, dietary patterns, and occupational activities dictate the likelihood and intensity of contact with EDC sources. Individuals who use a higher number of skin lotions, cosmetics, or fragranced products are more likely to exhibit higher internal concentrations of EDCs, including phthalates and parabens, compared with those who use fewer products [38]. Diet can contribute

substantially to overall exposure; consumption of foods that are packaged or stored in plastics, canned goods, and certain processed foods increases ingestion of bisphenols and other plasticizers that have endocrine-active properties. Similarly, occupational exposures in manufacturing, agriculture, or chemical-related industries may elevate contact with environmental EDCs through inhalation or dermal contact.

Environmental factors external to individual behaviours also shape the body's EDC burden. EDCs are pervasive in contaminated water sources, air, soil, and food chains due to industrial discharge, plastic waste, and agricultural runoff. Contaminated groundwater and surface water can serve as chronic sources of EDC exposure, particularly in regions with limited water quality management, where pesticides, steroid hormones, and phenolics are frequently detected above safety benchmarks [39]. Airborne EDCs from urban pollution and dust also contribute to inhalational exposure, layering another environmental burden onto lifestyle influences.

Geographic location, including distinctions between urban and rural environments, further affects EDC exposure patterns. Urban areas often have higher levels of environmental contaminants due to traffic emissions, industrial activity, and dense waste streams, which can elevate inhalation and contact exposure to EDCs, while rural settings may experience distinct exposures through agricultural chemicals used in farming and pesticide application. Studies have identified spatial patterns of EDC contamination, such as elevated levels in shallow urban wells and rural drinking water sources, indicating that both urbanization and land-use practices influence environmental EDC load [39]. Together, sociodemographic, lifestyle, environmental, and geographic factors interact to shape individual and community-level EDC exposure, underscoring the need for holistic approaches in exposure assessment and public health intervention.

Removal and Regulation of EDCs

The pervasive presence of endocrine-disrupting chemicals (EDCs) in environmental matrices and consumer goods has necessitated growing interest in both removal technologies and regulatory frameworks aimed at limiting human and ecological exposure. Although EDCs originate from diverse sources—including pharmaceuticals, personal care products, industrial chemicals, and agricultural agents—their chemical stability and widespread use present unique challenges for conventional wastewater and environmental treatment systems, as well as for the regulation of consumer products [30]. Understanding how EDCs are removed from wastewater and how they are regulated in products and environments is therefore critical to mitigating exposure risks.

Wastewater treatment plants (WWTPs) apply a combination of physical, chemical, and biological processes designed to remove traditional pollutants. However, these systems were not originally designed with EDC removal in mind, and their efficiency in eliminating such compounds varies widely. Studies have shown that conventional WWTP processes such as activated sludge, flocculation, and sedimentation can achieve moderate removal for some EDCs but often leave residual activity in effluent waters (e.g., steroidal estrogens and phenolic compounds) [40]. Advanced treatment technologies, such as advanced oxidation processes (AOPs)—including ozonation, photocatalysis, and hydroxyl radical-generating systems—have demonstrated much higher degradation efficiencies for a range of hormone-like compounds, sometimes exceeding 90% removal under optimized conditions [41]. Nonetheless, even advanced methods have limitations, such as incomplete mineralization of some intermediates and high operational costs. Emerging remediation strategies, including adsorption with engineered sorbents or biochar and microalgae-assisted degradation, also show promise for improved EDC removal but require further innovation and scale-up [42].

Alongside technological advances in remediation, regulatory frameworks play a central role in governing the presence of endocrine-disrupting chemicals (EDCs) in products and environmental outputs. Regulatory approaches differ substantially across regions, reflecting varying philosophies between hazard-based and risk-based regulation. In the European Union (EU), chemical regulations such as EC Regulation 1223/2009 on cosmetics set broad requirements for product safety, including restricted and prohibited lists for certain substances and mandated safety assessments prior to market entry [43]. The EU's precautionary principle often leads to stricter controls, and additional frameworks like REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) incorporate endocrine-disrupting properties as criteria for substance prioritization and restriction [44].

In contrast, United States regulatory approaches typically adopt a risk-based model, in which hazard identification is combined with exposure assessment to inform allowable levels and risk management actions. While statutes such as the Toxic Substances Control Act (TSCA) empower agencies to require testing and control of chemicals that pose

unreasonable risks, there is no comprehensive federal EDC-specific standard for personal care products alone, and restrictions often occur on a chemical-by-chemical basis (e.g., bans on triclosan in antibacterial soaps) [45]. Other countries, such as Canada and Japan, have begun modernizing risk assessment paradigms to include endocrine endpoints and develop hazard-based screening tools that may better capture EDC risks [46].

Despite these frameworks, challenges in EDC detection and regulation remain pronounced. Many existing testing protocols do not adequately capture low-dose, non-monotonic effects typical of EDC action, and regulatory systems often lag behind scientific understanding of mixtures and cumulative exposures [47]. Moreover, detection limits and mandated monitoring for EDCs in environmental matrices are frequently below regulatory thresholds, making enforcement difficult and contributing to ongoing environmental release. In the context of personal care products, regulatory limits on EDCs vary by region and chemical class, and many EDCs are not explicitly regulated in products but are instead restricted indirectly through safe use lists or product categories.

Public Health Implications, Prevention and Mitigation Strategies

The public health implications of endocrine-disrupting chemicals (EDCs) are far-reaching, extending from individual health burdens to broad societal and economic impacts. Endocrine disruptors—present in personal care products (PCPs), food packaging, water sources, and air—have the potential to interfere with hormonal systems that regulate growth, metabolism, reproduction, and brain development. They may contribute to chronic disease, disabilities, and diminished quality of life throughout the lifespan, reinforcing that EDC exposure is not merely a toxicological concern but a public health priority. Epidemiological and clinical studies have linked chronic EDC exposure to reproductive dysfunction, metabolic disorders such as obesity and diabetes, neurodevelopmental impacts, and even hormone-associated cancers, particularly in settings where exposure is persistent and unregulated [30].

Quantifying the disease burden attributable to EDCs is challenging, in part because exposures occur across multiple pathways and often involve low-dose, chronic contact with mixtures of chemicals. However, economic assessments suggest that the human health toll is considerable. For example, analyses in the European Union associated EDC exposures with both reproductive and neurobehavioral disorders, estimating annual economic costs in the hundreds of billions of Euros due to healthcare expenditures, productivity losses, and associated disability [47]. Similar cost estimations suggest substantial burdens in other regions, emphasizing that these exposures are not isolated health issues but form part of a complex, systemic public health problem.

Certain segments of the population are disproportionately affected due to vulnerability and susceptibility. Children and prenatal populations are uniquely sensitive because their endocrine systems and developmental processes are actively shaping organ systems and functional capacities. Studies document that early exposure to EDCs has been associated with childhood obesity, impaired cognitive development, and increased risks of metabolic syndrome later in life, indicating effects that extend across the life course and may manifest decades after the initial exposure [48]. Pregnant women who use PCPs and are exposed to chemicals like per- and polyfluoroalkyl substances (PFAS) may also carry elevated blood levels into gestation, affecting fetal hormone regulation and pregnancy outcomes, including hypertensive disorders of pregnancy [49]. Moreover, evidence reveals that socio-economic and environmental disparities can amplify these risks: low-income, minoritized, and structurally disadvantaged communities often face higher cumulative exposures and resulting health disparities, a pattern requiring targeted public health action [50].

Within this context, individual actions to reduce EDC exposure are essential, even as broader systemic change is pursued. Awareness of product ingredients and opting for EDC-free or lower-contaminant PCPs can serve as practical starting points. Lifestyle adjustments such as avoiding plastic containers, canned foods, and products with known endocrine-active ingredients—paired with increased consumption of fresh, organic foods—may help lower individual EDC intake, while nutritional strategies like ensuring adequate intake of antioxidant micronutrients can support resilience against oxidative stress from chemical exposure [51]. Public health messaging around these actionable steps complements education that empowers communities with knowledge about exposure sources and reduction techniques.

At the policy level, regulatory interventions are critical to reducing the population-level burden of EDC exposures. In contrast to historical models that often categorize chemicals as "safe until proven harmful," emerging policy discourse advocates for preventive frameworks that prioritize hazard identification, precautionary approaches, and pre-market safety testing, similar to models used in other regulatory domains such as cancer risk assessment [52, 53]. This includes establishing clear, evidence-based public health guidelines for allowable EDC concentrations in

consumer products, integrating mixture and cumulative exposure assessments, and enhancing monitoring systems for EDCs in both products and environmental media. Policies that mandate transparent labeling of product ingredients may contribute to safer consumer choices, while harmonized international standards can reduce regulatory fragmentation and enhance global protection.

Industry initiatives also have a pivotal role to play in reducing EDC exposure. Manufacturers bear corporate responsibility for prioritizing safety in product design and embracing green chemistry principles that replace hazardous chemicals with safer alternatives without compromising efficacy. Voluntary industry reforms—such as phasing out known EDCs from PCP formulations, adopting third-party safety certification, and investing in research on alternatives—may accelerate transitions toward safer products. Collaborative approaches between industry, researchers, and public health stakeholders further amplify the impact of these initiatives by aligning innovation with population health objectives.

The imperative to reduce EDC exposure is underscored by evidence that these chemicals contribute to disease burdens that span biological systems and age groups, while safeguarding health across generations remains a core objective of public health and regulatory science. Mitigating EDC exposures through individual behaviours, robust regulation, and responsible industry practices supports a comprehensive strategy for promoting endocrine health, preventing chronic disease, and protecting vulnerable populations.

Limitations

This study has several methodological limitations that should be considered. The inclusion of studies was limited to those published between 2021 and January 2026, which may have excluded valuable older studies that could provide historical context or broader insights. Additionally, only two databases (PubMed and ScienceDirect) were used in the literature search, which may have restricted the scope of available research, potentially missing relevant studies published in other databases or grey literature sources.

Another limitation is the lack of formal quality assessment for the included studies. Since this study followed a narrative review approach, we focused on synthesizing existing literature rather than evaluating the quality of individual studies, which could affect the strength of the conclusions drawn. Furthermore, while the review aimed to cover a broad range of studies, the heterogeneity in study designs and exposure contexts may limit the generalizability of the findings to all populations or settings.

Conclusion

Endocrine-disrupting chemicals (EDCs) in personal care products (PCPs) represent a significant public health concern due to their widespread use and the potential for exposure through multiple pathways. It was found that exposure to EDCs, primarily through dermal absorption, oral ingestion, and inhalation, occurs regularly due to the pervasive nature of personal care product use in daily life. These chemicals, such as parabens, phthalates, bisphenols, and triclosan, can interfere with hormonal systems even at low concentrations, leading to adverse health effects across various physiological systems. It was also found that the effects of EDCs are cumulative, with repeated exposure from multiple products increasing the total body burden of these chemicals over time.

The health effects of EDCs are extensive, with reproductive dysfunction, developmental disorders, metabolic disruptions, and thyroid imbalances being among the most commonly reported outcomes. The study highlighted that EDCs can alter reproductive health by affecting fertility, hormone regulation, and pregnancy outcomes. Additionally, it was found that EDCs can impair fetal development, affecting brain development, childhood growth, and cognitive function. Carcinogenic risks, especially in hormone-dependent cancers such as breast and prostate cancer, were also identified as a significant concern. The long-term exposure to EDCs was found to contribute to chronic diseases, such as obesity and diabetes, by disrupting thyroid function and metabolic processes.

It was found that the regulatory landscape for EDCs varies globally, with some regions adopting more stringent policies than others. The European Union has taken a precautionary approach, restricting several EDCs in cosmetics and other products, while in other regions like the United States, regulations are less comprehensive. The study found that the existing regulatory frameworks often fail to address the cumulative and mixed effects of EDCs, which complicates risk assessment and public health protection.

To address these gaps, it was found that prevention and mitigation strategies are essential. Individuals can reduce exposure by opting for EDC-free products and following lifestyle changes that minimize the use of plastic, processed foods, and

fragranced products. At the policy level, stronger regulatory frameworks are needed to limit EDC concentrations in consumer products and ensure safety through mandatory product labeling. Industry initiatives to adopt green chemistry and eliminate harmful chemicals in formulations can further contribute to reducing the overall public health burden from EDCs.

In conclusion, while significant progress has been made in understanding the health implications of EDC exposure, critical gaps remain in regulatory coverage, detection methods, and long-term health monitoring. It was found that continued research, improved regulatory approaches, and proactive industry practices are essential to reducing the health risks associated with EDCs and protecting public health in the long term.

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