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Review Article

Microplastics in Oral Healthcare in Dentistry

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Abstract

Microplastics is an important environmental and biomedical health concern as it is widely used in healthcare, cosmetics, consumer products, and personal hygiene materials. Dentistry and oral health sectors are highly dependent on plastic-based materials, where people depend on tooth brushes, toothpastes, dental composite materials, orthodontic aligners, dentures, floss, and other oral clinical products. People in today's scenario and Gen Z kids totally unfortunately rely on these materials and are exposed from age 1 to these microplastics till their lives end. It enters the oral cavity and interacts with saliva, affects oral microbiota, gingival tissues, and systemic circulation.

The oral cavity is the gateway for the entire metabolic process, where ingesting microplastics lead to gastrointestinal and systemic changes affecting the overall body functions. Recent research on microplastics suggests that it induces oxidative stress, inflammatory responses, endocrine disruption, microbial dysbiosis, and alter the immune system. Plastic-based endocrine disruptor such as bisphenol A is a major concern as it has the ability to affect the normal hormone signaling pathways, especially in estrogen-mediated oral health regulation. Estrogen is an important hormone involved in the maintenance of oral health, as it plays a critical role in gingival integrity, wound healing, collagen synthesis, and regeneration of the mucosal lining. Antimicrobial oral practices in children interfere with the oral microbiota and cause health concerns as it affects the digestion and immune maturation.

Though the indispensable role of plastic is significant in modern dentistry, sustainable and safe alternatives such as bamboo fibre brushes, neem-based oral care products, charcoal formulations, biodegradable dental composites, and an approach to green dentistry for young researchers, this review focuses on the sources, pathways, biological interactions, endocrine activities, microbiome disturbances, and sustainable alternatives for microplastics in oral health care.

Keywords: microplastics; oral health; Toothbrush bristles; oral microbiome; estrogen-mediated oral health

Introduction

Plastics revolutionized the modern oral health system due to its wide usage and cost-effective nature [1]. Dentistry relies heavily on plastic-based materials for high-tech restorative protocols, maintaining oral hygiene, in prosthetics, in orthodontics, and many more [2]. Day to day used materials such as tooth brushes, tooth pastes, dental floss, resin composites, aligners, dentures, impression materials, suction devices and many more are manufactured using synthetic polymers [3] proves to be a contributory factor to disrupt in maintaining oral health in humans.

Among different plastics used in dentistry, soft plastics play an important role as it is flexible, having cushioning properties, patient comfort and adaptability to oral tissues [2,4]. It is mainly incorporated into

- orthodontic aligners,
- retainers,
- mouth guards,
- denture liners,
- pediatric dental appliances,
- suction tubes,

- saliva ejectors,
- soft relining materials,
- gingival barriers,
- impression materials,
- disposable gloves and tubing.

These materials are flexible polymers such as polyethylene, polyurethane, silicone, Polyvinyl chloride (PVC), thermoplastic elastomers and acrylic based soft resins [5]. It reduces tissue trauma, improve fit, and support minimally invasive dental procedures. In orthodontics, transparent thermoplastic aligners are gaining more attention due to its aesthetic appearance and easy to use [6].

An added advantage of soft plastics in clinical system is their susceptible to mechanical wear, thermal degradation, hydrolysis and friction-based fragmentation in the oral environment [7].

Continuous exposure to saliva, fluctuating pH, chewing forces, brushing abrasions and temperature change slowly degrades these materials and release microplastics through the oral cavity into body systems [8]. These soft polymers have high concentration of plasticizers and additives to maintain its stability nature which leaches over time and contribute to endocrine-disrupting effects [9].

Despite the substantial therapeutic benefits of plastics, their continuous use and degradation produce microscopic particles called microplastics (particles <5 mm). In the present scenario people are realizing that these particles are contributing new pollutants that could harm ecosystems and human health. An underappreciated but significant source of microplastic exposure in humans is oral healthcare products. Additionally, polymer aging is accelerated by the warm, humid oral environment, which raises the risk of chemical leaching and particle shedding [10].

Microplastics not only present physically and causes toxicity, but enters the body and disturbs endocrine-disrupting additives involved in hormonal signaling pathways. These disturbances are especially pertinent to oral tissues, where body utilizes hormone such as estrogen for wound healing, vascularization, immune regulation and gingival homeostasis [11,12].

In order to overcome the impact of microplastics, the development of alternative sustainable oral care health products such as bamboo fiber tooth brushes, neem-based herbal pastes, charcoal-based formulations, and naturally derived oral hygiene products. These alternatives reduce the use of synthetic polymers to maintain the biocompatibility of oral hygiene products [13].

This review aims to explore the sources of microplastics in oral healthcare and the impact of plastics used in dentistry and bioplastics in oral and systemic health, endocrine implications, influence on oral microbiome and potential alternatives for future dentistry.

Figure 1: Different sources of microplastics in oral healthcare.

Toothbrushes and plastic bristles

Toothbrushes and plastic bristles are made of polypropylene handles and nylon bristles. Brushing and mechanical friction causes fragmentation of bristles and leads to microplastic particles into the oral cavity. Children are more vulnerable because of chewing the brush heads, accidental swallowing and improper brushing habits. Since the damaged brushes and bristles release toxic particles, care should be taken to replace them regularly [8,14].

Microplastics inToothpaste

Many tooth pastes have polyethylene or polypropylene microbeads to remove plaques, polishing and whitening. Direct oral exposure as well as ingestion during brushing contributes to environmental contamination which in turn accumulates within aquatic ecosystems and enters the food chain [15].

Dental floss and disposable dental products

Dental floss is manufactured with nylon, Teflon and synthetic polymers. During flossing, microscopic fibers remain in gingival tissues and some have fluorinated compounds capable of causing systemic toxicity.

Disposable products used in dentistry are made of plastic items and improper disposal leads to environmental microplastic contamination [8].

Composite resin restorations

Modern dentistry relies heavily on resin materials, which are composed of polymer matrices and filler particles. Chewing, mastication, polishing, and aging degrade the resins and release microplastics, which alter the oral microbiota and lead to chronic exposure [8].

Orthodontic aligners and retainers

It is made up of thermoplastic polymers present in daily wear, cleaning procedures, and mastication releases microplastic particles. These are more prevalent among youngsters [16].

Dentures and Acrylic prostheses

Surface degradation over time, mechanical cleaning and chemical disinfectants accelerate polymers to be fragmented and enter our system along with saliva [8].

Entry and fate of microplastics in the human body

Gateway for these microplastics to enter our body is mouth. These microplastics penetrate the oral lining by unintentional swallowing and biting of plastics present in the oral hygiene products. In addition, Saliva acts as a transport medium in to the gut. The microscopic natures of these particles cross biological barrier membranes enabling them to get incorporated into cells and tissues [17].

The oral cavity is lined by oral mucosa which are highly vascularized and permeable in [18]

- the sublingual mucosa
- buccal mucosa and
- gingival sulcus

In these areas, microplastics enter through different mechanisms [19] such as

Transcellular uptake

Microplastics is taken inside directly by epithelial cells by endocytosis, pinocytosis and passive diffusion. When microplastics enter inside the body, it penetrates deep into the tissue and reach blood vessels.

Paracellular transport

Inflammation, gingival damage and other dental issues causes a microscopic gap in the oral lining due to loosening of tight junction between epithelial cells to allow microplastics.

Uptake through immune cells

Macrophages and dendritic cells in oral tissues engulf these tiny particles as a part of immune surveillance, and immune cells transport these particles into lymphatic and circulatory systems.

Oral injury

Oral injuries caused by brushing vigorously, dental protocols, ulcers and orthodontic products force to loose mucosal integrity, increase permeability of oral tissues and allow the plastic particles to enter the oral lining.

On gaining entry these particles, enters the circulatory system and accumulate into distant organs such as liver, kidney, lungs, reproductive organ and recently reported in brain too resulting in chronic inflammation, oxidative stress, endocrine disruption, mitochondrial dysfunction, cellular inflammation, apoptosis, immune dysregulation and toxicity since, microplastics contain toxic substances such as heavy metals, plastic additives, endocrine disrupting chemicals and microbial toxins (Fig. 2).

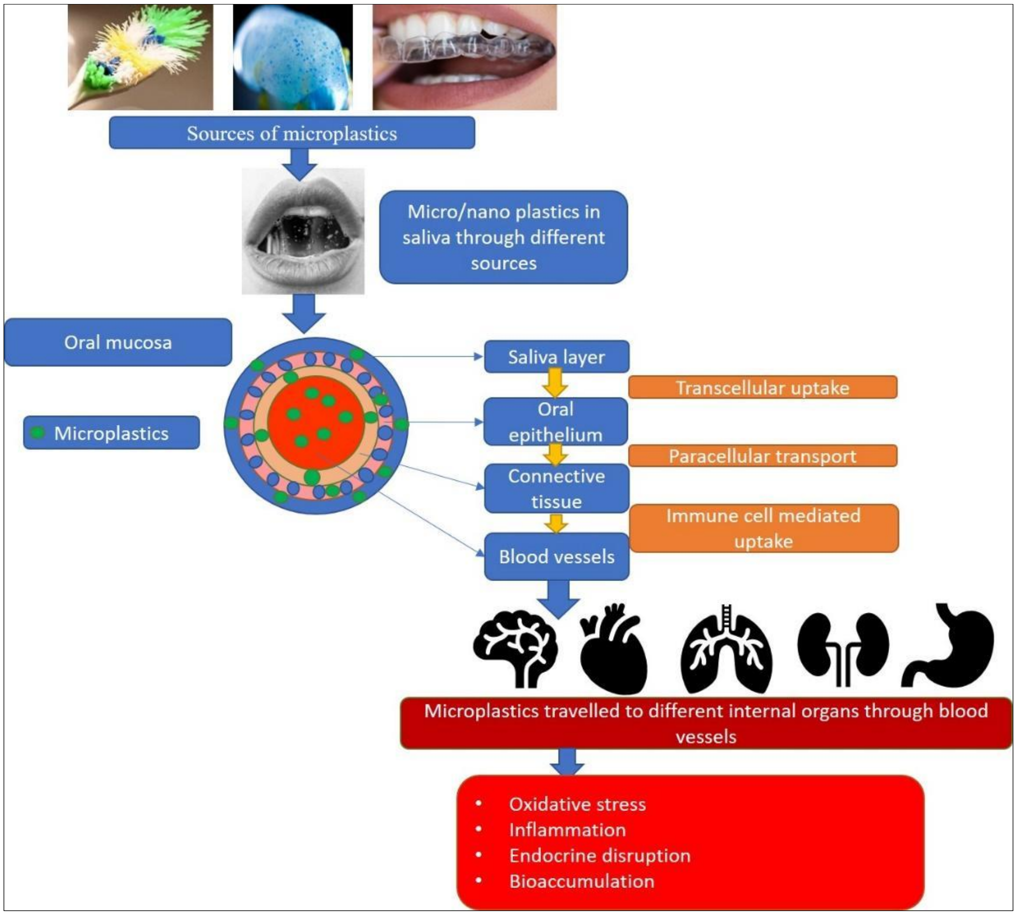

Figure 2: Mechanism of translocation of microplastics from oral healthcare products to systemic circulation.

Microplastics and the oral microbiome

The oral cavity is the gateway for the most complex microbial ecosystem [20] contributed by bacteria, fungi, viruses, and archaea responsible for maintaining oral and systemic health. These organisms help in digestion, metabolism, immune regulation, maintaining homeostasis, and preventing pathogenic colonization [21]. A balanced oral microbiome is essential in preserving periodontal integrity and protects against infectious and inflammatory diseases [22]. Dysbiosis in oral microbial equilibrium leads to [23]

- Dental problems
- gingivitis
- periodontitis
- halitosis and
- systemic inflammatory disorders

Microplastics present in the mouth through different sources alters the oral microbial ecosystem [24]. These microplastics particles interacts with organisms due to their hydrophobic surfaces and large surface-area to volume ratio which act as a substrate for attaching the microbes and develops biofilm. These microplastics support the colonization of opportunistic or pathogenic microorganisms, which alters the normal microbial composition. In addition, the role of microplastics

- changes the bacterial adhesion patterns,
- inflammatory response,
- interacts with salivary proteins and
- disrupt the microbial pathways

Chronic exposure to these microplastics and its chemicals disrupts the endocrine system causing oxidative stress and inflammatory responses in oral tissues, thereby disturbing and changing the microbial balance [25,26].

Let kids be kids

The oral microbiota in childhood is very important for immune maturation and digestive physiology. Excessive sterilization of the oral cavity in infants by using antimicrobial mouthwashes, bactericidal toothpastes and chemical disinfection disturb the beneficial microbial colonization [21]. Morning brushing is considered to be important but recent studies suggest that compared to morning, night brushing is more important for kids. The microbes present in morning has beneficial activity to aid in digestion [27,28] and other related mechanisms while night brushing removes harmful pathogens.

Moreover, night brushing maintains oral microbial balance because salivary flow decreases in sleep[24]. Reduced salivary action diminishes natural cleansing and anti-microbial activity, for prolonged bacterial metabolism and plaque accumulation overnight. Oral hygiene is essential and considered important to preserve the microbial diversity for long-term oral and systemic health in kids [29].

Oral microbiome and Gut health

In physiological perspective, oral bacteria lead to nitrate reduction pathways which influence cardiovascular and gastrointestinal functions. Oral microorganisms serve as an important microbial source for GI (gastrointestinal tract), thereby facilitating good gut microbial composition and its influence on digestion [30].

Microplastics entering the GI tract through mouth and oral care products, along with saliva and oral microorganisms, cause digestive abnormalities, potentially exacerbating gut dysbiosis and systemic inflammation. Altered changes of intestinal permeability, leaky gut facilitates the translocation of inflammatory mediators and toxic compounds into systemic circulation [30, 31].

Thus, the oral cavity and GI tract are closely interconnected through oral-gut microbiome axis [21,32] and prolonged exposure to microplastics disturb the delicate biological relationship and influence both oral and systemic health (Fig.3).

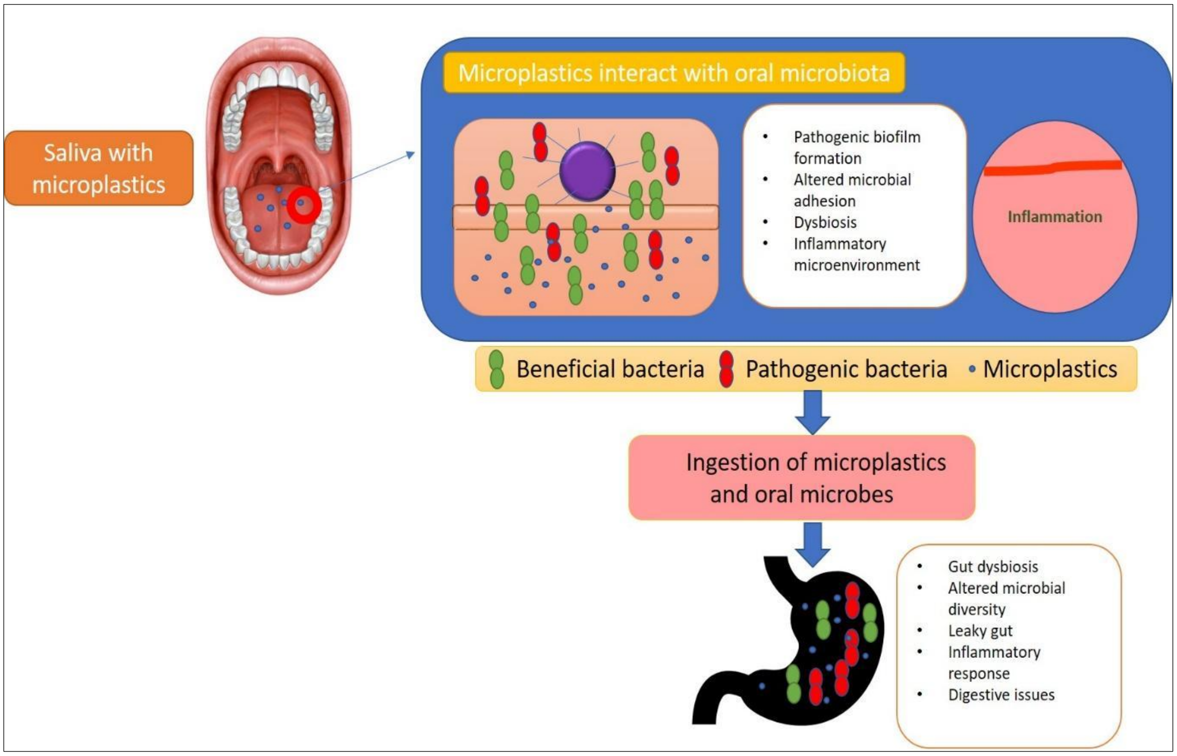

Figure 3: Impact of microplastics on the oral-gut microbiome axis.

Anti-inflammatory effects are modulated by cytokines and immune response through the action of estrogen, which helps to suppress inflammatory reactions [38,39,40] which otherwise contribute to periodontal disease progression.

Salivary gland response to estrogen balance signaling for the secretion of saliva and maintains oral lubrication, antimicrobial activity, and pH regulation. Reduced level of estrogen, especially at the time of menopause, is associated with xerostomia, burning mouth syndrome, and increased susceptibility to oral infections [41,25].

Thus, estrogen serves as a potential regulator of oral health by maintaining connective tissue integrity, supporting wound healing, controlling inflammation, and preserving mucosal homeostasis.

Endocrine disrupting chemicals in plastics

The microplastic contains BPA, phthalates, plasticizers and synthetic additives. These compounds act as xenoestrogens[43,44], and interfere with hormone signaling pathways and systemic health concerns such as oxidative stress leads to cellular injury, chronic inflammation[23], Gut dysbiosis[21], immune dysfunction[31], reproductive toxicity and neurological effects due to microplastic/nanoplastic translocation.

Sustainable and safe alternatives

Bamboo fiber toothbrushes [45] (*Bambusa bambos* L.)

An eco-friendly alternative to plastic brushes and has several advantages such as

- Environment friendly
- Biodegradable
- renewable resource
- lower environment burden
- natural antimicrobial properties
- reduced plastic waste
- good mechanical strength and
- moisture resistant

Neem based oral care [46,27] (*Azadirachta indica* L.)

A traditional method used in oral practice is *Azadirachta indica* L. Its advantages are

- antibacterial properties
- antifungal activity
- anti-inflammatory effects
- plaque-reducing ability
- Reduce chemical exposure

Bioactive compounds present in neem stop or inhibit the growth of *S.mutans*, plaque-forming bacteria, and gingival inflammation.

Charcoal-based oral care products [47, 48]

Activated charcoal is also one of the traditional practices in oral hygiene which was later destroyed due to modern plasticizer-containing pastes. Activated charcoal has now regained its importance due to

- adsorptive capacity
- stain-removal ability
- detoxification potential
- adsorb toxins
- reduce odour causing compounds

However, excessive abrasiveness should be avoided to prevent enamel erosion.

Herbal Dentifrices [49]

Herbal formulations reduce synthetic additives and microplastic abrasives which contains

- cloves (*Syzygium aromaticum* L.)
- miswak (*Salvadora persica* L.)
- tulsi (*Ocimum tenuiflorum* L.)
- neem (*Azadirachta indica* L.)
- licorice (*Glycyrrhiza glabra* L.)

Green dentistry[50]

Most recommended method against today's harmful oral care products and to bring sustainable approach through green dentistry which

- reduce plastic consumption
- biodegradable materials
- sustainable waste management
- environmentally responsible clinical practices

Future perspective

Future research should emphasize on reduce the usage of oral microplastic exposure, salivary microplastic analysis, safe biomaterials to be evaluated, biodegradable dental polymers. Microbiome friendly oral healthcare products are to be properly screened before human use. This approach will pave the way for the minimal use of microplastics in oral therapeutics to improve the health of the individual.

Conclusion

Microplastics is an emerging concern in oral products and dentistry. Though plastics remain indispensable for modern dental practices, continuous exposure causes serious health effects. The microplastics interacting with the body's metabolism and its function show that there is an urgent need for safer and more sustainable dental practices. Plastic-derived particles and additives may disrupt microbial balance, interfere with hormonal regulation, and induce inflammatory reactions that can affect both oral and systemic health. In particular, the relationship between estrogen-mediated oral protection and endocrine-disrupting chemicals present in plastics emphasizes the biological complexity and potential health risks associated with long-term exposure to plastic-based oral healthcare products. Sustainable approaches and biodegradable materials are promising strategies to reduce plastic burden while preserving oral health. Future dentistry should balance clinical efficiency with sustainability and biosafety measures for further action on safe practice measures.

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