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REVIEW ARTICLE

Plastics in dermatology: A review and solutions

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Abstract

Hazards to human and planetary health are present at every stage of the plastic life cycle, yet plastic production is projected to triple by 2060. This review focuses on three key areas: the life cycle of plastic, the impact of microplastics and their associated chemicals, along with recommendations to reduce plastic use. In dermatology, micro- and nanoplastics are especially problematic as they are present in over 90% of personal care products. They have been detected in utero, absorbed through the skin and found in the lungs and gastrointestinal tract. Numerous in vitro and animal studies have substantiated the negative impact of micro- and nanoplastics but gaps remain with regards to their effect on human health. In spite of this limitation, we review the evidence to date and offer evidence-based recommendations which can reduce plastic production, enhance health outcomes and promote environmental justice.

INTRODUCTION

Plastic is regarded as one of the four pillars of modern civilization[1] and is crucial in healthcare. It is used in a wide range of medical applications, including flexible tubes such as nasogastric and oxygen cannulas, sphygmomanometers, catheters, intravenous and blood bags; sterile packaging, trays, basins, bed components and thermal blankets.

At present, it is impossible to manufacture plastics without causing harm to humans and the planet.[2,3] Every stage of the plastic life cycle inflicts damage.[2] In spite of this, production has exponentially increased over the last 70 years. In 1950, global production was under 2 megatonnes—we now produce over 450 megatonnes[3] and this production is projected to triple by 2060.[4]

There is a paucity of manuscripts on plastics within the dermatology literature. Yet, as a specialty, we are surrounded by plastic. Up to 90% of personal care products—including emollients, hair dyes, cosmetics, deodorants, bath soaps, dental care products, shampoos, UV filters/sunscreens and fragrances—contain plastic, and nearly all are packaged in plastic.[5] In this review, we examine the environmental impacts of plastic across its entire life cycle, describe the effects of microplastics in dermatology, and offer evidence-based solutions. Our goal is to raise awareness among dermatologists and to curb plastic pollution.

WHAT IS PLASTIC?

The term ‘plastic’ derives from the Greek word ‘plastikos’ which translates to ‘mouldable’. Plastics should not be viewed as a singular entity, but rather as an exceptionally diverse compound with one common trait: the capacity to be moulded to meet human needs. Synthetic polymers can have liquid or gel-like texture which do not strictly fulfil the defining criteria of plastic. However, these compounds share common properties including poor biodegradability and the risk of accumulation in the environment. In this manuscript we use the term plastic to encompass synthetic polymers in all forms.

All plastics are composed of polymers derived from monomers like ethylene, propylene, styrene, phenol, formaldehyde, ethylene glycol, vinyl chloride and acetonitrile (Table 1). These monomers are primarily sourced from crude oil, which provides the essential organic hydrocarbon backbone. The desired property of plastic is achieved by either polymerizing different lengths of monomers, mixing

TABLE 1 Common plastic polymers and examples of their use.

Polymer	Abbreviation	Use
Polyamide	PA	Textiles (e.g. nylon fibres), automotive industry and kitchen utensils
Polycaprolactone	PCL	3D printing, biomedical applications and drug delivery services
Polyethylene	PE (including PE-LD, PE-LLD and PE-HD according to density)	Packaging (e.g. bags, foils and bottles), toys and medical products (e.g. implants, containers, pipes and tubes)
Polyethylene terephthalate	PET	Textiles (e.g. polyester fibres and thermal insulation), packaging (e.g. bottles and blister packs) and manufacturing
Polypropylene	PP	Medical (e.g. sutures and meshes) and laboratory items, sanitary products, (reusable) food containers and cutlery and construction (insulation and concrete additive)
Polystyrene	PS	Packaging, food containers, cutlery, buildings and construction
Polyurethane	PU	Buildings and construction and foams (mattresses, cushions and furniture)
Polyvinylchloride	PVC	Medical products (tubes and bags), buildings and construction (pipes, cables, etc.), packaging, inflatable products and textiles (e.g. canvas)

polymers and/or combining them with additives. Additives can be antioxidants, light stabilizers, heat stabilizers, biocides, flame retardants, plasticizers and/or reinforcement agents (glass and/or carbon fibres) depending on which property is required. The term 'additive' can be considered a misnomer as they constitute the majority (55%) of the 16,352 chemicals incorporated into plastics[6,7] and can constitute up to 70% of a plastic products' weight.[8]

WHY SHOULD DERMATOLOGISTS UNDERSTAND THE LIFE CYCLE OF PLASTIC?

Dermatologists need to understand the life cycle of plastics to fully appreciate the impact of plastics in dermatology because human and planetary health is harmed at every stage of the plastic life cycle—production, use and disposal (Figure 1). This broader understanding of the environmental impact of plastic pollution helps dermatologists consider sustainable practices and assist patients in making informed choices about the products they use.

Key points

Why was the study undertaken?

- Plastics are low-cost, high-volume, versatile materials, but their life cycle poses risks to human and planetary health. Despite projections of tripled production by 2060, literature on microplastics' impact on dermatological and environmental health remains scarce. The sustainability groups of the Australasian College of Dermatologists, the European Academy of Dermatology & Venereology and the German Dermatological Society have collaborated to address this gap.

What does this study add?

- This review explores the plastic life cycle, microplastic exposure routes, associated chemicals and their adverse effects relevant to dermatology, offering science-based recommendations to mitigate these issues.

What are the implications of this study for disease understanding and/or clinical care?

- Plastics harm health globally, with personal care products and topical preparations being a major source of microplastics which can be ingested, inhaled and absorbed through the skin. Dermatologists can lead efforts to reduce plastic use by adopting the recommendations within this manuscript which will improve both dermatological and global health while combating climate change.

Production

The manufacture of plastics spans across continents as large enterprises exploit inequalities in resource distribution (fossil fuels), economic efficiencies (manufacturing in countries with cheaper labour costs), trade agreements/market demand and environmental regulations where countries with lax laws often handle more environmentally harmful production stages (Figure 2).[2]

Coal, oil and natural gas are the raw materials for more than 98% of global plastic production.[9] Extraction of these fossil fuels by conventional means causes significant environmental impacts (Figure 1). Fracking, (engineering jargon for hydraulic fracturing), is an unconventional but increasingly common technique used to recover large volumes of oil and gas trapped in porous, low-permeable rock formations such as shale. It generates multiple hazards but one of its biggest problems is the irreversible loss of freshwater.[10]

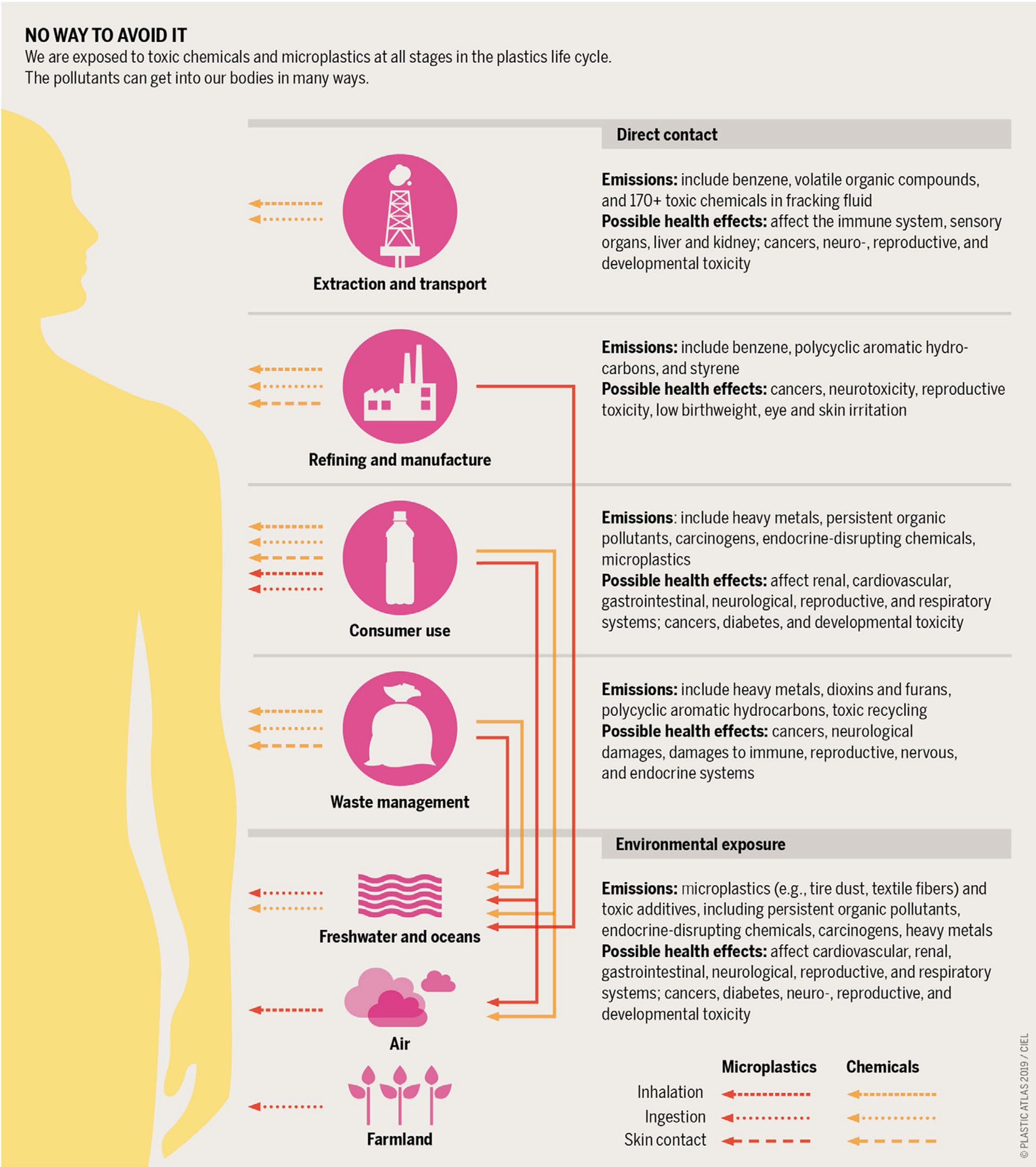

FIGURE 1 Life cycle of plastic. The plastic life cycle is long and complex (circles down the centre of the illustration). It begins with the extraction of fossil fuels and ends with disposal. Extensive pollution and health hazards occur at every step (right panel of the illustration). Obtained from PLASTIC-ATLAS|Appenzeller/Hecher/Sack; licence: CC-BY 4.0.

Following extraction, crude oil and natural gas need to be transported from the wellhead to the refinery and beyond. Due to the multiple links within the logistic chain, human exposure and accidents occur with catastrophic consequences. For example, a recent train derailment near East Palestine, Ohio, caused the release of vinyl chloride and other hazardous chemicals into the environment. Conventional clean-up methods were unfeasible due to the products' extreme toxicity and flammability, so officials had to carry out a controlled vent and burn further dispersing these chemical by-products into the air.[11]

At the refinery, crude oil and natural gas are heated and distilled to separate the liquid and vapour fractions based on their molecular weight and boiling points to produce the raw materials for plastic manufacture such as naphtha (a precursor of petrol), natural gas liquids and syngas.[9,12] These

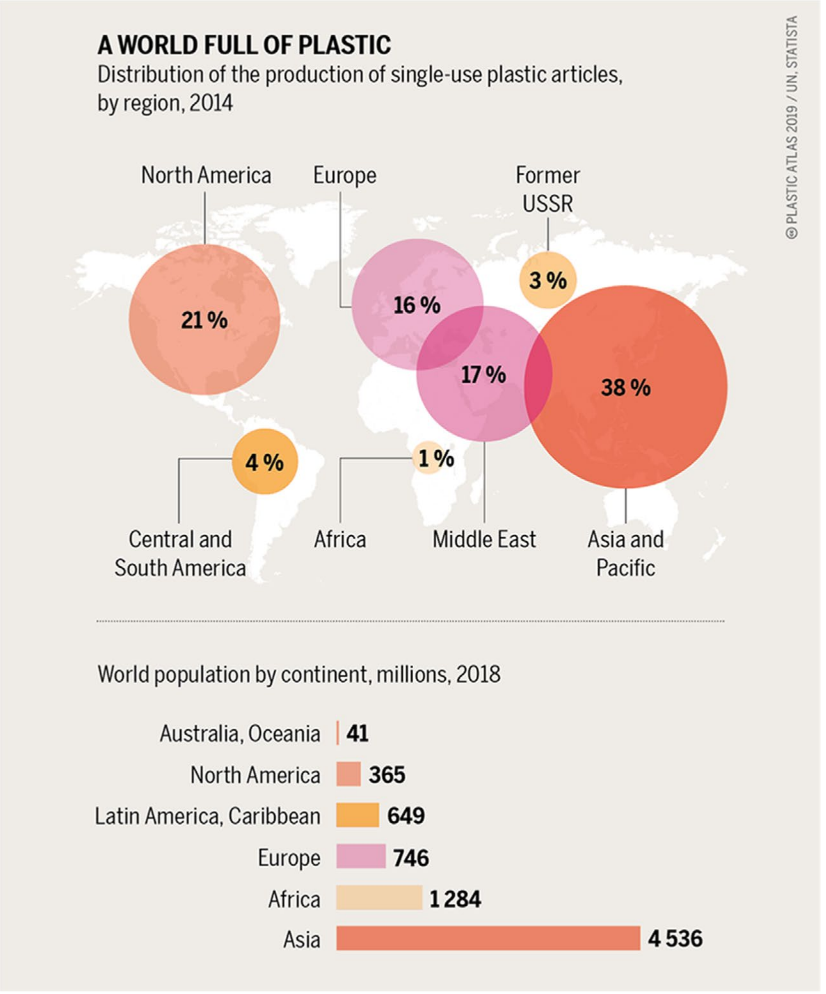

FIGURE 2 Distribution of plastic production by continent. Obtained from PLASTICATLAS|Appenzeller/Hecher/Sack; licence: CC-BY 4.0.

raw materials are long chain hydrocarbons which need to be broken down into plastic monomers by the process of steam or catalytic cracking. Cracking facilities produce multiple airborne pollutants (e.g. benzene, toluene, formaldehyde and volatile organic compounds) (Figure 1). The resultant monomers are polymerized and compounded with additives and processing agents to produce the properties required for the specific plastic product.

Of the 16,352 chemicals used in the production of plastic, 30% cannot be categorized due to insufficient hazard information,[6,7] and of those that are categorized, many are in the highest category for human health hazards.[13]

Use

Single-use plastics make up 35% of global plastics production, with 99% of this being utilized for packaging.[14] This trend is evident in dermatology, particularly in the packaging of skincare and pharmaceutical products.[14] Single-use plastics also constitute a significant portion (62%) of the waste produced during the excision of skin cancer.[15]

The majority of plastics used today are virgin plastics rather than recycled ones.[4] This ongoing reliance on virgin plastics requires the continuous extraction of fossil fuels and the production and release of hazardous chemicals into the environment.

Disposal

Plastic recycling rates are dismal, with less than 10% of new plastic produced globally each year being recycled.[4] For instance, Australia's largest soft plastic recycling scheme, REDcycle, was revealed to be disingenuous and collapsed leaving 3000 tonnes of plastic with an uncertain fate.[16] Plastic recycling per se has many negative environmental impacts, such as the generation of air pollution and toxic ash.[17] Furthermore, the end-product, recycled plastics, tend to leach out more hazardous chemicals than their virgin counterparts.[18]

Incineration and landfill remain as the most common route of plastic disposal but are invariably associated with significant environmental degradation and release of hazardous substances (Figure 1). Plastic waste is often exported from OECD countries to non-OECD countries within South East Asia such as Malaysia, Thailand and Vietnam.[19] This transcontinental movement further increases the carbon footprint of plastic and transfers the problem to countries less well-equipped to deal with the waste appropriately.[19]

HOW DO PLASTICS TRANSITION FROM HUMAN-USE PRODUCTS TO BEING ENVIRONMENTAL POLLUTANTS?

The exponential rise in plastic production, combined with very low recycling rates, poor waste management and littering, leads to a large share of plastic waste entering the environment, particularly on shores and in oceans.[20]

The ultimate fate of all macro-plastics, or large plastic waste, is to break down into smaller particles called microplastics and/or nanoplastics. Microplastics are plastic particles smaller than 5 mm in diameter, and nanoplastics are those with a diameter of less than 1 µm (100 nm). These two types often coexist, forming a continuum of degradation products. Environmental degradation processes such as mechanical/abrasive, thermal or photolytic forces turn macroplastics into *secondary* micro- and nanoplastics. Bacteria and other microorganisms also play a role in biodegradation. Microplastics can also be intentionally manufactured (known as *primary* microplastics) and incorporated into consumer products such as cosmetics.

Irrespective of which category they fall under, these small particles are a concern because they are essentially indestructible, allowing them to persist in ecosystems for long periods.[2,21–23] They are frequently consumed by aquatic and terrestrial organisms, causing them physical harm and transferring up the food chain, ultimately reaching humans.[24] Microplastics also adsorb and concentrate harmful chemicals from the environment, such as pesticides, heavy metals, and persistent organic pollutants, along with the chemicals used in plastic production. This phenomenon is termed the 'Trojan horse' due to the fact that microplastics act as carriers for these harmful substances, much like the ancient Greek story of the Trojan Horse.[25] This property makes it particularly challenging to isolate the impacts of microplastics from the chemicals they carry, as the two are tightly intertwined. Due to their small size, microplastics are challenging to remove from the environment. Traditional filtration and waste management systems are often ineffective at capturing these tiny particles, making mitigation efforts difficult and costly.[26,27]

HOW ARE PLASTICS CONNECTED TO THE FIELD OF DERMATOLOGY?

Dermatology is closely intertwined with the use of plastics. Topical treatments continue to be fundamental in managing many dermatological conditions and primary microplastics are incorporated in an overwhelming majority of formulations.[5] Additional sources of plastics include the packaging of personal care products and topical treatments, medical devices and tools (such as biopsy kits, syringes, needles, auto-injectors and prefilled syringes of subcutaneous drugs such as biologics), surgical consumables (including gloves, sutures and dressings) and patient care items like bed protectors and absorbent pads.

Exposure routes

Microplastics from personal care products have been detected in utero, absorbed through the skin and found in the lungs and gastrointestinal tract.

In utero

Microplastics have been detected in human placenta by Raman spectroscopy.[28] All the microplastics found were pigmented due to consumer demand for artificial colours. For example, the pigment iron hydroxide oxide yellow is used in blemish balm creams and foundations; the pigment violanthrone is used in fragrances and ultramarine blue is used in soap, lipstick, mascara, eye shadow and other make-up products.[28] Within these microplastics are plastic monomers such as bisphenol-A (BPA), along with additives like poly-fluoroalkyl substances (PFAS), which are known endocrine disruptors.[29,30] These chemical substances utilize microplastics as carriers and their structural resemblance to certain hormone receptors allows them to cross the placenta and alter early sexual dimorphic markers in the offspring.[31]

These findings suggest that embryos and foetuses are exposed to microplastics and additives at a very vulnerable stage of development. The range of chemicals implicated can be extensive, with one study finding more than a hundred environmental chemicals in the blood of newborns.[32] Exposure to bisphenol in pregnant women can cause DNA hypomethylation in the JAK–STAT and PI3K–AKT pathways, which are crucial for skin barrier function and immune responses. This might be associated with the onset of atopic dermatitis.[33]

Skin absorption

The skin is constantly exposed to microplastics and nanoplastics present in indoor dust, textile microfibres and numerous personal care and cosmetic products, including face and body scrubs, shower gels, sunscreen and shampoos.[34] The absorption of micro- and nanoplastics and their additives depends on particle size, skin condition (whether normal, inflamed or damaged) and the particle load on the skin (higher loads create a greater gradient for absorption).[35] Particles less than 4 nm in size easily penetrate the skin whereas nanoplastics between 21 and 45 nm can only penetrate skin that is damaged or affected by conditions that impair the barrier function, such as atopic dermatitis, ichthyosis or bullous dermatoses.[36] Upon contact with keratinocytes, they interact with toll-like receptors on Langerhans cells, dendritic cells, macrophages and T-cells to induce oxidative stress and inflammation.[37–40] They can also be taken up via endocytosis or phagocytosis and accumulate in lysosomes causing cellular apoptosis.[39] This dysregulation of inflammation has been proposed to be the mechanism of lupus-like symptoms in an animal model.[41] Owing to the previously mentioned 'Trojan Horse' effect, microplastics contain chemicals like phthalates, bisphenols and PFAS. These substances can contribute to the development or worsening of conditions such as atopic dermatitis,[42–44] trigger allergic contact dermatitis[45] and aggravate teenage acne.[46]

Mucous membranes serve as another entry point for micro- and nanoplastics from products such as eye shadow, mascara, lipstick and contact lenses.[47] In vitro studies have demonstrated that corneal and conjunctival epithelial cells can absorb polystyrene microplastic particles, with the microplastics accumulating around the cell nuclei.[48] This can lead to direct toxicity, inflammation/oxidative damage and microbiome dysbiosis.[47]

Inhalation

Micro- and nanoplastics in perfumes, fragrances and deodorants can become airborne and be inhaled due to their small size.[49] Due to the volatility and degradation susceptibility of many fragrance components,[50,51] fragrance encapsulates were developed to provide a long-lasting scent, particularly in laundry care products.[52] These encapsulates often have shells made from cross-linked melamine-formaldehyde polymers, but can also be composed of other cross-linked polymers like polyurethane, polyurea and polyamide.[53]

The respiratory system effectively filters out many particles but airborne particles with a diameter less than 10 µm, and especially those of less than 2.5 µm, are most likely to reach into the lower airways and enter the blood circulation. Within the lung, micro- and nanoplastics induce cytotoxic effects, increase pro-inflammatory markers, disrupt mitochondria, alter cell morphology and decrease cell viability.[54–57] Insufficient bronchoalveolar clearance leads to the accumulation of these particles. Consequently, the presence of micro- and nanoplastics in human lungs has been found to increase with advancing age.[58,59]

Ingestion

Micro- and nanoplastics in toothpaste and lipstick can be ingested.[60] Animal studies have reported various local effects of micro- and nanoplastics in the gut, including inflammation, deterioration of barrier function and changes in gut microbiota.[61] This disruption of gut microbiome was rigorously tested in a human in vitro model and the decrease of microbial taxa (*Bacteroides*, *Parabacteroides* and *Alistipes* species) mimics the imbalance seen in inflammatory bowel disease and irritable bowel syndrome.[62]

RECOMMENDATIONS

Table 2 lists recommendations specific to dermatology which is based on guidelines from professional societies and health organizations.[2,21,22,63–68] Sustainable alternatives already exist[69] and none of these recommendations necessitate any breakthrough inventions. Petroleum-based substances like petrolatum jelly, as well as acrylates and silicones, could potentially be replaced with natural ingredients such as fatty acids, waxes and squalenes. Biopolymers such as gums, resins, pectin and starch offer eco-friendly alternatives to polyethylene glycols.

The 'EcoBeauty Consortium' (https://www.ecobeautyscore.com/) comprising 71 companies, is working on a scoring system to evaluate the environmental impact of personal care products. While creating a product with zero environmental impact may not be feasible, this initiative aims to empower consumers to make informed purchasing choices. Although the scoring system is still under development, it shows promise. Additionally, using tools like the United Nations Environment Programme (UNEP) recommended software to identify microplastics in topical products[66,70] and opting for microplastic-free alternatives can shift consumer demand and drive industry change. Practicing evidence-based medicine by selecting only products with proven efficacy also supports high-value care, as it minimizes waste while ensuring effectiveness.[71]

The distribution of sample-sized cosmeceuticals to healthcare professionals and patients should be critically reassessed. Packaging of samples can use up to 10 times more plastic than standard retail packaging, with some samples containing less product than the weight of their packaging.[72] At major dermatology conferences, such as the AAD Annual Meeting or the EADV Congress, there are typically 250–350 commercial exhibitors. Even with a conservative estimate of 20–30 cosmetic companies each distributing 1000–5000 bags containing 10 product samples, this could lead to the distribution of 200,000–1.5 million plastic items at a single event. This practice contributes to plastic pollution, and manufacturing these plastic containers (assuming 10 mL sizes) is estimated to produce 2.4–18 tonnes of CO_2 equivalents.[72]

LIMITATIONS

Many of the negative effects of micro- and nanoplastics mentioned above have been derived from animal models

TABLE 2 Evidence-based recommendations specific to dermatology for reducing exposure to micro-and nanoplastics.[2,21,22,63–68]

Action	Comment
Check dermatological formulations for the presence of microplastics before use. Choose options that are free from microplastics	The United Nations Environment Program recommends an app that will allow consumers to check whether personal care products contain microplastics or microbeads: https://www.beatthemicrobead.org/download-btmb-app/. It is also available as a web interface: https://www.beatthemicrobead.org/product-lists/
Lobby industries to eliminate microplastics from all topical preparations	Micro- and nanoplastics are often added to topical preparations to improve texture or feel and enhance the overall user experience. The necessity of adding in these particles must be balanced against the severe environmental damage from plastics production
Promote evidenced-based dermatology by encouraging patients to use topical treatments with proven efficacy	The cosmeceutical industry is large and projected to grow significantly. Many cosmeceuticals do not have evidence of efficacy. Using these products harms the planet and constitutes low-value care because it is wasteful and ineffective
Minimize the distribution of samples and eliminate sachets and fingertip unit-sized samples	Small single-use samples are particularly harmful to the environment as they use a greater amount of plastic packaging per volume of product than standard sized containers and are difficult to recycle; meaning they often end up in landfills or the ocean
Eliminate superfluous packaging of dermatological consumables	The health care sector generates substantial volumes of plastic waste, and depending on the medical facility, plastics comprise between 20% and 65% of all waste generated. While some plastics are essential in health care, many are not. There is no need for consumables to be double or triple-wrapped in plastics
Avoid single-use plastic instruments and use sterilizable, reusable surgical instruments instead	Using reusable surgical instruments not only reduces plastic waste but also reduces greenhouse gas emissions of up to 227%
Avoid synthetic textiles and use natural textiles such as cotton or bamboo cotton instead	Washing of synthetic textiles releases at least half a million microfibres from each kilogram of clothing and is an important source of microplastic deposition on the skin. Between 200,000 and 500,000 tonnes of microplastics from textiles enter the global marine environment each year, according to the European Environment Agency
Join Sustainability Working Groups	Numerous sustainability working groups are active within dermatology societies. Examples include the Working Group on Sustainability in Dermatology (AGN) of the German Dermatological Society, the EADV Climate Working Group, and the Environmental Sustainability Group of the Australasian College of Dermatologists. These groups often provide valuable resources on reducing plastic use and waste, such as the information available at https://agderma.de/en/topics/plastic-in-the-dermatology/
Support organizations such as Healthcare without Harm and the Minderoo Foundation	Health Care Without Harm (https://europe.noharm.org/) and the Minderoo Foundation (https://www.minderoo.org/) are non-governmental organizations with a shared mission to reduce and eliminate harmful plastics in patient care and our daily lives. They also emphasize prioritizing reusable plastic products, a Global Plastics Treaty and wherever possible, to reuse and recycle
Encourage and fund research on plastics and human health	The full extent of plastic's impact on human health remains poorly understood. To bridge this gap, research funding is necessary to clinically assess the effects of microplastics and the myriads of chemicals associated with plastics, including non-intentionally added substances (NIAS). Additionally, funding is needed to develop sustainable alternatives to plastic. Currently, numerous startups around the world are focused on creating alternative, sustainable medical-grade bioplastics. Materials like fungi and agricultural waste show great promise and could play a pivotal role in this innovation

or in vitro approaches.[28,29,31,35–39,41,47,48,50,53–62] Only one manuscript to date has demonstrated the negative effects of microplastics in a clinical setting where microplastics within atheromas increase the risk of myocardial infarction, stroke or death from any cause by fourfold.[73] While criticisms exist in terms of measurement techniques and potential contamination within the study protocol,[74] the size of the clinical effect cannot be explained by measurement errors, chance or confounding.

This review is limited to micro- and nanoplastics and excludes the detailed review of more than 16,352 chemicals associated with plastics production along with non-intentionally added substances (NIAS), which may also be toxic.[7]

Despite the acknowledged limitations, we strongly support the hypothesis that micro- and nanoplastics pose severe risks to human health. This assertion is drawn from extensive studies on biological disease models,[4,5,16,17,20–23,29–31,36,39–41,47–51,60–62] the well-documented dangers of various monomers and additives[22,30,75] and the undeniable environmental impact.[2] Addressing the knowledge gaps highlighted in Table 2 is crucial[76,77] but this must occur alongside actions outlined above. Recent evidence revealing the harmful effects of plastics and their associated chemicals has raised concern in other fields including cardiology,[78] neurology,[79] and paediatrics.[80] We cannot afford to delay action and continue with 'business as usual' while waiting for further studies on clinical harm as the consequences could be irreversible. Prospective studies would require extremely long follow-up periods, and interventional studies would be unethical or impractical. Our stance aligns with recommendations from professional bodies and health authorities, emphasising the need to act now.[2,22,63,64,66,81]

CONCLUSION

Plastics have revolutionized medicine and dermatology, yet their impact on human health and the planet cannot be ignored. While some plastics are essential, many are not. We urge dermatologists to take action with the recommendations proposed and reduce plastic use within our specialty. Our actions and recommendations have far-reaching consequences and can alter society's consumption in a positive way. Reducing plastic production and waste will benefit both human health and mitigate environmental damage simultaneously.

AUTHOR CONTRIBUTIONS

Eugene Tan: conceptualization (lead), methodology (equal) and writing – original draft preparation, review and editing (equal); Susanne Saha and Dennis Niebel: conceptualization, methodology (equal) and writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analysed in this study.

ETHICS STATEMENT

Not applicable.

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