Environmental Impacts of Contact Lens Waste

by Abigail Wilhelmi

Contact lenses have been used for decades to correct vision. Over 150 million people use contact lenses today (Moreddu et al., 2019). The materials used to make contact lenses have evolved over many decades, but ultimately resulted in silicone-derived hydrogel, a plastic polymer that provides maximal comfort and clear vision, while also maintaining the eye health of the user. Contact lenses have enhanced the lives of many people, but a topic that is often left out of contact lens discussions is that of plastic waste.

Plastic has become an item that surrounds us every day. As a material that is cheap, lightweight, strong, and malleable, plastic has become the desired material for many purposes (IUCN, 2021). However, single-use plastic and increased plastic pollution have recently been areas of concern and expanded research. Contact lenses are often forgotten when analyzing personal plastic use, likely due to their small size and therefore low contribution to a person's overall plastic waste. Yet, a 2020 survey found that 21% of people still flushed their contact lenses down the drain, putting them directly into the water system (Rolsky et al., 2020). These flushed contact lenses have the possibility of breaking down into microplastics that persist in water systems for years to come. This paper examines the evolution of plastic polymers used for contact lens material and discusses how current materials are contributing to plastic waste and microplastic contamination. Further, a discussion of current disposal options for contact lens users is included.

Microplastic Contamination

Over 300 million tons of plastic are produced globally each year, with 8 million tons designed for single use items (IUCN, 2021). These single use plastics often end up in water systems and eventually contaminate the ocean. Plastic materials can be broken down through ultraviolet (UV) radiation, wind, or currents. However, after being broken into smaller fragments, these pieces can accumulate and persist in the aquatic environment for years (Enfrin et al., 2019). Microplastics are small particles of plastics that are under five millimeters by the longest dimension, while nanoplastics consist of plastic particles under 100 nanometers (IUCN, 2021). These materials are currently irretrievable contaminants that exist in oceans and other water systems. One study compiling microplastic counts from global deep-sea sediment studies estimates 8.4 million tons of microplastic on the ocean floors alone (Barrett et al., 2020). This does not include suspended microplastic or larger plastic materials currently in the ocean. If plastic production and waste continue as usual, it is estimated that there will be more plastic than fish in the ocean by 2050 (Ellen Macarthur Foundation, 2016).

There are many negative impacts surrounding the problem of increased microplastic in the ocean. First, ingestion of microplastics by marine organisms can impact digestion and cause physiological consequences (Issac & Kandasubramanian, 2021). A recent study in the Tropical Eastern Pacific consisted of collecting water samples and organisms for microplastic analysis. Researchers found microplastics in all water samples and in the digestive tracts of 166 of 240 marine organisms (Alfaro-Núñez et al., 2021). Even more concerning is that the marine organisms analyzed consisted of those that are consumed by humans: 14 species of fish, one species of mollusks, and one species of crustaceans. There have been studies indicating altered function in immunity, metabolism, neurotransmission, endocrine function, and reproduction in marine organisms that have ingested plastic (Horton et al., 2018). These drastic impacts may come not only from the microplastics themselves, but also from any additives, such as plasticizer, flame retardant, or pigments, contained in the plastic pieces (Issac & Kandasubramanian, 2021). Additionally, microplastics can serve as vectors for toxic contaminants adsorbed from the environment, such as pesticides as well as harmful bacteria (O'Donovan et al., 2018).

Another area of research has been microplastic contamination of wastewater treatment plants. Nano and microplastics can vary greatly in shape and chemical nature, making it easy for them to travel along water within treatment plants (Enfrin et al., 2019). Fortunately, most wastewater treatment plants studied in the United States have shown over 95% effectiveness in removing microplastics (Sun et al., 2019). However, other parts of the world still have varying amounts of microplastics remaining in their water. For example, a study completed in the Czech Republic with three different treatment plants found microplastic in all water samples, even those of treated water (Pivokonsky et al., 2018). The amount of microplastic in treated water was on average 83% lower than raw water, but still indicated that treated water could be an important source of microplastics to humans. Similar to the impacts of microplastic on marine organisms, chemical contaminants adsorbed to microplastic that remains in drinking water can have adverse effects on human health (Eerkes-Medrano et al., 2019). As previously mentioned, flushed contact lenses may be adding to this problem, which will be discussed in more detail in a later section. To understand how contact lenses could be contributing to microplastic contamination, particularly in wastewater treatment plants, a review of the types of plastic used for contact lens materials will be discussed next.

Contact Lens Materials History and Background

There are certain properties that a contact lens material must have. These include easy manufacturing, low cost, medium fracture toughness, lower elasticity modulus, transparency, and biocompatibility (Findik, 2011). It is estimated that 150 million people use contact lenses worldwide, which demonstrates easy manufacturing and low cost are important consideration factors. Medium fracture toughness implies that the contact lens will not fracture while it is being worn, and lower elasticity modulus ensures that the material will not be uncomfortably stiff. Finally, transparency and biocompatibility ensure that visual acuity will be improved while still maintaining eye health.

One important biocompatibility factor to consider for a contact lens material is oxygen permeability. The cornea, which is covered by a contact lens, has no blood vessels to provide oxygenation for metabolism. Consequently, the cornea obtains oxygen from the surrounding air through diffusion, and limited exposure to the ambient air can produce hypoxic conditions (Morgan & Brennan, 2007). Mild cases of corneal hypoxia can include blurred vision, burning, and excessive tearing, while more severe cases can result in death of corneal epithelial cells (Long Island Ophthalmic Concepts, 2018). For this reason, each contact lens material has sought to limit disruption of oxygen intake to the cornea.

Another important biocompatibility aspect of the contact lens is the wettability. The tear film that is present on the eye functions to maintain hydration, ensure lubrication, and distribute nutrients (Walsh et al., 2019). Ideally, the contact lens will minimally disrupt this tear film. The contact lens material must have polar regions that are allowed to cluster at the surface and attract the tear film for adhesion of the lens (Matters, n.d.). Hydrophilic character of the contact lens is essential if it is to remain wet during use, preventing discomfort during blinking. However, if the contact lens material is too hydrophilic, drawing in too much of the tear film to remain wet during use, the patient may experience dry eye symptoms (Walsh et al., 2019). Therefore, the contact lens material must be wettable, but not so hydrophilic that it interferes too greatly with the tear film.

Aside from manufacturing properties, there are specific demands of the user for contact lens material, including length of wear, comfort durability, practicality of handling, and stability of vision (Musgrave & Fang, 2019). It is clear that there are many properties to take into consideration when discussing contact lens materials. Multiple factors will be discussed throughout the consideration of past and current contact lens materials, as they point to how plastic provides an excellent material to meet these needs.

When contact lenses were first made in the 1880s, they were made of glass and covered the entire sclera (Heiting, 2021). These lenses were uncomfortable and could not be worn for more than a few hours. Glass is not permeable to oxygen, making prolonged wear a hazard for corneal health. Consequently, glass contact lenses did not gain widespread acceptance.

The 1940s brought the advent of plastic, and polymethyl methacrylate (PMMA) provided material for the first plastic lens. PMMA is an inexpensive, durable, optically transparent polymer (Musgrave & Fang, 2019). However, PMMA contact lenses are stiff and do not mold to the shape of the eye, making them one of the least comfortable types of contact lenses (University of Michigan Health, 2021). Additionally, PMMA polymers exhibit dipole-dipole intermolecular forces created by negatively charged oxygen and positively charged carbon and hydrogen. These forces prevent the polymer from moving or rotating easily, hindering wettability of the lens by preventing internal water and oxygen flow (Musgrave & Fang, 2019). To provide a solution for this lack of essential oxygen permeability, contact lens producers fit the lenses to move with each blink, allowing oxygen carrying tears to be pumped under the lens onto the surface of the cornea (Findik, 2011). Regardless of this manufacturing technique, PMMA did not provide optimal comfort for the wearer and did not gain widespread acceptance until the 1950s and 1960s (Heiting, 2021). More recently, wettability was improved by increasing hydrophilicity through adding surfactants to the PMMA surface (Musgrave & Fang, 2019). These hard lenses make up less than 1% of the market today (Musgrave & Fang, 2019).

Current hard lenses include rigid gas permeable lenses (RGPs). These lenses are more flexible than PMMA lenses due to incorporation of low-modulus components that break up the strong intermolecular forces within the polymer (Musgrave & Fang, 2019). These components include silicone or fluoropolymers which allow oxygen to pass directly through the lens (Findik, 2011). They are less durable and more expensive than PMMA lenses, but more comfortable and can be used for two to three years before replacement (University of Michigan Health, 2021).

During the 1960s and 1970s, soft contact lenses were introduced. Generally, soft contact lenses are highly flexible, oxygen permeable materials with high water content (Musgrave & Fang, 2019). High flexibility means that soft lenses fit to the user's eye much faster than rigid lenses, giving almost instant restored vision for the patient. The first soft lenses were composed of hydroxyethyl methacrylate (HEMA), which contains about 37% water by weight (Findik, 2011). HEMA contact lenses exhibit high polarity, and therefore high wettability, allowing for the contact lens to attract tears for wetness and creating a much more comfortable wearing experience than PMMA lenses (Musgrave & Fang, 2019). Despite decreased adjustment time for maximal visual acuity and increased comfort, HEMA contact lenses still did not have optimal oxygen permeability. To increase this essential function, contact lens manufacturers once again began incorporating silicone or fluoropolymers, permeability-increasing compounds, directly into the gel matrix. However, unaltered HEMA lenses are still used in specific cases today. Examples include patients who are intolerant to additive materials, have poor tear film quality, or have more complex prescriptions (Yu, 2019). Due to this, HEMA contact lenses still occupy about 22% of the market in the United States (Musgrave & Fang, 2019).

The most common additive to HEMA contact lens material is silicone. Silicone-derived hydrogel is the most frequently used contact lens material today, making up 64% of the market in the United States (Musgrave & Fang, 2019). These modified polymers can contain up to 80% water by weight (Findik, 2011). Silicone added to the polymer allows the highest oxygen permeability of any material that has been used for contact lenses by breaking up tightly bound intramolecular forces. This helps to reduce complications that had resulted from increased hypoxia associated with previous materials and makes the silicone hydrogel the "go-to" contact lens for many practitioners (Yu, 2019). However, incorporating silicone into hydrogel has certain drawbacks as well. Discomfort and dryness are two of the main reasons for user's discontinuation, as silicone incorporation leads to decreased wettability of the lens (Musgrave & Fang, 2019). Contact lens manufacturers have each taken an individual approach to improve these problems, such as incorporating further additives or adding a surfactant (Matters, n.d.).

Contact lens material has evolved through different polymers over the last decades. As seen through this discussion, there are many factors to consider when proposing a contact lens material, and finding a polymer that works perfectly with the physiology of the eye has not yet been done. However, hydrogel polymers currently offer the best solution to the health concerns that accompany contact lens use. At present, there is no naturally occurring material that would provide all the necessary properties (Johnson & Johnson, 2021).

Review of Contact Lens Waste Related Research

There have been few studies that have reviewed contact lens waste, and even fewer that have discussed microplastic contamination resulting from contact lens waste. This is possibly due to the small amount of plastic that contact lenses contribute to an individual's overall plastic use. However, these studies provide crucial information for eye care providers and contact lens users who want to reduce their overall plastic waste. Additionally, disposal methods are vital to discuss, as contact lens entry into the water system may be providing a source of microplastic contamination.

The most prevalent recent study on the degradation of contact lens waste focused on microplastic hydrogel found in wastewater treatment plants. In a survey completed for this study, 21% of people admitted to flushing their used contact lenses down the drain (Rolsky et al., 2020). To see if there was any chemical degradation occurring once these contact lenses traveled through wastewater treatment plants, contact lenses were exposed to wastewater both with and without naturally occurring microbes. After varying time intervals, the longest being 192 hours, the contact lenses showed very little chemical changes (Rolsky et al., 2020).

Despite the lack of chemical degradation, most contact lenses extracted from the wastewater treatment plant had already experienced physical degradation, resulting in contact lens fragments. Once these fragments are removed from wastewater and remain in a dry environment, they become very brittle and break into tiny pieces (Rolsky et al., 2020). Microplastics can then be consumed by animals, making their way into the food chain (Cornelius, 2018). Conversely, if the contact lenses remain in a wet environment, they can use their water attracting properties to not only absorb water, but also any contaminants that are present in the water, such as pesticides and bacteria (Cornelius, 2018). This can lead to the adverse health effects studied in humans and animals discussed previously.

Additionally, using information gathered from various manufacturing companies about the types of contact lenses purchased annually, Rolsky et al. (2020) were able to quantitively estimate how much contact lens waste is affecting water systems. With 21% of users flushing their contact lenses, it is estimated that 42,300 to 45,700 kilograms of contact lenses are sequestered in United States sewage sludge each year (Rolsky et al., 2020). This is equal to 420 contact lenses within every metric ton of dry treated sludge (Rolsky et al., 2020).

Further studies on contact lens waste have included discussion of plastic care products that are necessary for certain contact lens modalities. These studies focus less on microplastic contamination and look more deeply at the overall plastic waste produced from all contact lens products. For example, Morgan et al. (2003) compared conventional (non-replacement), planned (monthly) replacement, and daily disposable contact lenses, along with their care products. The daily disposable method does not require any additional supplies for care, while the other two replacement methods do. The conventional system, which would include a pair of hard contact lenses worn throughout the entire year, comprised of a peroxide-based care system, surfactant cleaner, saline, enzyme tablets, and four lens cases. This method contained the most disposed plastic by mass over the course of one year due to plastic packaging of the care supplies, equaling 1,893 grams (Morgan et.al., 2003).

Within the planned replacement system, the authors considered 12 pairs of monthly replacement contact lenses along with a cleaning solution and 12 lens cases. This replacement system showed the least amount of disposed plastic throughout one year, with a mass of 549 grams (Morgan et al., 2003). Additionally, although the authors chose to assume a monthly replacement for contact lens cases within the planned replacement system, the American Optometric Association (AOA) recommends switching a contact lens case at least every three months, and most contact lens wearers likely replace their cases even less frequently than that (AOA, n.d.). Taking this into consideration would further decrease the amount of plastic that is associated with the planned replacement contact lens modality.

Finally, the daily disposable system consisted of 360 pairs of daily contact lenses. No supplemental care products are required for this system. The mass of disposed plastic using the daily disposable method was 953 grams (Morgan et al., 2003). This places the daily disposable modality as using less plastic than the conventional system, but more plastic than the planned replacement system.

To analyze the total amount of contact lens related plastic waste discarded each year, 150 million total contact lens wearers are estimated worldwide in the study by Moreddu et al. (2019), and the approximate mass of plastic waste discarded for each contact lens modality is taken from Morgan et al. (2003). Additionally, the percentage of contact lens wearers using each modality is taken from the survey completed by Rolsky et al. (2020). These approximations result in hard lens and monthly disposable lens systems each producing around 40 million kilograms of plastic waste annually, while daily disposable lenses result in over 50 million kilograms of plastic waste annually. In total, this is over 132 million kilograms, or 291 million pounds, of contact lens related plastic waste each year.

Finally, after looking at how much contact lens waste is produced through each modality, it is important to discuss how much of this plastic can be recycled, and how easily. Multi-purpose solution bottle lids, tamper evident rings, and bottle stoppers, as well as lids of contact lens cases do not carry a resin identification code (RIC) and would not be identifiable to the consumer (Smith et al., 2021). There is also no recycling information printed on the foil used to seal blister packs. However, it is important to note that the presence of a RIC does not always mean that a certain plastic material is accepted locally for recycling, and its absence does not necessarily mean the product is not recyclable (Cramer, 2017). Within the daily disposable contact lens modality, the cardboard packaging is the only recyclable material that can be recycled at home. However, using a specific contact lens recycling program along with household recycling enables 100% of daily disposable materials to be recycled (Smith et al., 2021). Reusable systems are limited by tamper evident rings, bottle lids, bottle stoppers, and contact lens cases which are not accepted for household recycling or specialist recycling methods.

Contact lens recycling and disposal methods are not always the same for each contact lens modality and can be unclear to the consumer. Inquiry must be done locally to find which products can be recycled at home, which can be recycled through a specific recycling program, and which products are not recyclable. Using this information, eye care providers and staff can play a key role in informing patients about the recyclability of their contact lens products (Smith et al., 2021).

Current Contact Lens Disposal Options

As discussed previously, scientists and manufacturers have determined silicone-derived hydrogel to be the safest contact lens material option for a vast majority of the population. Recognizing this will contribute to plastic waste, most manufacturers are seeking or encouraging alternative disposal options for consumers. Currently, the single recycling option for contact lens wearers in the United States is through Bausch and Lomb's One-by-One recycling program. Bausch and Lomb partnered with TerraCycle to provide this recycling service for contact lens users of any brand. After collection, TerraCycle melts the contact lenses into plastic that can be upcycled into playground sets, park benches and more (Bausch and Lomb, 2021). In 2020, Bausch and Lomb reported the One-by-One recycling program had recycled nearly 27 million used contact lenses, foils, and blister packs since the launching of the program in 2016 (Bausch and Lomb, 2020). This would be equal to more than 162,000 pounds of contact lens waste (Bausch and Lomb, 2020).

Acuvue has also worked with TerraCycle to establish a contact lens recycling program in the United Kingdom. If contact lens recycling is not available for users, the company recommends throwing contact lenses out with the trash and discourages any disposal down the drain. Their website explains the reasons for using plastic packaging, including benefits that ensure the contact lenses will be delivered to the patient well-hydrated, unblemished, and germ-free (Johnson & Johnson, 2021).

CooperVision is another manufacturer that is making efforts to provide more sustainable options for contact lens users. A survey conducted by the company revealed 93% of eye care professionals in the United States agree that keeping plastic out of the ocean is important to them, and 84% agree manufacturers should take responsibility for the waste they create (CooperVision, 2021). To meet the values of optometrists and patients, CooperVision partnered with Plastic Bank to produce the first net plastic neutral contact lens in the United States, Clariti-1-Day. With the purchase of these daily disposable contact lenses, CooperVision funds the collection, processing, and reuse of plastic waste equivalent to the weight of plastic contained in the contact lenses and packaging bought (CooperVision, 2021).

A survey completed by the Recycling Partnership in 2020 revealed that 78% of consumers are more conscious of supporting green and sustainable companies than they were five years ago. As this trend continues, eye care professionals will face questions from patients about contact lens sustainability and waste. It will be essential for providers to be aware of what research has been done and what manufacturers are doing to address this issue to adequately answer these questions. Further, providing education on this issue will be essential to minimizing the amount of contact lens waste that contributes to landfills and microplastic contamination in water systems.

Conclusion

Increased plastic waste has resulted in countless negative impacts on the environment. Specifically, microplastic contamination of water systems has shown harmful health effects on marine organisms, and the consequences of ingested microplastics on human health are not fully known. The International Union for Conservation of Nature states recycling and reuse of materials as the most effective actions available to reduce the environmental impacts of plastic. They also point out that governments, research institutions, and industries need to work collaboratively to redesign products and rethink their usage and disposal. The field of optometry must also use this approach to address the waste produced by contact lenses and their packaging.

Contact lens materials have undergone extensive evolution, ultimately resulting in silicone-derived hydrogel which is prescribed to most patients today. This hydrogel material has provided clear vision while maintaining eye health in many individuals. However, inadequate education on appropriate disposal methods has resulted in hydrogel contact lenses contributing to microplastic contamination of water systems. Informing contact lens users of their disposal options and the consequences of flushing contact lens waste down the drain is essential. Manufacturers are beginning to address the issue of plastic waste that their products produce, and options for recycling are becoming available for contact lens wearers. As patients are beginning to ask more questions about the sustainability of their contact lenses, eye care professionals must be prepared to answer questions about how they can reduce their contact lens waste. In this way, the field of optometry can partake in decreasing plastic pollution.

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