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Systematic Review

The Impact of Endocrine Disruptors in Cosmetic Products: A Systematic Review

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Abstract

Nowadays, technology is developing so rapidly that it implicitly drives economic growth by increasing the productivity of artificial products. Endocrine disruptors (EDs) are increasingly recognized as emerging contaminants in cosmetic formulations, raising concerns about their ability to alter hormonal homeostasis through long-term, low-dose exposure. The objective of this systematic review is to synthesize current evidence on the presence, mechanisms of action, and health effects of endocrine-disrupting chemicals commonly found in cosmetic formulations, as well as existing regulatory frameworks and gaps in consumer protection. A systematic search across major scientific databases for studies published between 2000 and March 2026 was conducted in accordance with PRISMA guidelines, yielding 102 eligible studies. The most commonly identified endocrine disruptors were parabens, phthalates, benzophenones, and triclosan. Evidence shows that these compounds can mimic or block endogenous hormones, disrupt estrogenic, androgenic, and thyroid pathways, and contribute to reproductive, metabolic, and developmental disturbances. Several studies reported bioaccumulation in human tissues and measurable internal exposure with higher vulnerability in pregnant women and adolescents. Current evidence supports a biologically plausible and clinically relevant association between exposure to cosmetic-derived endocrine disruptors and adverse health outcomes. Despite regulatory progress, major gaps persist in long-term exposure assessment, mixture toxicity, and cumulative real-world risk. Strengthening surveillance, harmonizing international regulations, and encouraging safer cosmetic formulations remain essential to reducing population exposure. Although regulatory measures have been introduced, comprehensive protocols for the use of endocrine disruptors in cosmetics are still under development; additional targeted research is required to refine health risk assessments and strengthen regulatory frameworks.

Keywords: endocrine disruptors; cosmetics; public health; consumer safety; endocrine system; parabens; phthalates; benzophenones; triclosan

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1. Introduction

The endocrine system is a highly integrated regulatory network composed of specialized glands—such as the pituitary, thyroid, adrenal glands, pancreas, and gonads—that synthesize and release hormones directly into the bloodstream, enabling long-distance biochemical communication essential for maintaining physiological homeostasis. These hormones, whose name derives from the Greek hormáō ("to set in motion" or "to stimulate"), act as potent signaling molecules that modulate metabolism, growth and development, reproductive function, cardiovascular activity, circadian rhythms, mood regulation, and adaptive responses to stress. By coordinating cellular activity across multiple organ systems and adjusting bodily functions in response to internal and external stimuli, the endocrine system serves as a central regulatory axis whose integrity is critical for overall health and stable biological function [1].

Despite the growing number of studies investigating endocrine disruptors in cosmetics, the available evidence remains fragmented, heterogeneous, and difficult to interpret. Existing reviews often focus on single chemical classes, specific health outcomes, or regulatory aspects, without integrating exposure pathways, mechanisms, and population-level risks. Therefore, a comprehensive and systematic synthesis is needed to consolidate current knowledge and identify critical gaps for future research and regulation. Cosmetics represent a unique and understudied exposure pathway because they are applied directly to the skin, often daily and in combination, leading to chronic low-dose exposure that differs from that of dietary or environmental sources. Given their widespread use, potential for dermal absorption, and cumulative exposure patterns, endocrine disruptors in cosmetic products represent an emerging public health concern requiring systematic evaluation [1–3].

1.1. Objective

The objective of this systematic review is to synthesize current evidence on the presence, mechanisms of action, and health effects of endocrine-disrupting chemicals in cosmetic products, and to evaluate existing regulatory frameworks and knowledge gaps regarding consumer exposure.

1.2. The Endocrine System and Its Physiological Role

Maintaining endocrine health supports every major physiological system because hormones coordinate growth, metabolism, reproduction, stress responses, and internal stability. The endocrine system maintains this balance by producing and regulating hormones that act as chemical messengers, enabling organs and tissues to communicate efficiently and adapt to internal and external changes (Figure 1). These hormones regulate a wide range of physiological processes, and their main role is to link the nervous system to body functions such as development, metabolism, and reproduction. By coordinating these critical functions, the endocrine system ensures the harmonious functioning of the body's organs and tissues and adapts to internal and external changes [1–3].

Functional disorders of the endocrine system can be influenced by various factors, which can cause different diseases, such as diabetes, obesity, infertility, certain types of cancer, congenital malformations, and developmental and learning disabilities. An essential factor in the damage to the endocrine system is attributed to exposure to chemicals that can have side effects on the endocrine system, called endocrine disruptors (EDCs) [4–7].

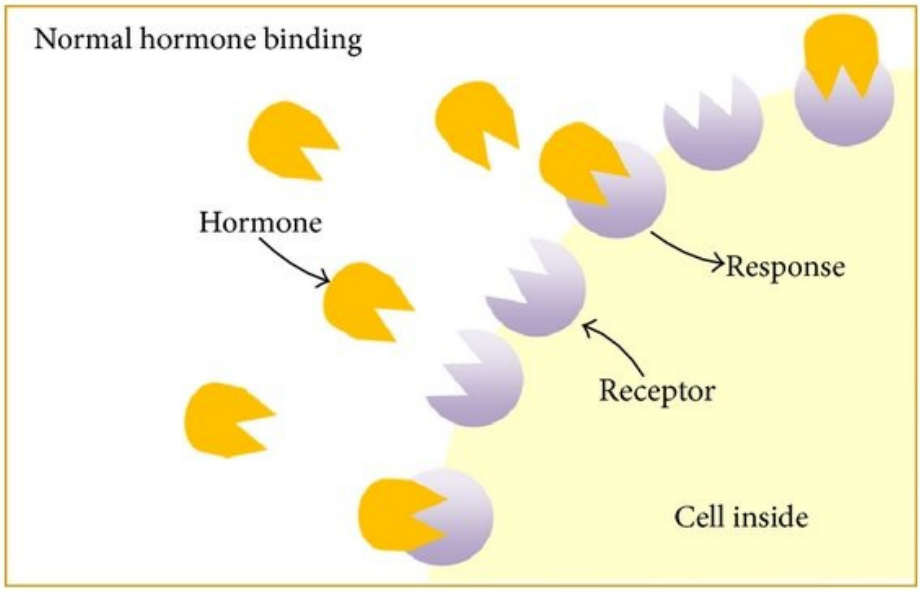


Figure 1. Normal hormone–receptor binding. Adapted from BioMed Research International (Sosa-Ferrera Z., Mahugo-Santana C., Santana-Rodríguez J.J., 2013) [8], available via ResearchGate. DOI: 10.1155/2013/674838.

1.3. Mechanisms of Endocrine Disruption

Endocrine disruptors are exogenous chemicals, including combinations of unnatural (synthetic) chemicals, that interfere with the proper functioning of the endocrine system [9–14]. They can affect hormone synthesis, their transport to cells, and their metabolism and excretion [8,15–17]. Endocrine disruptors are known to act primarily by altering the hormonal and homeostatic systems of living organisms. Therefore, they can mimic the action of hormones, "tricking" the body into reacting in a certain way, they can block the connection between hormones and their receptors (without binding to receptors, hormones do not reach the cell where their action is needed), or they can act on glands influenced by hyperproduction or underproduction of hormones [18–21].

Some (EDCs) bind directly to hormone receptors, mimicking the hormone or acting as its antagonist. For example, bisphenol A has been reported to act as an agonist when binding to estrogen receptors and as an antagonist when binding to androgen receptors/androgen receptors. Phthalates show a negative correlation in anti-androgenic activity in men and women for the anti-Müllerian hormone. Others may interact with proteins that influence hormone delivery to the target cell or affect proteins/tissues that influence hormone production (Figure 2) [22–25].

According to the Endocrine Society, more than 85,000 synthetic chemicals are in widespread use, and at least 1000 are known or suspected to act as endocrine disruptors. The true number is likely higher, as most synthetic compounds have not been systematically tested for endocrine-related effects. Endocrine disruptors have become a major public health concern due to their widespread presence in cosmetics, personal care products, food packaging, household materials, and the environment. Their relevance stems from their ubiquity, biological potency, and subtle mechanisms of action. These compounds can exert effects at very low doses, some of which may be irreversible, with implications for future generations. Their impact may be acute or long-term, and certain substances can accumulate in the body, contributing to cumulative biological effects [3,5,7].

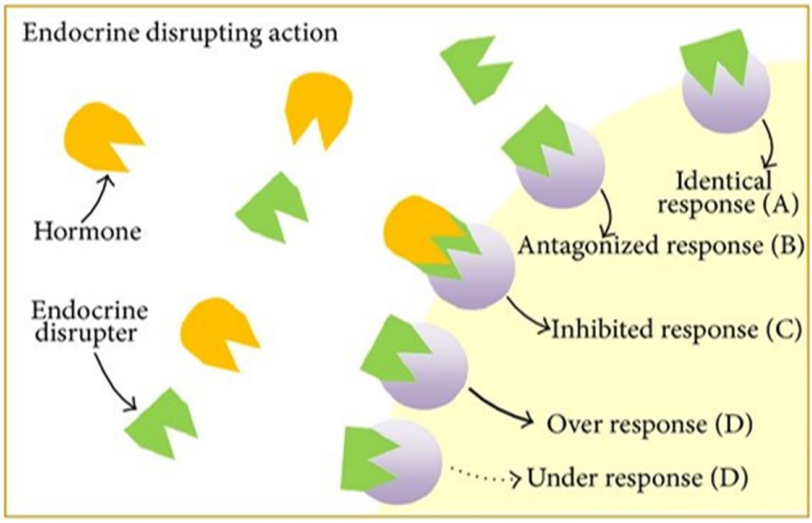


Figure 2. Schematic representation of endocrine-disrupting mechanisms: (A) mimicking natural hormones, (B) antagonizing hormone action, (C) altering hormone synthesis or metabolism, and (D) modifying the expression of specific receptors. Adapted from BioMed Research International (Sosa-Ferrera Z., Mahugo-Santana C., Santana-Rodríguez J.J., 2013) [8], available via ResearchGate. DOI: 10.1155/2013/674838.

Exposure to endocrine-disrupting chemicals has been associated with a wide range of adverse health outcomes. Their impact on reproductive function includes reduced fertility, malformations of the female and male reproductive tract, altered sex ratios, miscarriages, menstrual cycle irregularities, and changes in circulating hormone levels. Endocrine disruptors have also been linked to early puberty, neurodevelopmental and behavioral disorders, impaired immune function, and an increased risk of various hormone-dependent cancers. These effects may occur even at low exposure levels and can manifest across different stages of life, raising significant concerns for population health [13,16,22,23]. Men exposed to endocrine-disrupting chemicals may experience reduced testosterone levels, impaired sperm quality, and an increased incidence of benign testicular tumors [6,7,14,23]. In women, exposure has been associated with blocked fallopian tubes, ovarian and uterine disorders, impaired ovulation, abnormal oocyte quality, local inflammatory processes, and broader endocrine dysfunctions. Because the reproductive system is highly sensitive to hormonal imbalance, it is often among the first to show signs of disruption when overall health is compromised [4]. A major challenge is that it may take many years to accumulate sufficient evidence to confirm the harmfulness of specific substances, during which time these chemicals continue to spread and accumulate in the environment [10,23].

Endocrine disruptors are now present in plastics, cosmetics, pesticides, industrial chemicals, detergents, pharmaceuticals, and numerous other everyday products, contributing to continuous and widespread human exposure [5,7,8,10].

1.4. Cosmetics as a Source of Endocrine Disruptor Exposure

Cosmetics and personal care products have become a significant focus of public concern due to the presence of endocrine-disrupting chemicals in their formulations. The use of creams, lotions, shampoos, sunscreens, perfumes, and related products has increased markedly in recent decades, becoming ubiquitous in modern society and integral to daily routines. This widespread use raises safety concerns, as several ingredients commonly found in these products are known or suspected to interfere with the endocrine system [11,12,15,25].

Although cosmetics and topical products can provide clear benefits, certain chemical components may also pose health risks. Ingredients present in creams, lotions, sunscreens, and other formulations have been associated with allergic reactions, hormonal imbalances, and, in some cases, an increased risk of neoplastic changes when used over long periods [26–28]. The combination of frequent use, dermal absorption, and chronic exposure underscores the importance of evaluating the endocrine-disrupting potential of cosmetic ingredients.

Interest in this topic has grown steadily because exposure to endocrine-disrupting chemicals from cosmetics is often chronic—products are applied regularly, sometimes multiple times per day—and cumulative, as individuals typically use several formulations containing different compounds [29]. Repeated low-dose exposure through creams, lotions, and sunscreens has been associated with subtle hormonal imbalances, disruptions of thyroid and sex hormone regulation, and adverse effects on fertility, development, reproductive health, and other physiological functions. Many endocrine-related diseases do not become apparent during the period of exposure; instead, they may manifest later in adulthood or with aging, and this long latency complicates efforts to clearly link specific disorders to earlier exposure to endocrine disruptors [10,14,16]. Certain population groups, including pregnant women, children, and individuals with chronic health conditions, are particularly vulnerable to the effects of EDCs and may experience more pronounced or long-lasting consequences [12,17,19].

Attempting to define dose–response relationships for endocrine disruptors is challenging because these substances do not follow the classical toxicological principle that "the dose makes the poison." Many EDCs display non-monotonic dose–response curves, meaning that low doses can produce effects that are not predictable from high-dose testing. This makes traditional safety assessments—based on a few tested concentrations—insufficient for identifying reliable thresholds. Endocrine disruptors often produce effects that do not appear immediately after exposure. Hormonal systems regulate development, metabolism, reproduction, and aging through long, interconnected pathways, and disruptions in these pathways may take years to become clinically visible. This means that exposure during childhood, adolescence, pregnancy, or other sensitive windows can lead to health problems that only emerge much later in life. The delay between exposure and disease expression complicates the identification of causal relationships and makes early risk detection more difficult [19].

To address these issues, we conducted a systematic review following PRISMA guidelines to identify, evaluate, and synthesize evidence on endocrine-disrupting chemicals present in cosmetic products.

2. Materials and Methods

This systematic review was conducted in accordance with PRISMA guidelines and has been retrospectively registered in PROSPERO (CRD420261389531), available at (https://www.crd.york.ac.uk/PROSPERO/view/CRD420261389531) (accessed on 10 May 2026).

2.1. Eligibility Criteria

Eligible studies examined human or experimental exposure to endocrine-disrupting chemicals present in cosmetic or personal care products. Research assessing mechanisms of endocrine disruption, health effects, or exposure pathways related to cosmetic ingredients was considered relevant. Both observational and experimental studies were included when they provided data on reproductive, developmental, metabolic, immunological, or hormonal outcomes associated with cosmetic-related EDC exposure.

2.1.1. Inclusion Criteria

Studies were considered eligible when they met the following conditions:

- Population: Humans of any age, or experimental models used to investigate human-relevant endocrine effects.
- Exposure: Endocrine-disrupting chemicals found in cosmetics or personal care products.
- Outcomes: Hormonal changes, reproductive effects, developmental outcomes, metabolic alterations, immune effects, or mechanistic endocrine endpoints.
- Study designs: Observational studies, in vivo studies, in vitro studies, and toxicological investigations providing primary data.
- Articles written in English and available in full-text format were included.

2.1.2. Exclusion Criteria

Studies were excluded if they met any of the following:

- Articles not involving exposure to endocrine-disrupting chemicals from cosmetic or personal care products.
- Studies lacking primary data.
- Research unrelated to endocrine outcomes.
- Non-human studies without human relevance.
- Articles not published in English.
- Studies with insufficient methodological detail.

2.2. Information Sources and Search Strategy

The literature search was conducted across several major scientific databases to identify studies examining endocrine-disrupting chemicals present in cosmetic and personal care products. Literature searches were conducted for the period of 2000–March 2026 across PubMed/MEDLINE, Scopus, Web of Science, ScienceDirect, and Google Scholar, and were complemented by academic sources from Romania and the Republic of Moldova to ensure comprehensive coverage of relevant publications. The following Medical Subject Headings (MeSH) keywords were used to search for studies reporting on the role of environmental endocrine disruptors in cosmetics: "endocrine disruptors", "cosmetic products", "hormonal effects", "reproductive outcomes", and "toxicological mechanisms". Boolean operators (AND, OR) were used to link concepts and to broaden or narrow the search as needed, and search strings were adapted to each database's indexing structure.

2.3. Selection Process

Two independent reviewers screened the titles and abstracts of all identified studies to exclude irrelevant publications, using predefined eligibility criteria. Full-text articles were procured for all studies that met the initial screening requirements. Subsequently, the same two reviewers independently evaluated the full texts to ascertain final eligibility. Any disagreements regarding study inclusion were resolved through discussion until consensus was reached. When necessary, a third reviewer was consulted to adjudicate unresolved discrepancies. The final set of studies included in the review consisted only of those that provided primary data on endocrine-related outcomes associated with cosmetic-related exposure to endocrine disruptors.

2.4. Data Collection Process and Data Items

Data extraction was carried out using a standardized form developed prior to the review process to ensure consistency across studies. All full-text articles that met the eligibility criteria were examined in detail, and relevant information was recorded systematically. Extraction was performed independently by two reviewers, with discrepancies

resolved through discussion and consensus to minimize errors and reduce subjective bias. The process focused on capturing methodological characteristics, exposure details, and outcome measures relevant to endocrine disruption associated with cosmetic or personal care products. Collecting detailed exposure and outcome information allows for a nuanced understanding of how cosmetic-related endocrine disruptors affect human health. Recording methodological features supports transparent evaluation of study quality and strengthens the reliability of the synthesis. Capturing both biological endpoints and contextual factors ensures that the review reflects real-world exposure patterns and the complexity of endocrine-related outcomes.

2.5. Study Risk of Bias Assessment

The risk-of-bias evaluation was conducted using validated tools appropriate for each study design to ensure that the evidence included in the review was interpreted within a transparent methodological framework. Randomized or controlled experimental studies were assessed with the RoB 2 tool, which examines five domains: (1) bias arising from the randomization process, (2) bias due to deviations from intended interventions, (3) bias due to missing outcome data, (4) bias in outcome measurement, and (5) bias in the selection of reported results. Non-randomized human studies were evaluated using the ROBINS-I instrument, focusing on potential confounding, participant selection, exposure classification, deviations from intended exposures, missing data, outcome assessment, and reporting bias. Each study was independently reviewed by two evaluators, and any discrepancies were resolved through discussion to reach consensus. To ensure consistency across study designs, the final risk-of-bias judgments were harmonized into three categories: "low", "some concerns", and "high". An overall high risk of bias was assigned when at least one domain was rated "High" or when multiple domains were rated "Some Concerns". Disagreements between reviewers were resolved through discussion until consensus was reached, and the final judgments were used to contextualize the strength and reliability of the evidence included in the review. Detailed scoring for each study is provided in the Supplementary Materials: File S1 (PRISMA 2020 Checklist), File S2 (Characteristics of Included Studies), File S3 (Risk of Bias Assessment).

2.6. Effect Measures and Data Synthesis

Effect measures were extracted as reported by each study, with attention to maintaining the original statistical format to preserve comparability and interpretive accuracy. Studies commonly presented associations using odds ratios, relative risks, hazard ratios, correlation coefficients, or mean differences, depending on the design and the type of endocrine-related outcome assessed. When available, measures of variability such as confidence intervals, standard deviations, or standard errors were recorded to support the evaluation of precision and statistical robustness. Because the included studies varied substantially in design, exposure assessment methods, outcome definitions, and analytical approaches, a quantitative meta-analysis was not feasible.

Instead, the findings were synthesized narratively, emphasizing patterns of association, consistency across studies, and the biological plausibility of reported effects. Particular attention was given to differences in exposure metrics, population characteristics, and methodological quality, as these factors influenced the interpretation of endocrine-related outcomes. The synthesis aimed to integrate evidence across observational designs while acknowledging heterogeneity and the limitations inherent in the available data.

2.7. Study Selection

The study selection process adhered to PRISMA 2020 guidelines and followed a structured sequence to ensure transparency and compliance with the predefined eligibility

criteria [30]. The database search yielded 744 records: PubMed (n = 272), Embase/Scopus (n = 145), Web of Science (n = 126), Cochrane Library (n = 118), and Google Scholar (n = 83). After removing 56 duplicates, 688 records remained for screening. Of these, 154 were automatically marked as ineligible based on database filters, and 18 were excluded for other reasons (e.g., non-retrievable records, incomplete metadata). A total of 516 records proceeded to title and abstract screening. During the screening phase, 329 records were excluded for failing to meet the predefined eligibility criteria. The remaining 187 full-text articles were assessed for eligibility, and reasons for exclusion were documented systematically to maintain methodological rigor. Following a detailed evaluation, 102 studies met all inclusion criteria and were included in the final synthesis. This multi-stage selection process was documented in detail to support the construction of the PRISMA flow diagram and to ensure replicability (Figure 3).

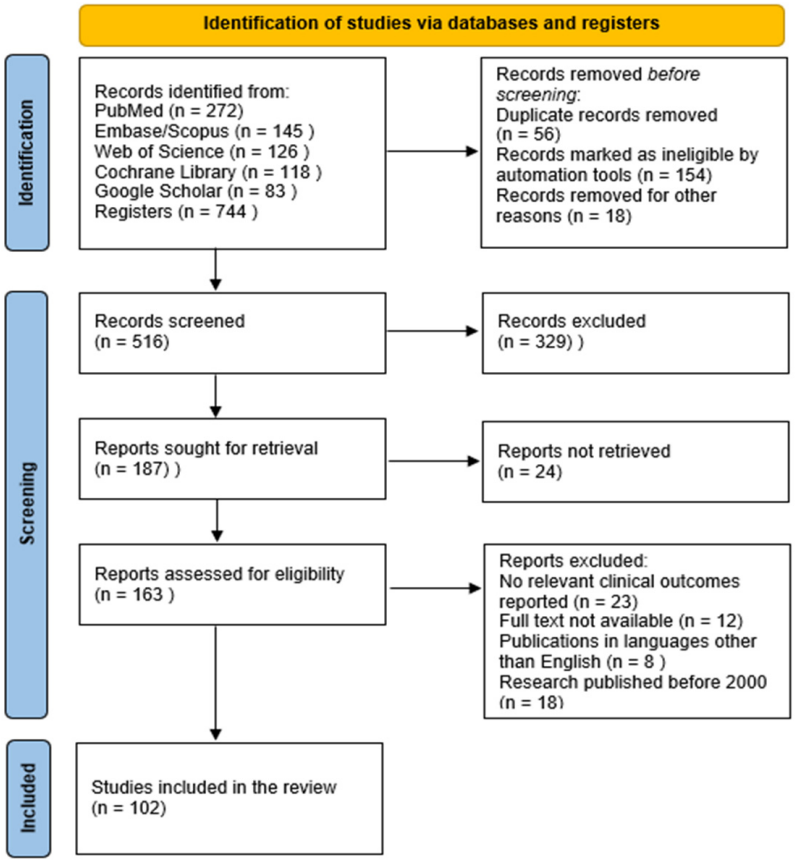


Figure 3. PRISMA flow diagram of the study selection process. Adapted from the PRISMA 2020 Statement [30].

3. Results

The final selection comprised 102 studies that met all predefined eligibility criteria and provided primary human data on endocrine-related outcomes associated with exposure to cosmetic-derived EDCs. These studies varied in design, including cross-sectional analyses, cohort studies, case–control investigations, and controlled human exposure assessments. Across the included literature, sample sizes ranged widely, reflecting both population-based datasets and smaller, targeted investigations. Most studies were conducted in North America, Europe, and East Asia, focusing on commonly used cosmetic products such as lotions, creams, shampoos, sunscreens, fragrances, and makeup formulations. The health status of the population is an integrated indicator of the country's social development and can be affected by numerous chemicals that may pose health hazards [10,24,25].

Chemicals that affect endocrine activity and disrupt it pose a major public health problem, given that the human body can be exposed to these substances through everyday products. These substances are found in the human body, in blood, urine, amniotic fluid, and adipose tissue, among other places. These substances can also migrate through the placenta from a pregnant woman to her developing fetus or through breast milk to her infant [13,15,18,21–23,31]. Given their widespread use and direct link to adverse human health effects, the Endocrine Society published a scientific statement in 2009 stating that endocrine disruptors represent a "significant public health concern" [32].

The population is exposed to endocrine disruptors through ingestion (e.g., lipsticks), inhalation of airborne particles (e.g., perfumes, hair, and body sprays), topical application, and in utero exposure [8,13,17,19,23,33]. EDCs are present in many of the products we use every day, can affect the balance of the hormonal system, and have the potential to cause long-term negative health effects.

Most endocrine disruptors are lipophilic and accumulate in adipose tissue, with a very long half-life in the body. Plasticizers lack these characteristics and are usually eliminated from the body within 24 h, yet humans are exposed to them daily [8,15,16]. We can classify these chemicals by their lipophilicity. Chemicals with high lipophilicity and longer half-lives are called "persistent EDCs" or "persistent organic pollutants" (POPs), which can bioaccumulate in fat and be bioamplified through the food chain. Representative chemicals are dioxins, dichlorodiphenyltrichloroethylene, heptachlor, and polychlorinated biphenyls. There are other chemicals with shorter half-lives and lower fat solubility, called non-persistent EDCs (npEDCs). Examples of NPEDCs are bisphenol A (BPA), phthalates, parabens, and triclosans (TCS) [34].

3.1. Cosmetic EDCs and Associated Health Risks

Cosmetic endocrine-disrupting chemicals (EDCs) pose heightened health risks during sensitive developmental windows, particularly the prenatal period, early childhood, and puberty, when hormonal systems are highly vulnerable, potentially leading to long-term effects on growth, reproductive health, and the metabolic axis, through mechanisms involving adipogenesis, insulin signaling, and lipid homeostasis. Exposure during these critical periods can alter developmental trajectories and increase susceptibility to disease later in life, a concept often described as the developmental basis of adult disease. Evidence indicates that early-life exposure to EDCs is associated with long-term effects on growth, metabolism, reproductive function, and immune and neurological development [8,15,16,18,35].

Several studies also highlight the potential for EDCs to induce epigenetic modifications that alter gene expression without changing the DNA sequence, with some of these changes persisting across generations and amplifying health impacts over time. These disruptions have been linked to congenital anomalies, thyroid dysfunction, obesity, diabetes, metabolic syndrome, asthma, infections, behavioral and learning disorders, cardiovascular disease, and cancers of hormone-sensitive tissues. The main route of exposure to chemicals in cosmetics is through application to the skin, so the integrity of the skin's protective barrier is an important factor in determining the latency of endocrine effects, as ingredients penetrate the skin barrier and subsequently enter the body. Many cosmetic products contain active substances, preservatives, and fragrances that can penetrate the skin barrier and enter systemic circulation, making dermal exposure a significant route by which these endocrine effects may arise. The integrity of the skin barrier, therefore, plays a key role in determining the extent and latency of systemic endocrine responses [18,23,30,32,35–37].

Any change in the environment can be "imprinted" on the body, leading to effects on human health and susceptibility to a wide range of diseases and disorders, such as congenital malformations, increased risk of short stature, thyroid dysfunction, obesity,

diabetes, and metabolic syndrome, as well as the development of infections, asthma, behavioral and learning disorders, cardiovascular disease, and cancer in hormone-sensitive tissues later in life [15,38]. EDCs can act as obesogens, increasing the risk of weight gain and related metabolic disorders, including type 2 diabetes, dyslipidemia, hypertension, and cardiovascular disease. They may also alter basal metabolic rate, gut microbiota composition, and hormonal regulation of appetite and satiety [25].

Chemicals in a range of cosmetic products, such as parabens, phthalates, and triclosan, can affect the endocrine system by acting as endocrine disruptors (Table 1). These substances can mimic hormones, affect hormonal balance, and are associated with various health problems, such as fertility problems, neurodevelopmental disorders, and an increased risk of certain types of cancer [18,29].

Table 1. Summary of endocrine-related risks associated with cosmetic ingredients in adolescents. Reproduced from The Conversation (Leslie Hart), licensed under CC-BY-ND. La face cachée des cosmétiques: quels risques pour la santé reproductive des adolescentes? Source: [Leslie Hart, based on research created with Datawrapper https://theconversation.com/la-face-cachee-des-cosmetiques-quels-risques-pour-la-sante-reproductive-des-adolescentes-230983] (accessed on 8 November 2025).

Product	Endocrine-Disrupting Chemicals Found in Some Brands
Liquid Hand Soap	Parabens, Phthalates, Triclosan
Lip Balm	Phthalates
Deodorant	Phthalates
Face Cleanser	Parabens, Phthalates
Face Lotion	Parabens, Phthalates
Body Lotion	Parabens, Phthalates, Oxybenzone
Body Wash	Phthalates
Mascara	Parabens
Shampoo	Parabens, Phthalates
Conditioner	Parabens, Phthalates

The effects of endocrine disruptors have been observed in wildlife, including fish, crustaceans, mollusks, reptiles, birds, and mammals, with many chemicals persisting in their food and habitats. Many endocrine disruptors are degraded in the environment, for example, by sunlight, bacteria, and chemical processes, while others persist for varying lengths of time. The organism may follow the same route of absorption as humans, such as ingestion or absorption through the skin. In some species, a decrease in reproductive capacity has been observed, affecting animal populations [13,38].

The impact on fertility has also been suggested in public health studies, with endocrine disruptors being the main factors causing a decrease in sperm count, an increase in the number of children with genital malformations, and the occurrence of hormone-sensitive cancers [6,7,12,34]. They have also been shown to affect immunity, the thyroid, and the liver, cause neurological diseases, and increase the risk of obesity [28,29,32].

The endocrine effects of chemicals result from mimicking endogenous hormones (estrogens and androgens), altering the physiological synthesis and metabolism of hormones, antagonizing endogenous hormones, and modifying hormone receptors [7,9,11,12]. This list is not exhaustive; many substances have unknown effects due to study limitations, and some are currently being evaluated.

Due to ongoing progress and changes in people's lifestyles, the human environment has been loaded with an increasing number of chemicals that can interfere with the nor-

mal functioning of the human body. Recent studies and reviews frequently report that many ingredients commonly used in skincare products have been identified as endocrine-disrupting [14,20,27–30,37,39]. Table 2 shows some of the best-known of these substances in cosmetics, where they are found, and why they are problematic.

Table 2. Chemicals used in cosmetics that are suspected endocrine disruptors and their potential effects on the human body [1–3].

Chemical Class	Representative Substances	Cosmetic Use	Endocrine Mechanism	Type of Evidence
Parabens	Methylparaben, Propylparaben, Butylparaben	Preservatives in creams, lotions, and makeup	Weak estrogenic activity; binding to estrogen receptor α (ERα)	In vitro studies; epidemiological associations
Phthalates	DEP, DBP, DEHP	Solvents, plasticizers, fragrance stabilizers	Anti-androgenic effects; inhibition of testosterone synthesis	Human biomonitoring; epidemiology; in vivo toxicology
UV Chemical Filters	Benzophenone-3 (BP-3), Homosalate, Octyl-methoxycinnamate	Sunscreens, daily skincare products	Estrogenic activity; thyroid hormone disruption	In vitro assays; animal studies
Triclosan	Triclosan	Antimicrobial agents in soaps, toothpaste, and deodorants	Interference with thyroid hormone signaling; possible estrogenic effects	In vitro studies; population-based studies
Synthetic Musks	Galaxolide, Tonalide	Fragrances in perfumes, lotions, and detergents	Bioaccumulation; potential PPAR-mediated metabolic effects	Limited evidence; environmental biomonitoring

3.2. Health Risks and Endocrine Effects Associated with Paraben Exposure

Parabens—including methylparaben, propylparaben, isobutylparaben, isopropylparaben, and butylparaben—are among the most widely used preservatives in cosmetic formulations such as creams, lotions, makeup, and shampoos due to their antibacterial and antifungal properties. The most common types encountered in consumer products are methylparaben (MeP), ethylparaben (EtP), propylparaben (PrP), and butylparaben (BuP). During both manufacturing and consumer use, significant quantities of parabens are released into the environment, contributing to widespread human exposure through ingestion, dermal absorption, and inhalation. Their presence in multiple exposure pathways underscores their relevance as ubiquitous endocrine-active chemicals in daily cosmetic use [11,20,24,38,40].

Parabens exhibit both estrogenic and anti-androgenic properties, thereby interfering with hormonal pathways that regulate energy metabolism, adipogenesis, and reproductive function. Their ability to bind estrogen receptors has raised concerns about their role in hormone-dependent cancers, particularly breast cancer, where they may mimic endogenous estrogens and disrupt normal signaling. Evidence links certain parabens to early sexual maturation, ovarian effects, and increased susceptibility to breast cancer, reflecting their capacity to influence reproductive and neuroendocrine development during sensitive life stages. These endocrine actions place parabens among the cosmetic ingredients most closely scrutinized for their potential contribution to metabolic disorders and hormone-related diseases [38,40–42].

Parabens are easily detectable in various environmental media, as well as in human blood, urine, and breast milk, raising concerns about their potential health risks [28]. They

are easily absorbed through the skin and have been linked to numerous health risks, including endocrine disruption, reproductive toxicity, metabolic disorders, neurological problems, and even cancer [25,26,40,41]. For this reason, some countries and companies have begun to restrict the use of certain long-chain parabens (e.g., Denmark has banned propylparaben and butylparaben in children's products) [24].

A tenfold increase in propylparaben concentration was associated with a 40% higher prevalence of metabolic syndrome among men. Among women, methylparaben was inversely associated with obesity, and methylparabens, propylparabens, and ethylparabens were associated with higher levels of HDL (high-density lipoprotein) cholesterol [25]. A German study shows that pregnant women who use products containing butylparaben (BuP) have a higher risk of their daughters becoming overweight in the first years of life [43]. Across experimental models, butylparaben consistently exhibits the highest toxicity, with cytotoxic and developmental effects observed at low micromolar concentrations. Benzylparaben shows intermediate toxicity, whereas methylparaben exhibits markedly lower cytotoxicity, with effective concentrations in the high micromolar to millimolar range. These findings support the established structure–activity relationship whereby longer-chain parabens display stronger endocrine and toxicological activity. Although these concentrations exceed typical human exposure levels, the differential potency among parabens remains relevant for regulatory assessment and cumulative exposure considerations (Table 3) [40–43].

Table 3. Summary of Toxic Concentrations for Selected Parabens [40–43].

Paraben	Toxicity Endpoint	Toxic Dose/Concentration	Model/System
Butylparaben (BuP)	Cytotoxicity EC50	~1.5 µM	Human keratinocytes
Benzylparaben (BeP)	Cytotoxicity EC50	~3.3 µM	Human keratinocytes
Methylparaben (MeP)	Cytotoxicity EC50	536–1313 µM	Human keratinocytes
Butylparaben	Zebrafish developmental toxicity	2–10 µM	Zebrafish embryos
Methylparaben	LC50	~73.4 mg/L	*Daphnia magna*
Butylparaben	LC50	~11.2 mg/L	*Daphnia magna*
Butylparaben	EC50	2.34 mg/L	*Aliivibrio fischeri*

The European Union and China have set the maximum permissible level for individual compounds in cosmetics at 0.4% and for mixtures at 0.8%. In addition, in 2015, China's National Medical Products Administration revised the 2007 Safety and Technical Standards for Cosmetics, restricting the permissible levels of PrP and BuP and banning long-chain branched parabens, including isopropylparaben, isobutylparaben, and phenylparaben. Therefore, some manufacturers may resort to alternative preservatives, such as benzoic acid, sorbic acid, and nitrite, to partially replace parabens, while others may use structural analogs that mimic parabens in preservative-free products [27].

3.3. Health Risks and Endocrine Effects Associated with Phthalate Exposure

Phthalates are a class of chemical compounds used primarily as plasticizers, that is, to make plastics (such as PVC) more flexible. In cosmetics, phthalates are used as solvents and fixatives for fragrances, eyelash glue, and other ingredients. For example, diethyl phthalate (DEP) is used to prolong the persistence of fragrance on the skin, and dibutyl phthalate (DBP) is used in nail polish to prevent cracking. Recent studies have shown that DEHP (diethylhexyl phthalate) is extremely toxic, especially during reproduction and growth, in both animals and humans. In addition, exposure to DEHP causes impaired ovarian

steroidogenesis, as well as low levels of progesterone, an inversely proportional (negative correlation) anti-androgenic effect, particularly related to testosterone concentration [44,45].

Phthalates hidden under the generic term "Fragrance/Perfume" contribute to nearly universal exposure, making their endocrine effects especially relevant to public health. Biomonitoring studies consistently detect phthalate metabolites in over 95% of the general population, reflecting the pervasiveness of these compounds in cosmetics, personal care products, and household environments. Their ability to mimic or block sex hormones places them among the most concerning endocrine-active chemicals, particularly because they interfere with the development and maturation of the reproductive system during sensitive life stages [33–35,37,46,47].

In boys, certain phthalates have been linked to early puberty and problems with genital development and may reduce sperm quality. Prenatal exposure to high levels of phthalates has been linked to negative effects on children's neurocognitive development and an increased risk of metabolic problems (e.g., obesity) later in life, and may influence thyroid hormones [48,49]. A 2024 study found higher urinary phthalate concentrations among young children who frequently used lotions, oils, sunscreens, and other skin care products, suggesting that cosmetics may be a direct source of phthalate exposure [50]. To avoid them, it is recommended to check the label and omit products with unspecified "fragrance" or those that list compounds such as "DBP," "DEHP," "BBP," etc. At the same time, opt for unscented (fragrance-free) products or those scented with natural essential oils, especially for children or during pregnancy. Volatile substances in perfumes and phthalates in packaging that migrate into the contents can have adverse health effects [49,50].

Across toxicological models, DEHP, DBP, and BBP demonstrate consistent endocrine-related toxicity, with reproductive and antiandrogenic endpoints being more sensitive than hepatic ones. DEHP shows lower NOAEL values for female reproductive toxicity (5 mg/kg/day) compared with hepatic effects (14 mg/kg/day), indicating heightened vulnerability of the reproductive axis. In aquatic models, DBP and BBP exhibit high embryotoxic potency, with LC50 values below 1 ppm in zebrafish embryos. All three phthalates induce antiandrogenic effects in rodent assays at doses ranging from 20 to 500 mg/kg/day, and human occupational studies report reduced serum testosterone following exposure to DBP and DEHP, supporting translational relevance. At higher doses, DBP and DEHP also produce hepatotoxic changes, including increased liver weight and histopathological alterations. Overall, the table highlights a coherent pattern of endocrine disruption across species, with reproductive and developmental endpoints being the most sensitive (Table 4) [51–54].

Table 4. Summary of Toxic Concentrations for Selected Phthalates [51–54].

Phthalate	Toxicity Endpoint	Toxic Dose/Concentration	Model/System
DEHP	Hepatotoxicity NOAEL	14 mg/kg/day	Rat
DEHP	Female reproductive NOAEL	5 mg/kg/day	Rat
DBP	Embryo toxicity LC50	~0.63 ppm	Zebrafish embryos
BBP	Embryo toxicity LC50	~0.72 ppm	Zebrafish embryos
DEHP, DBP, BBP	Antiandrogenic effects	20–500 mg/kg/day (varying doses)	Rat (Hershberger assay)
DBP, DEHP	Serum-free testosterone reduction	High occupational exposure	Human workers
DBP, DEHP	Hepatotoxicity (histopathology, liver weight)	250–300 mg/kg/day	Mouse

3.4. Cosmetic Chemical UV Filters and Their Endocrine-Related Concerns

Chemical UV filters are key active substances incorporated into sunscreen formulations to protect the skin from ultraviolet radiation. UV-filtering agents fall into two major

categories: physical (mineral) filters and chemical (organic) filters. Physical filters—most notably zinc oxide and titanium dioxide—act primarily by reflecting and scattering UV radiation at the skin's surface. In contrast, chemical UV filters absorb UV photons and convert them into less harmful forms of energy, making them widely used in modern cosmetic and personal-care products [55].

Commonly used chemical UV filters include benzophenone-3 (BP-3), 3-benzylidene camphor (3-BC), 4-methylbenzylidene camphor (4-MBC), octyl-methoxycinnamate (OMC), octocrylene (OCT), octyl-dimethyl-PABA (OD-PABA), and para-aminobenzoic acid (PABA). These compounds are frequently incorporated into sunscreens, daily moisturizers, and other skincare formulations due to their ability to absorb UVA and/or UVB radiation and prevent photoinduced skin damage [56–58].

Chemical UV filters are intended to protect the skin from ultraviolet radiation, yet several commonly used compounds have raised concerns due to their potential endocrine activity. Certain organic UV-filtering agents—such as oxybenzone (benzophenone-3), octinoxate (ethylhexyl methoxycinnamate), avobenzone, and 4-methylbenzylidene camphor (4-MBC)—possess molecular structures that enable them not only to absorb UV radiation but also to interact with hormone receptors. Oxybenzone, a frequent ingredient in conventional sunscreens, has been associated with estrogenic and anti-androgenic activity, suggesting possible disruption of both female and male hormonal pathways. Similarly, 4-MBC has demonstrated estrogen-like effects in animal studies [59].

Regular sunscreen use is particularly important for individuals at increased risk of developing non-melanoma skin cancers (NMSCs), such as those with fair skin phototypes, a history of chronic sun exposure, a history of NMSC, or immunosuppression. In these populations, ultraviolet radiation is a major carcinogenic driver, and consistent photoprotection is a key preventive strategy [60–62]. Although sunscreen use is widely recommended as an effective strategy to prevent ultraviolet-induced skin damage and non-melanoma skin cancers, excessive or inappropriate use may also carry certain drawbacks. Overreliance on sunscreens can lead to prolonged sun exposure and a false sense of security, potentially increasing cumulative UV dose if products are not applied in sufficient quantity or reapplied adequately. In addition, some chemical UV filters—such as oxybenzone, octinoxate, and 4-methylbenzylidene camphor—have raised concerns regarding systemic absorption, endocrine-disrupting potential, and environmental persistence. Frequent application of high-SPF formulations may also contribute to skin irritation or contact allergies in susceptible individuals. Therefore, sunscreen use should be integrated into a broader photoprotection strategy that includes shade-seeking behavior, protective clothing, and avoidance of peak UV hours [56,63].

Regulatory actions have begun to reflect these concerns. In 2024, the European Union announced a ban on 4-MBC in cosmetic products, citing evidence of its endocrine-disrupting properties. Products containing this compound were required to be reformulated or removed from the EU market by 2025. From a public health perspective, several scientific and regulatory bodies now advise caution regarding certain chemical UV filters and encourage the use of safer alternatives. These compounds may interfere with sex-hormone or thyroid-hormone signaling through multiple mechanisms, underscoring the need for careful evaluation of their long-term biological effects [64].

3.5. Health Risks and Endocrine Effects Associated with Triclosan Exposure

Triclosan is an antibacterial and antifungal compound widely used as a preservative in personal-care and cosmetic products, including soaps, shower gels, toothpastes, mouthwashes, deodorants, and makeup. Its popularity increased substantially during the 1990s and early 2000s due to its marketing as an "antibacterial" ingredient. Over time,

however, substantial evidence has raised concerns about its safety. Experimental and epidemiological studies indicate that triclosan can interfere with thyroid hormone homeostasis and reproductive hormone signaling, suggesting a potential role as an endocrine disruptor. Additional research links triclosan exposure to the promotion of antibiotic-resistant bacterial strains, further amplifying public-health concerns. These findings have led to increased regulatory scrutiny and a gradual reduction in triclosan use in consumer products across several regions [65,66].

In 2016, the U.S. Food and Drug Administration prohibited the use of triclosan in over-the-counter antibacterial soaps and hand sanitizers after concluding that the available evidence did not demonstrate a meaningful benefit relative to traditional hygiene measures, even as concerns about safety continued to accumulate [67]. Despite this restriction, triclosan remains permissible in several other categories of cosmetic and personal-care products, including certain toothpastes, wet wipes, shaving products, and deodorants. On product labels, it typically appears under the name "triclosan", although the structurally related compound triclocarban may also be present in similar formulations [32,68].

Given its documented potential to interfere with thyroid and reproductive hormone signaling, minimizing exposure to triclosan-containing products is considered prudent from a public-health perspective. A range of alternative antimicrobial agents—such as ethanol or isopropanol in disinfectants, chlorhexidine in medical and dental applications, and selected essential oils—provide effective antimicrobial activity without the same level of concern regarding endocrine disruption. The shift toward these alternatives reflects a broader trend in regulatory and scientific communities to prioritize compounds with more favorable toxicological profiles [33].

Across toxicological endpoints, the substance exhibits a consistently low acute toxicity profile, with oral LD50 values ranging from 3750 to 5000 mg/kg and subcutaneous LD50 values exceeding 14,600 mg/kg. Subchronic dermal exposure in mice increased liver weight and induced PPARα-related responses, effects known to be species-specific and not directly extrapolable to humans. Long-term oral studies in rodents and non-rodents revealed no carcinogenic potential, and reproductive and teratology studies showed no evidence of developmental toxicity, even at high doses. Importantly, safety margins derived from repeated-dose studies range from 1000 to 25,000 above NOELs, indicating a substantial buffer between human exposure levels and doses associated with adverse effects. Overall, the toxicological profile suggests low systemic hazard under realistic exposure conditions (Table 5) [69–71].

Table 5. Summary of Toxicological Endpoints and Safety Margins for Triclosan [69–71].

Dose/Concentration	Test System/Species	Notes/Additional Information	Reference Dyson ID
Acute Oral LD50	3750–5000 mg/kg body weight	Multiple animal species	Indicates relatively low acute oral toxicity
Subcutaneous LD50	>14,600 mg/kg body weight	Multiple animal species	Low acute systemic toxicity via subcutaneous injection
Dermal Exposure (13 weeks)	58 mg/kg and 125 mg/kg body weight/day	Female mice, dermal application	Liver weight increase and PPARα target gene activation; species differences noted
Chronic Oral Toxicity/Carcinogenicity	High doses exceeding typical exposure	Rodents and non-rodents	No carcinogenic potential observed at tested doses

Table 5. *Cont.*

Dose/Concentration	Test System/Species	Notes/Additional Information	Reference Dyson ID
Reproductive Toxicity & Teratology	High doses in rodent studies	Rodents and non-rodents	No evidence of teratogenic effects
Safety Margin	1000 to 25,000 times above NOELs	Derived from repeated daily dosing	Indicates a large margin of safety between no-effect levels and potential toxic doses

3.6. Other Persistent Cosmetic Chemicals with Endocrine Activity

Several additional cosmetic-related chemicals, including certain phthalates and per- and polyfluoroalkyl substances (PFAS), raise concern due to their persistence, bioaccumulation, and potential endocrine-disrupting properties. Some phthalates exhibit long environmental half-lives and have been associated with adverse effects on hepatic function, endocrine gland activity, and metabolic regulation. PFAS, a large class of highly stable fluorinated compounds, are incorporated into a variety of cosmetic formulations—such as moisturizers, foundations, nail polish, eye shadow, mascara, and shaving products—to enhance durability, spreadability, and water resistance. Their chemical stability contributes to environmental persistence and long-term human exposure [10,29,32].

Regulatory bodies have begun establishing threshold values for endocrine-active substances in environmental matrices to mitigate ecological and human-health risks. Within the European Union, guideline concentrations for 17β-estradiol and 17α-ethinylestradiol in surface waters have been set at 0.4 ng/L and 0.035 ng/L, respectively, reflecting their potent hormonal activity. In Canada, a water-quality guideline of 0.47 µg/L has been established for triclosan to protect aquatic organisms, acknowledging its endocrine-disrupting potential and ecological impact [72,73].

These regulatory benchmarks illustrate the increasing recognition of endocrine-active contaminants in both consumer products and the environment, underscoring the need for continued monitoring and evaluation of persistent chemicals used in cosmetics.

4. Discussion

The findings of this review underscore the pervasive presence of endocrine-active chemicals in modern cosmetic formulations and highlight the convergence of multiple exposure pathways that may collectively influence human health. Although parabens, phthalates, UV filters, triclosan, and PFAS differ in chemical structure and intended function, they share several toxicological features, including the ability to interfere with hormonal signaling, accumulate in biological tissues, and persist in environmental matrices. Biomonitoring studies consistently demonstrate widespread human exposure, often at low but continuous doses, raising concerns about cumulative and mixture effects that are not fully captured by traditional risk-assessment models [22]. Regulatory actions—such as the EU restrictions on 4-MBC and the FDA ban on triclosan in certain applications—reflect a growing recognition of these risks, yet significant gaps remain in ingredient disclosure, the safety evaluation of replacement chemicals, and the harmonization of international guidelines. The historical use of toxic cosmetic ingredients further illustrates that safety concerns are not new but part of a long trajectory in which scientific understanding has repeatedly lagged behind consumer practices. Taken together, the evidence emphasizes the need for more comprehensive toxicological assessment, improved regulatory oversight, and continued research into the long-term health implications of chronic exposure to endocrine-active cosmetic chemicals [74].

4.1. Cumulative Risk from Multi-Chemical Cosmetics

The combined exposure to multiple endocrine-active chemicals present in cosmetic products raises concerns that extend beyond the toxicological profiles of individual compounds. Humans are rarely exposed to a single substance in isolation; instead, daily cosmetic use results in complex mixtures of parabens, phthalates, UV filters, PFAS, and antimicrobial agents such as triclosan. Experimental and epidemiological studies increasingly demonstrate that these mixtures can produce additive, synergistic, or non-linear effects, even when each component is present at concentrations considered safe on its own. Endocrine pathways are particularly vulnerable to such interactions because hormonal signaling operates through highly sensitive, low-dose mechanisms that can be disrupted by multiple chemicals acting on the same receptor systems or metabolic pathways [75].

The cosmetic product categories that contribute most significantly to exposure to endocrine-disrupting chemicals vary across populations, depending on age, sex, and usage patterns. In adults, the highest contributors are leave-on products such as moisturizers, lotions, perfumes, deodorants, and makeup, which often contain parabens, phthalates, UV filters, and synthetic musks. Among adolescents and young adults, frequent use of fragranced body sprays, hair products, and makeup results in greater cumulative exposure. In infants and children, exposure is primarily associated with baby lotions, diaper-area creams, and sunscreens. Overall, leave-on and fragranced products are the major sources of dermal and inhalation exposure to endocrine-active cosmetic ingredients across all age groups. The phenomenon of mixtures challenges traditional risk-assessment models, which typically evaluate chemicals individually and may underestimate real-world health risks. This growing body of evidence underscores the need for regulatory frameworks that incorporate cumulative exposure and mixture toxicity into safety evaluations, especially for products used daily and in combination [76,77].

4.2. Historical Use of Cosmetics and Their Toxicological Implications

Cosmetics have been used for thousands of years, but many early formulations contained substances now known to be highly toxic. Lead-based powders, mercury-containing skin lighteners, and arsenic preparations were widely used across different cultures, often causing severe poisoning, neurological damage, and chronic illness. These historical examples illustrate how cosmetic practices evolved long before toxicology or consumer safety standards existed [78–80].

EDCs raise concern because they interfere with hormonal regulation in ways that can affect multiple biological systems across the lifespan. Their ubiquity in consumer products, including cosmetics, increases the likelihood of continuous low-dose exposure. Research shows that many cosmetic ingredients with endocrine-disrupting properties—such as parabens, phthalates, triclosan, and certain UV filters—are widely used and can contribute to hormonal imbalances, reproductive issues, and long-term health effects. These substances are present in thousands of cosmetic formulations, and their toxicological impact includes carcinogenesis, reproductive toxicity, and metabolic disturbances. They mimic or interfere with natural hormones, and their widespread presence in everyday products has raised public health concerns, prompting regulatory scrutiny in the EU and internationally [5,7,64].

4.3. Changing Beauty Ideals and the Growth of Cosmetic Use

The rapid expansion of cosmetic use over recent decades is closely intertwined with broader cultural transformations in how beauty is defined, pursued, and socially valued. Contemporary beauty standards increasingly emphasize constant self-optimization, youthfulness, and flawless appearance—ideals amplified by digital media, advertising, and

image-centric social platforms [81]. These evolving norms have contributed to a shift from occasional cosmetic use to daily, multi-step routines that involve a wide array of products, each promising targeted enhancement or correction. This cultural redefinition of beauty not only drives market growth but also increases cumulative exposure to cosmetic ingredients, underscoring the importance of understanding how societal expectations shape both consumer behavior and potential health implications [82–85].

Providing clear guidance on evidence-based scar care—such as photoprotection, hydration, appropriate topical therapies, and the expected timeline of scar maturation—can help patients develop realistic expectations and reduce the impulse to rely excessively on cosmetic products for concealment. When cosmetic camouflage is used without proper instruction, it may reinforce negative self-perception and encourage maladaptive concealment behaviors. By contrast, educating patients on the judicious use of camouflage products as supportive, rather than primary, strategies can promote healthier coping mechanisms and improve overall satisfaction with appearance [86–89].

4.4. Regulatory Frameworks Governing Endocrine-Active Cosmetic Chemicals

Regulatory frameworks for cosmetic ingredients increasingly acknowledge the complexity of endocrine disruption, yet current policies remain fragmented and often insufficient to address real-world exposure patterns. Restrictions implemented by agencies such as the U.S. Food and Drug Administration and the European Commission demonstrate a gradual shift toward precautionary regulation, as seen in the ban of triclosan in certain applications and the prohibition of 4-MBC in cosmetic products. However, many endocrine-active substances—including several phthalates, UV filters, and PFAS—continue to be permitted despite accumulating toxicological evidence. A major challenge is that most regulatory assessments evaluate chemicals individually, without accounting for cumulative or mixture effects that characterize daily cosmetic use. Furthermore, ingredient disclosure requirements vary widely across jurisdictions, allowing some compounds, such as phthalates, to remain hidden under generic terms like “fragrance” [34,64].

The issue of endocrine disruptors has been on the European Union’s (EU) agenda since 1999, when the European Commission published a policy approach with short-term (research and cooperation to determine the effects generated), medium-term (causality testing methods), and long-term (regulatory measures) actions, with the aim of reducing exposure to the lowest possible levels. During this time, the EU has managed to identify and minimize exposure across sectors such as chemicals, water, and cosmetics. As a result of REACH—the Regulation on the Registration, Evaluation, Authorization, and Restriction of Chemicals, ECHA (European Chemicals Agency) has included endocrine disruptors on the list of substances of concern [33,34]. Environmental guidelines, such as EU limits for estradiol and ethinylestradiol in water or Canada’s threshold for triclosan, highlight growing concern about ecological impacts, yet similar protective thresholds for cosmetic formulations themselves are less consistently applied. Strengthening regulatory oversight will require harmonized international standards, improved transparency in ingredient labeling, and risk-assessment models that incorporate low-dose effects, vulnerable populations, and the combined action of multiple endocrine-active chemicals [68,73].

Regulation 1223/2009 on cosmetic products defines a cosmetic product as “any substance or mixture intended to come into contact with the various external parts of the human body (skin, hair, scalp, nails, lips and external genitalia) or with the teeth and the mucous membranes of the oral cavity with a view exclusively or mainly to cleaning them, perfuming them, changing their appearance and/or correcting body odours and/or protecting them or keeping them in good condition” [64]. The criteria for identifying EDCs are based on a compound’s ability to cause adverse effects, the presence of an endocrine mode

of action (MoA), and the adverse effects resulting from that MoA. Regulatory assessment of toxicological substances (ES) requires extensive animal testing to identify toxicological effects and a high level of understanding of the mechanism of toxicity [90].

4.5. Preventive Measures to Limit Exposure to Endocrine-Disrupting Ingredients

Reducing exposure to endocrine-active cosmetic chemicals is challenging, given their widespread presence in consumer products and the environment. Nonetheless, several evidence-informed behavioral strategies can substantially decrease cumulative risk.

One effective approach is to limit the number of cosmetic and personal-care products used daily. Each additional product represents a potential source of chemical exposure, and simplifying personal-care routines by selecting fewer high-quality, multifunctional formulations can meaningfully reduce the overall chemical burden. For instance, a single unscented cleansing product may replace multiple scented alternatives, and a basic, well-formulated moisturizer may serve as an adequate substitute for several layered serums [91,92].

Careful examination of ingredient lists is another essential preventive measure. In the European Union, full ingredient disclosure is mandatory, enabling consumers to identify substances of concern such as parabens, triclosan, or specific phthalates. Selecting products from brands that prioritize transparency and adhere to recognized certification standards—such as COSMOS Organic or COSMOS Natural—can further reduce exposure, as these certifications restrict the use of many synthetic endocrine-active compounds. Digital tools, including barcode-scanning applications, can help consumers quickly identify products containing hazardous or controversial ingredients. In the European Union, all ingredients must be listed on the packaging, which helps identify substances such as parabens and triclosan [93,94].

Choosing sunscreens formulated with mineral filters, such as zinc oxide or titanium dioxide, provides an additional layer of protection, rather than those with potentially problematic chemical filters (avobenzone, octinoxate, oxybenzone, etc.). Unlike certain chemical UV filters associated with endocrine activity, mineral filters act as physical barriers on the skin's surface and exhibit minimal dermal penetration. Special consideration is warranted for pregnant women and children, whose physiological vulnerability and higher absorption rates may increase susceptibility to endocrine disruption. For these groups, fragrance-free products with minimal preservatives and formulations specifically designed for sensitive or infant skin are preferable, while intensive chemical treatments—such as ammonia-based hair dyes—should be avoided [95].

Dietary strategies that enhance endogenous photoprotection offer a valuable complement to topical sunscreens and may help reduce reliance on excessively high SPF values. Carotenoids such as β-carotene, lycopene, lutein, and zeaxanthin accumulate in the skin and mitigate UV-induced oxidative stress, while glutathione and its precursors support redox balance and DNA repair. Additional nutrients—including vitamins C and E, polyphenols, omega-3 fatty acids, niacinamide, and selenium—further strengthen the skin's antioxidant defenses, modulate inflammation, and improve barrier resilience. Although these nutritional approaches cannot replace sunscreen application, they contribute to a more robust systemic defense against UV radiation and may be incorporated into patient education as part of a holistic, sustainable photoprotection strategy [96–98].

Staying informed about emerging scientific evidence is a critical component of preventive behavior. Organizations such as the Endocrine Society, the National Institute of Environmental Health Sciences, and other public-health bodies regularly publish updates on endocrine-disrupting chemicals, including lists of substances of concern and guidance for safer consumer practices. Maintaining awareness of these developments supports informed decision-making and contributes to long-term risk reduction [33,34,64,67,68].

Young children represent physiologically vulnerable populations for whom exposure to endocrine-disrupting cosmetic ingredients warrants particular caution. Infants and children have a higher dermal absorption capacity relative to adults, and their developing endocrine and metabolic systems may be more susceptible to disruption by exogenous chemicals. For this reason, cosmetic products intended for these groups should be as simple as possible in their formulations—fragrance-free, free of harsh preservatives, and ideally certified or labeled as suitable for infants or sensitive skin. Minimizing the number of products applied and selecting formulations with well-characterized safety profiles can further reduce potential exposure [8,13].

Pregnant women may also face heightened vulnerability due to the hormonal sensitivity of pregnancy and the potential for certain chemicals to cross the placental barrier. It is advisable to avoid intensive chemical treatments, including ammonia-based hair dyes and other high-exposure cosmetic procedures, as well as products containing ingredients identified as endocrine-active in the scientific literature. Prioritizing mild, low-additive formulations and avoiding unnecessary cosmetic interventions during pregnancy can help limit exposure during this critical developmental period [17,19,22].

Careful evaluation of product composition remains one of the most effective strategies for limiting exposure to endocrine-disrupting cosmetic ingredients. Selecting formulations explicitly labeled as paraben-free, phthalate-free, and fragrance-free can substantially reduce contact with several major classes of endocrine-active compounds. Ingredient lists provide critical information for informed decision-making, particularly in regulatory environments such as the European Union, where full disclosure of cosmetic components is mandatory. This transparency enables consumers to identify and avoid substances associated with endocrine activity or other toxicological concerns [77,93,99,100].

Digital resources further support safer product selection. Mobile applications capable of scanning barcodes or retrieving product profiles by name can rapidly identify formulations containing ingredients of concern and suggest alternatives with fewer endocrine-active substances. These tools help bridge the gap between complex chemical nomenclature and practical consumer understanding, facilitating consistent, evidence-informed choices in daily personal-care routines [101,102].

Complementary behaviors, such as maintaining a diet rich in antioxidant-containing foods, supporting adequate sleep, and reducing unnecessary chemical exposures in the home environment, contribute to the body's natural resilience, although they cannot counteract direct hormonal interactions caused by endocrine disruptors. These combined strategies promote a more protective lifestyle framework while broader regulatory and environmental factors continue to evolve [99].

4.6. Limitations of Current Evidence

Research on endocrine-disrupting ingredients in cosmetic products has expanded substantially, yet several methodological and conceptual limitations constrain the strength of current conclusions. Much of the available evidence is derived from cross-sectional biomonitoring studies, which can identify associations between chemical exposure and biological markers but cannot establish temporal or causal relationships. Experimental studies often rely on concentrations that exceed typical consumer exposure, making it difficult to extrapolate laboratory findings to real-world conditions.

Another challenge arises from the rapid evolution of cosmetic formulations: as certain chemicals become restricted or publicly scrutinized, manufacturers frequently replace them with structurally similar analogs whose toxicological profiles are not yet well characterized. This "regrettable substitution" phenomenon complicates long-term risk assessment and may perpetuate exposure to poorly studied endocrine-active compounds. Addition-

ally, most regulatory and scientific evaluations continue to assess chemicals individually, despite growing evidence that mixture effects—particularly additive or synergistic interactions—may better reflect actual exposure scenarios.

Vulnerable populations—including pregnant women, infants, and adolescents—remain insufficiently represented in current research, and longitudinal evidence capturing developmental or long-term health outcomes is still scarce. These gaps underscore the need for more comprehensive, long-duration studies that incorporate real-world mixture exposure scenarios to better characterize the health implications of endocrine-active cosmetic ingredients. Although European regulatory frameworks and risk assessment approaches employ the no-observed-adverse-effect level (NOAEL) and Margin of Safety (MoS) calculations for endocrine disruptors, current methodologies acknowledge important limitations, particularly regarding mixture effects and low-dose, nonmonotonic responses. Experimental studies often use higher doses than typical cosmetic exposure, though low-dose endocrine effects complicate interpretation.

4.7. Future Research Directions

Future investigations would benefit from longitudinal cohort studies that track exposure and health outcomes over time, enabling stronger causal inference than cross-sectional biomonitoring can provide. Improved exposure assessment is also essential. This includes integrating high-resolution analytical methods, repeated biomonitoring across life stages, and refined models that capture dermal absorption, inhalation, and aggregate exposure from multiple product categories.

A major research need is to characterize the combined effects of chemical mixtures commonly encountered in cosmetic use. Experimental systems capable of modeling additive, synergistic, or antagonistic interactions at environmentally relevant concentrations would provide more realistic risk estimates. Particular attention is needed for non-monotonic dose–response relationships, which challenge traditional toxicological assumptions and complicate regulatory thresholds.

As regulatory pressure increases on well-known endocrine disruptors, manufacturers frequently introduce structurally similar substitutes whose safety profiles remain poorly understood. Systematic evaluation of these replacement chemicals—using high-throughput screening, in vitro endocrine assays, and computational toxicology—would help prevent cycles of "regrettable substitution."

Research should prioritize groups at heightened risk, including pregnant women, infants, adolescents, and individuals with dermatological conditions that may affect absorption. Studies examining exposure during critical developmental windows, such as prenatal and early childhood periods, are particularly important for understanding long-term endocrine and metabolic outcomes.

Future work should also inform regulatory decision-making by developing cumulative risk-assessment frameworks, improving predictive toxicology tools, and generating data that support harmonized international standards. Collaboration among academic researchers, regulatory agencies, and industry stakeholders will be essential to translating scientific findings into effective public health protections.

5. Conclusions

The increasing presence of endocrine-disrupting chemicals in the environment represents a growing global public health concern. Evidence across cosmetic ingredients indicates that these substances remain problematic, driven by complex exposure patterns, continually evolving formulations, and gaps in regulatory oversight. Although individual compounds such as parabens, phthalates, UV filters, triclosan, and PFAS differ in struc-

ture and intended function, they converge in their capacity to interfere with hormonal signaling, accumulate in biological systems, and persist in environmental reservoirs. The most exposed products include deodorants, shower gels, lotions, makeup, and hair products, which are used daily for extended periods. The available evidence indicates that a substantial proportion of cosmetic products—over 70% in some market surveys—contain at least one ingredient with suspected endocrine-disrupting activity, and biomonitoring studies consistently detect parabens, phthalates, and UV filters in more than 90% of tested populations, highlighting the ubiquity of exposure.

The development of novel analytical methods, enhanced biomonitoring techniques, and interdisciplinary approaches presents promising opportunities for more precise characterization of exposure and risk. Preventive strategies at the consumer level—such as simplifying product use, scrutinizing ingredient lists, and selecting certified formulations—can meaningfully reduce exposure, but long-term protection ultimately depends on stronger regulatory frameworks and sustained scientific inquiry. Public health in the context of widespread cosmetic use depends on a coordinated, multi-level approach that aligns scientific evidence, regulatory progress, and informed consumer practices. As research on endocrine-active and other potentially hazardous cosmetic ingredients continues to advance, understanding cumulative exposure patterns and mixture effects becomes increasingly important for accurate risk assessment. These insights are essential for shaping more protective regulatory policies, guiding the development of safer formulations, and supporting educational initiatives that empower consumers to make evidence-based choices.

Future research should prioritize longitudinal cohort studies with quantitative exposure assessment, mixture-based toxicological models, and harmonized analytical methods to better characterize dose–response relationships and cumulative risk, particularly for vulnerable groups such as children, adolescents, and pregnant women.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/cosmetics13030141/s1, S1: PRISMA 2020 Checklist, S2: Characteristics of Included Studies, S3: Risk of Bias Assessment.

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