The hidden hazards: The silent invasion of microplastics in dentistry (Review)

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Abstract. Every single piece of plastic that has been produced globally, still exists in one form or another. Upon degradation, this plastic may enter the marine or terrestrial environment. Upon its entry, it may cause entanglement, suffocation and death of these life forms or be consumed by the organisms, which disrupts the food chain in the ecosystem. Subsequently, the pieces of plastic become ingested by mammals and humans, and elicit local and systemic toxic reactions. Dentistry, as a profession, generates plastic waste, particularly with the advent of single-use plastics. Plastic waste can be produced in the dental office, through the use of resin-based restorative materials and through the use of oral hygiene measures, such as plastic toothbrushes, dental floss, toothpaste and mouthwashes. Furthermore, the burden of COVID-19 further accelerated the use of plastics in the form of personal protective equipment in an aim to maintain the disinfection protocol and minimise the spread of the virus. The present review provides a summary of dental materials and procedures, which contribute to plastic accumulation and suggest strategies which can be used to mitigate this production towards an ecologically friendly and sustainable environment.

Contents

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1. Introduction

The planet is choking on plastic. Plastic is one of the most widely used products and since the 1970s, the rate of production has grown rapidly as compared to other materials (1). It is estimated that plastic accounts for >80% of marine litter (2). By 2019, plastic accounting for approximately nine and a half billion tonnes was generated globally, which amounts to more than one tonne of plastic for every person alive today (3).

The spread of COVID-19 was further boosted by the use of single-use plastics, particularly personal protective equipment (PPE). The extensive use of PPE can prevent the spread of infection; however, it can add to the accumulation of plastic waste (4).

Every piece of plastic ever produced, still exists today and may accumulate in the natural environment and marine bodies, and can persist for centuries (5). By the action of atmospheric agents, such as waves, ultraviolet rays, photo-oxidation and bacteria, pieces of plastic are broken down into larger particles known as macroplastics and smaller particles (<5 ml) termed microplastics (6). Macroplastics can persist for decades in the shorelines, and may eventually come to a halt in offshore locations (3). Microplastics persist in the environment due to resistance to degradation by microorganisms (7). Microplastics sink into larger depths of oceans and can enter living organisms, including mammals (8).

Plastics are not only ubiquitous in everyday lives, but also form a core part of medical equipment. A vast amount of medical equipment used in the general hospital environment is either made from plastic or comes in plastic wrapping. Similarly, dentistry is continuously evolving to incorporate newer technologies and innovations, some of the dental materials still used contain heavy metals and biochemical wastes (1) (Fig. 1).

Microplastics are currently considered an evolving global issue that can harm marine and terrestrial life, including humans and mammals (2). This may lead to potential chronic effects include development of cancer, a weakened reproductive activity, impaired immunity and developmental malformations in animals and humans (3). Scientific reports by the World Economic Forum in 2016 estimate that oceans will contain more microplastics than fish by the year 2050 (4). The impact of plastics (particularly single-use plastics) on marine life must be emphasised and strategies must be undertaken to mitigate the toxic effects (5,6). The present review summarized the dental procedures and dental materials that have a notable detrimental effect on the environment and encourages measures to mitigate these consequences.

2. Literature search methods

To identify articles that evaluated use of microplastics in dentistry, a search was performed using the electronic databases, PubMed, Web of Science, Scopus and Google Scholar, including articles published up to April, 2024. The search terms used were 'Microplastics', 'Pollution', 'Plastics', 'Dentistry', 'Dental Materials', 'Environment' and 'COVID-19'. These search terms were constructed with the aid of Boolean operators with the use of English language filters. A manual search was conducted of the articles obtained. Following the removal of duplicate articles, 27 articles were obtained (6-32).

3. Materials and procedures in dentistry

Dentistry is a field that is constantly evolving; however, some materials and procedures that are still in use include heavy metals and biomedical wastes, which pose a major challenge to the environment (33).

The exploitation of single-use plastics and other plastic equipment has amplified to maintain asepsis, reduce contamination and prevent health challenges to the practitioner. However, it remains to be determined if all this plastic is truly degradable (34).

In the field of eco-friendly dentistry, two major aspects must be recognized. One being at the level of the dental office and the second including dental products that enhance oral care.

Dental office. According to the Eco-Dentistry Association (35), waste generated from the dental office includes 1.7 billion plastic sterilisation packets and >680 million plastic barriers for dental chairs, covers for light handles and drapes. Additionally, the use of items such as personal protective equipment, plastic disposable dental trays and plastic packaging of various dental products (syringes, polythene or polyvinyl chloride foils and dental materials) further exacerbate the existing burden (36).

Hence, evidence suggests that dentistry has a major influence on the environment and contributes to the carbon footprint; greater emphasis should be placed on changing these practices towards an eco-friendly and sustainable environment.

Dental materials. Focus on the environmental impact of dentistry has been limited, up until the past few decades. The majority of materials used in dental practice have a high potential to subsequently breakdown and become incorporated into the environment as pollutants. A major part of the discussions regarding environmental pollution in dentistry have been concentrated on amalgam and its potential health effects due to mercury toxicity (8).

Controversies surrounding amalgam have led to its replacement with resin-based restorative materials, which are considered inert or to have a reduced impact on the environment, which is in accordance with the mandates in the Minamata Treaty (37).

All the constituents of resin-based composites have the potential to act as environmental pollutants upon degradation. The environmental impact of these materials mainly originates from their contribution to the carbon footprint during the process of manufacturing, distribution, disposal, finishing and polishing and removing old resin-based restorations (9).

Resin-based composites can be classified on the basis of fabrication and use as follows: i) Direct placement in the oral cavity and activation: The conversion of monomers to polymers through this method is incomplete due to partial conversion. At best, only 60-75% of the monomers convert to form polymers. These levels can drop as low as 30% at the base of a restoration (10). ii) Indirect placement: This method involves the fabrication of appliances and restorations outside the oral cavity, in dental laboratories through either heat cure polymerisation or blocs/ingots for machined CAD/CAM. Restorations fabricated in this method have relatively higher degrees of conversion of monomers into polymers (38).

Resin-based composites have the potential to enter the environment by either chemical means (dissolution and breakdown of the material within the oral cavity), or physical means (through the process of milling or grinding, finishing and polishing and removing old/defective restorations). The illustrating in Fig. 2 depicts microparticulate waste derived from resin-based composite materials. However, most commonly, this release is a result of a combination of both processes (7). According to the U.S. Environmental Pollution Agency (USEPA) (39), potential contamination by dental composites occurs through its accidental discharge during the transportation of dental waste or any malfunction of landfills which can cause potential environment contamination of dental composites (11).

Polymethylmethacrylate-based denture base materials. Denture base polymers can either be heat cured, autopolymerised self-cured, light-activated or thermoplastic resin (40). However, this polymerisation has been often incomplete and residual monomer leaches out into the oral cavity, causing health hazards upon entering the gastrointestinal tract and the inhalation of these particles can cause asthma, anorexia, headache and drowsiness (41).

Bisphenol A from orthodontic appliances. Polymers are widely used in orthodontics in elastomeric ligatures and chains, polycarbonates for esthetic brackets and myofunctional appliances. The amount of bisphenol A released is of minimal risk to humans; however, the effects of long-term exposure need to be considered (13). Bisphenol A is known to be a toxic chemical in the environment and recently, in animal models, it has been shown to induce carcinogenesis and mutagenesis (13,42).

In orthodontics, the release of bisphenol A can occur through three main ways: i) Through the peripheral margins of orthodontic brackets (43); ii) in bonded fixed retainers, a large surface to volume ration of the adhesives is exposed in the oral cavity and it allows aging, degradation and leaching of bisphenol A in an unpredictable manner (15); iii) upon the completion of orthodontic treatment, grinding and elimination of the adhesive with instruments is done which releases the components into the environment via aerosols (12).

Figure 1. Montage illustration depicting the types of single-use plastics in the dental office. Top row (from left to right): Disposable toothbrushes with plastic handles, plastic suction tips, disposable syringes, orthodontic elastic chain, disposable tips. Bottom row (from left to right): Disposable glasses, bite blocks, plastic sheets for radiographs, dental floss, applicator tips and plastic impression trays, personal protective equipment.

Figure 2. Image representing microparticulate waste derived from resin-based composite materials.

Additionally, a recent *in vitro* study highlighted the detachment of microplastics from commercial clear aligners due to their mechanical friction. The majority of microplastics have a diameter ≥20 μm, which can be excreted from the gastrointestinal tract (17).

Bisphenol A from composite restorations and pit and fissure sealants. During the finishing and polishing of dental restorations, or when old, defective restorations are removed, secondary microplastics are released into the oral environment (18). These materials may contain additives such as bisphenol A, phthalates, some brominated flame retardants that give desirable properties in colour and transparency and also counteract the breakdown from ozone, bacteria, temperature and provide thermal and electrical resistance (19). However, they have been proven to be endocrine disruptors which alter the homeostasis of endocrine system, inhibit the action of natural hormones and alter its synthesis (44). The superficial layers of pit and fissure sealants remain unpolymerized on exposure to oxygen which causes leaching, particularly during the initial few hours post-placement, which gradually decreases (45).

Microparticulate waste generated from the process of finishing, polishing and removal of old defective restorations. Microparticulate waste is generated chairside when resin-based composites undergo clinical grinding through the use of high-speed rotary and abrasive burs and discs. This is usually performed while removing defective and/or old restorations or while shaping, finishing and polishing the restorations. These wastes can also be generated from laboratory processes, such as the milling and grinding of pre-polymerized resin blocks to design indirect restorations such as crowns, inlays, onlays and implant abutments (7). In comparison of the amount of waste produced, it was noted that indirect restorations generated significantly higher quantities of microparticulate wastes (46). These wastes are removed from the oral cavity by means of a suction tip or an aspirator, which is released into the sewage wastewater, and eventually, into the environment (21).

4. Oral hygiene practices

Toothbrushes. The American Dental Association recommends changing a toothbrush every 3 to 4 months, or more often if the bristles are visibly matted or frayed (47). In the US market, approximately one billion toothbrushes are thrown away each year and 50 million pounds of toothbrushes are added into the landfills annually (36). Considering the world's population of 7.53 billion individuals, ~29.4 billion toothbrushes are discarded each year. On average, a plastic toothbrush weighs ~20 g; it can thus be calculated that the whole of humanity produce 600 million kg of plastic toothbrush waste in only 365 days (47).

Among the currently available toothbrushes, including manual plastic and bamboo toothbrushes and electric toothbrushes, the greatest contribution to the overall environmental impact has been observed by traditional plastic manual toothbrushes (23) as they are made from polypropylene plastic and nylon, which are derived from non-renewable fossil fuels (48). The manufacturing process of the nylon bristles releases nitrous oxide (36). Nitrous oxide is a greenhouse gas, which is 310-fold more potent than carbon dioxide (49). The toothbrush handles are relatively larger, made of polypropylene plastic which is neither biodegradable, nor recyclable (23). The amount of derived plastic waste in landfills further increases over time.

Toothpastes. In the Indian scenario, the mean yearly release of microplastics from toothpastes into the environment was gauged as 1.4 billion grams per year, which poses a significant environmental threat (24). In order to systematically assess the effects of toothpaste on the environment, two main aspects must be considered:

i) Toothpaste packaging: The toothpaste tube is primarily comprised of high-density polyethylene with the cap comprised of polypropylene. Of note, ~4,000 empty tubes of plastic need can become converted into one ton of plastic (24).

ii) Contents in toothpastes: Toothpastes are open-use consumer products, which are intended to be washed off and ultimately end up in the drains. Active contents of toothpastes are remineralizing agents (50), antibacterials (51) and lately, also probiotics (52). Numerous personal care and cosmetic products, such as toothpastes, soaps and gels, include microplastics to enhance the scrubbing and cleansing action (25). In toothpastes, they can be added to improve the whitening properties and act as a polishing aid (26). These microplastics which eventually accumulate in marine bodies through the drainage system and in turn within the tissues of aquatic life as shown in Fig. 3. The constituents include polyethylene (27), cellophane, polypropylene, polyvinyl chloride and polyamide in varying concentrations (28). The most widely prevalent microplastics are polyethylene and toothpastes contain up to 1.8% of this component (29). A previous study demonstrated various changes in marine organisms, such as the complete or partial absence of contacts in the filaments of gills, the presence of hemocytic infiltration in gills or mutation of ciliated epithelium to squamous epithelium within digestive organs and severe necrosis was noted in the gonads (30).

Dental floss. On average, each individual uses approximately three million miles of dental floss each year (53). Plastic forms a major component in the preparation of dental floss and its packaging.

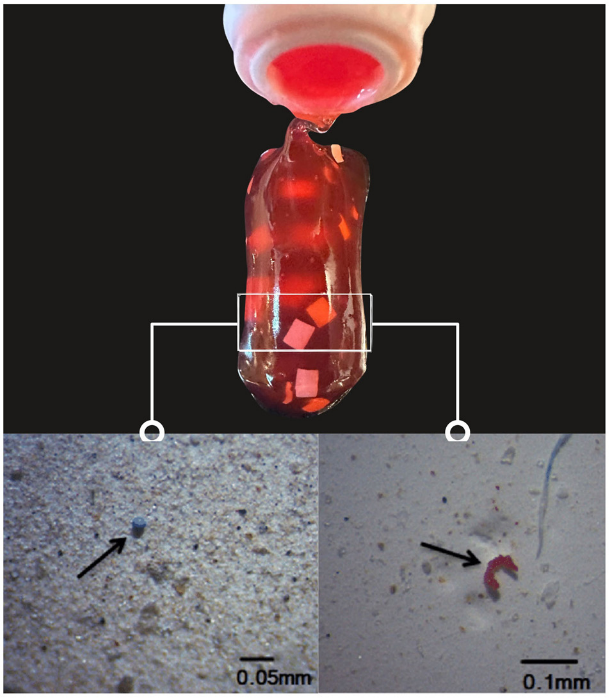

Figure 3. Microplastics from toothpastes showing microplastics released into the marine environment. The images were created on Adobe Photoshop.

Dental floss contains plastic. Traditional dental floss is comprised of non-recyclable and non-biodegradable materials, such as synthetic waxed nylon and teflon that add on to singe use plastic waste that pollutes marine bodies. Additionally, it may be coated with pre- and polyfluoroalkyl substances to allow passage between teeth; however, these chemicals are released while decomposing, which is toxic to the environment. It is also inadvertently consumed by marine life, which can cause starvation, poisoning or suffocation. Corals, that form an essential part of the marine ecosystem have floss entangled within them.

Dental floss with plastic packaging typically comprised of polypropylene plastic have the worst carbon footprint and highest environmental impact compared to other interdental cleaning aids. The handle alone formed 49% of the overall carbon footprint.

Mouthwashes. Mouthwashes contain antimicrobials, such as triclosan [5-chloro-2-(2,4-dichlorophenoxy) phenol]. The use of triclosan is not highly regulated due to its low acute toxicity and safety. The continual exposure of on marine life to triclosan leads to its accumulation within tissues and acute and chronic toxic effects, such as increased catabolic activity within tissues. Concentrations >34.5 nmol/l triclosan in river biofilms have been shown to exert inhibitory effects on periphytic algae (31).

5. Effects of COVID-19

Since the emergence of COVID-19 and its declaration as a pandemic by the World Health Organization, stringent measures to prevent the rapid spread were undertaken in all aspects of life (54). Some of the measures undertaken include the incorporation of protective equipment by the general public and healthcare industry (55). PPE ranges from disposable masks, head caps, protective eye wear, single use gloves, respirators and 'splashproof' protective clothing (56). The use of this protective equipment shifted from being used almost exclusively in the healthcare industry to widespread use by the general population against the pandemic (32).

Additionally, the rate of plastic production exhibited a notable surge due to two main reasons: One being the temporary relaxation with the use of disposable plastics to combat virus transmission; and second being the decrease in petroleum prices due to the reduced demand in various countries. The decrease in the oil rates translated into a decrease in the cost of plastic production. Industries took advantage of this reduction in cost to boost plastic production (20).

PPE. PPEs are prepared from various synthetic polymers, including high- and low-dentistry polymers which are neither recyclable, nor biodegradable. High-density polymers include polyester, polyvinyl chloride and polyvinyl alcohol, which sink into deep marine sediments (57). On the other hand, low-density polymers, such as polyethylene, expanded polystyrene and polypropylene float on sea water (58).

Disposable masks comprise of three layers where the inner layer is made up of hydrophilic soft fibers, the middle layer is made of melt-blown filter and the outer layer is made of non-woven hydrophobic fibers. The main filtering layer is the middle layer, which is manufactured by the entanglement of micro- and nanofibers (59).

Gloves were mostly made up of polyvinyl chloride, latex and nitrile. Face shields are made using a wide variety of materials, including polyethylene terephthalate glycol, acetate, polyvinyl chloride and polycarbonate (60). The fate of these microplastics ranges from either floating along the ocean currents, or sinking into the sediments and becoming a part of the geological record (61).

6. Mitigation strategies and challenges of implementation

General considerations for the dental office. Various practices can be adopted by the dental team to make environmentally friendly choices. To begin with, further attention should be directed towards purchasing products with minimal plastic packaging and the use of reusable plastic containers should be encouraged. Non-critical and semi-critical items, such as paper towels, cotton rolls or wool rolls made from recycled or partially recycled materials can be used. Containers or packaging with polyvinyl chloride should be avoided, whenever practical. Digital platforms for the maintenance of records and the use of both sides of pages with single spacing can reduce the amount of paper used in the office.

The use of biodegradable bags made out of vegetable starch should replace plastic bags as natural materials, such as vegetables are degraded readily and completely and serve as natural soil fertilizers, as compared to plastics. To disinfect the dental operatory, the Occupational Safety and Health Administration (OSHA) recommended reusable nitrile gloves should be used instead of disposable examination gloves. Furthermore, the use of gloves should be limited as per requirement, and injudicious use should be restricted.

Instruments that require sterilization in an autoclave should be packed in metal autoclave cassettes or reusable cloth or fabric bags, instead of plastic backed paper. This alternative is more cost-effective, protects practitioners and patients and does not overburden the environment (14). Instead of using plastic suction tips, metal or autoclavable suction tips can be used. Special considerations should be made towards incorporating a container for recyclable items and effort to ensure the correct disposable of recyclable items to designated centers, rather than adding on to landfills (7).

Dental materials. The concept of 'green dentistry' incorporates the four R's: Reduce, reuse, recycle and rethink. The use of trays for the application of fluoride should be substituted by the use of fluoride varnish. If the need for trays is mandated, such as for the preparation of dental impressions, metal or reusable trays should be used instead. Clinical recommendations should be followed to avoid overbuilding resin-based composite restorations so as to avoid further reduction and generation of microparticulate waste (62). Consideration towards repairing defective restorations, as compared to complete removal. In the case that the removal of resin-based restorations is deemed necessary, a water spray should be then used in conjunction to reduce the generation of microplastics (9). The development of measures is required to allow the complete conversion of monomers, such as placing the curing light as close to the adhesive as clinically possible during polymerization to allow the maximum direct conversion of the monomer and reduce the amount of bisphenol A released (14). Clinicians are advised to perform a pumice prophylaxis after bonding to the surface of these resin adhesives (43). Rinsing of the oral cavity is recommended after bonding orthodontic brackets within the first hour of placement to prevent the potential leaching of monomers (14). Brackets comprised of ceramic release lesser amounts of unpolymerized resin than polycarbonate brackets (16). The use of manual toothbrushes with replaceable heads and bamboo toothbrushes have a marked positive environmental impact in terms of their effect on climate change, resource use, ozone depletion and accumulation in marine bodies (23). Additionally, they use >97% less plastic than traditional plastic toothbrushes. However, the higher purchase costs of bamboo toothbrushes may pose as a barrier for consumer use (23). Alternatives to dental floss include silk and candelilla wax floss, silk and beeswax floss with packaging comprised of glass and aluminum dispensers or in carbohydrate or bioplastic boxes (36). It is essential to advise patients to not flush down used dental floss, as it can cause severe clogging in the sewer systems by entangling with other debris, hair or other particles.

The present review aimed to provide a comprehensive overview of the environmental impacts of plastic use in dentistry, from restorative practices to oral hygiene products, and their contribution to microplastic waste. However, the present review has certain limitations, such as a lack of quantitative data on the specific contributions of dental practices to global plastic pollution, limited focus on the regional variations and how local regulations and practices may influence this generation and management of plastic waste in dentistry.

7. Conclusion and future perspectives

While the present review provides valuable insight into the environmental impacts of plastic use in dentistry, several gaps in current knowledge warrant further investigation. Questions such as the specific contribution of dental specialties to microplastic pollution and the unique environmental impact of dental wastes compared to medical or general wastes remain unanswered. Additionally, evidence on the long-term impact of biodegradable or alternative materials in dentistry is limited.

Future research is thus required to focus on exploring emerging sustainable technologies and practices, as well as to evaluate the effectiveness of current knowledge and policy interventions in reducing plastic consumption. Such efforts could facilitate the widespread adoption of sustainable practices in dentistry.

In conclusion, the environmental impact of dentistry should be considered and voluntary efforts should be taken to reduce the production and discharge of plastics. The utilization of plastics, particularly single-use plastics, should be carefully monitored in the dental office and measures should be taken to curb its use and encourage use of ecologically friendly measures.

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DAT was involved in the conceptualization of the study, in the literature search and in the screening of all selected articles and in the removal of duplicates, in project administration and visualization. DAT was also involved in the writing of the original draft of the manuscript, and in the writing, review and editing of the manuscript. SB was involved in the screening of all selected articles and in the removal of duplicates, study supervision, validation of the data obtained from the literature for inclusion in the review, and in the writing, review and editing of the manuscript. Both authors have read and approved the final manuscript. Data authentication is not applicable.

Ethics approval and consent to participate

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Competing interests

The authors declare that they have no competing interests.

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