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ORIGINAL ARTICLE

Evaluation of the leaching of microplastics from discarded medical masks in aquatic environments: a case study of Mashhad city

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Abstract
The COVID-19 pandemic has led to a significant increase in the global use of face masks, with reports indicating that approximately 129 billion people worldwide use them every month. Many masks contain MPs, which can pose environmental and health risks. The aim of this study is to assess the properties of MPs that are released from ten different mask brands. The masks that were selected were weighed, immersed in deionized distilled water, stirred, and MPs that were released into the water were collected using a cellulose ester membrane. The collected MPs were then analyzed using an optical microscope to observe their shape and color. The results showed that the rates of MPs released from N95 masks, surgical masks, and 3D masks were 54, 23, and 23%, respectively. The N95 mask had the highest percentage of MPs due to its heavy weight. The observed shapes of MPs, in terms of abundance percentage, were filamentous > spherical > irregular > fragmented. Furthermore, the majority of MPs were found to be transparent or black in color. This study offers valuable insights into the mechanisms behind the release of MPs from disposable face masks, shedding light on the critical issue of microplastic pollution resulting from mask waste.

Keywords Microplastics · Mask · COVID-19 · Health risks

Abbreviations
MPs Microplastics
SMs Surgical masks

Introduction

The Covid-19 pandemic is widely regarded as the most significant global health crisis of our time, presenting significant health, economic, environmental, and social challenges for the entire human population (Maghsodian et al. 2022). Global pollution from plastic polymers has significantly increased, particularly during the coronavirus outbreak (Khoshmanesh et al. 2023). During the COVID-19 pandemic, face masks were used to reduce the transmission of disease (Mirzaie et al. 2022; Moshirfar et al. 2020).

According to reports, about 129 billion face masks are used every month worldwide, often containing plastic microfibers (Prata et al. 2020). Plastic waste is one of the most prevalent environmental pollutants (Geyer et al. 2017). Plastics in aquatic environments may fragment or disintegrate due to physical, chemical, and biological processes, eventually releasing MPs (Bonyadi et al. 2022). MPs enter the aquatic environment through water channels, industrial and municipal effluents, and wind currents (Khoshmanesh et al. 2023). Microplastic particles in aquatic environments vary in terms of size, specific density, chemical composition, and shape (Khoshmanesh et al. 2023; Maghsodian et al. 2021). In fact, the fate of MPs in aquatic environments depends on the density and constituents of the polymer (Maghsodian et al. 2021).

MPs released from masks are considered an environmental and health issue. Most of these pollutants are composed of polypropylene, polyurethane, nitrile, acrylic, polystyrene, polycarbonate, and polyethylene (Smereka and Szarpak 2020). These polymer materials have a detrimental effect on numerous plants and animals (Fadare and Okoffo 2020;

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Kwak and An 2021). In a study, it was discovered that masks can release significant amounts of MPs into the environment (Chen et al. 2021). Various MPs are released from masks due to environmental factors, such as exposure to sunlight and changes in ambient temperature (Zahmatkesh Anbarani et al. 2023). The release of MPs from polypropylene masks occurs slowly due to their high resistance to fluctuations in water flow, high molecular weight, absence of active functional groups, and presence of methyl chains. The penetration of MPs into the human body can cause damage to the lungs and intestines. The detection of MPs in the nasal mucosa of individuals wearing masks suggests that they may be inhaling them while wearing a mask (Ma et al. 2021). MPs ingestion may cause cytotoxic and inflammatory effects in human lung epithelial cells, which can directly harm the body (Hajiouni et al. 2022; Kashfi et al. 2022). Furthermore, these pollutants can carry toxic chemicals and pathogenic microorganisms, which can harm various organs (Vethaak and Leslie 2016). SMs are the most commonly used personal protective equipment during the COVID-19 pandemic. However, their widespread use and improper disposal have led to the release of large amounts of MPs into aquatic environments. It is estimated that approximately 47 microplastic fibers are released into the environment daily from a single mask (Sun et al. 2021a). Wang et al. (2021) conducted a study on the changes in characteristics and environmental behavior of disposable masks when exposed to coastal environments (Wang et al. 2021). In a study, the researchers compared the number of microfibers released from masks in dry state (ranging from 14,031.97 to 177,601.58 fibers/mask) to that in wet state (ranging from 2557.65 to 22,525.89 fibers/mask) (Rathinamoorthy and Balasaraswathi 2022). The release rate of MPs from masks increases with age due to mechanical wear and tear and exposure to natural environments (Morgana et al. 2021). This study enhances our understanding of the mechanisms involved in the release of MPs from disposable masks and provides a basis for estimating the extent of microplastic pollution caused by mask waste. The aim of the present study was to investigate the release of MPs from discarded medical masks and determine their characteristics, such as shape, color, number, and size.

Materials and methods

Materials

The masks selected for this research included ten different brands of medical masks commonly used in Mashhad, Iran. The main material of all masks was polypropylene. The selection of these masks was based on various factors, including their availability, cost, and effectiveness in filtering particles. To determine the release rate of microplastics, we conducted tests on surgical masks, 3D masks, and N95 masks. Table 1 shows the characteristics of selected mask brands.

MPs release test

To determine the amount of microplastics released, we first weighed the selected masks using a digital scale. The specimens were subsequently submerged in 200 mL of deionized distilled water that had been filtered through a 0.45 µm cellulose ester membrane. The reaction mixture was stirred using a magnetic stirrer at a speed of 220 rpm for 24 h. After the reaction time, the mask was removed using clean tweezers. The surface of the mask was then washed with 50 ml of deionized distilled water and shaken to dislodge any remaining MP on the surface of the mask into the reaction vessel. Next, the water that contained MPs released from the mask was collected by a 0.45 µm cellulose ester membrane. After completing the process, the cellulose ester membrane, with a pore size of 0.45 µm, was dried at 60 °C for 24 h (Chen et al. 2021; Liang et al. 2022a, 2022b).

MPs analysis

An optical microscope (Olympus CX23), equipped with a digital camera, was used to observe MPs trapped on the filter membrane and analyze their shape and color (De Falco et al. 2018; Liang et al. 2022a, b; Zhang et al. 2023).

Quality assurance and quality control

Precautions were taken during the experiment to avoid contamination. Particle-free nitrile gloves and lab coats were utilized, and glassware was thoroughly rinsed with deionized water. The water utilized in the experiment underwent filtration through a 0.45 µm filter, and the filtration device was sealed with aluminum foil to prevent contamination. An ultra-clean environment was maintained throughout the

Table 1 Characteristics of selected mask brands

Brand No	Type	Weight(mg)	Layer	Color
Mask A1	Surgical mask	3016.8	Three layers	Green
Mask A2	Surgical mask	2950.5	Three layers	Green
Mask A3	Surgical mask	2611.2	Three layers	Blue
Mask A4	Surgical mask	1706	Three layers	Blue
Mask B1	3D mask	3882.1	Four layers	Green
Mask B2	3D mask	3856.2	Four layers	Green
Mask B3	3D mask	5003	Five layers	White
Mask B4	3D mask	4962.8	Five layers	White
Mask C1	N95 mask	11,487.5	Eight layers	Gray
Mask C2	N95 mask	11,504.6	Eight layers	Gray

entire filtration process. Prior to the experiment, all containers and tools were cleaned using ultra-pure water. Blank controls were used to subtract any MPs detected in the experimental groups (Liang et al. 2022a).

Data analysis

A statistical analysis was conducted using SPSS version 26 to examine the differences in microplastic release among different brands and types of masks. One-way ANOVA was used for this purpose, with statistical significance set at a P-value < 0.05 (Liang 2et al. 2022a, b; Zhang et al. 2023).

Results and discussion

The unprecedented production and use of face masks has resulted in a significant influx of MPs into the environment. The adverse risks of MPs released from masks in aquatic environments deserve serious attention, as MPs cause numerous harmful effects on the environment and human health. Therefore, the contamination of microplastics from masks is a critical issue that requires further research.

MPs concentration

All three types of face masks released MPs into the water environment continuously for 24 h. The masks analyzed in this study were new and in and in an intact and unbroken state, and nose bridges and other accessories were not removed.. Therefore, the amount of MPs in our findings may be lower than what occurs in actual environmental conditions. Figure 1 indicates the percentage frequency of MPs in different types of masks. According to Fig. 1, N95 masks released the highest amount of MPs into the water environment over a 24-h period. MPs released from N95 masks, surgical masks and 3D masks were 54, 23, and 23%, respectively. N95 masks released more MPs into the water environment than 3D and surgical masks due to having multiple synthetic layers. The filter layer in N95 masks is composed of molten polypropylene, a type of extremely fine plastic fiber. When exposed to water or other environmental conditions, this layer can break down into small particles such as MPs. In contrast, 3D masks and certain types of surgical masks are made from natural materials such as cotton or cellulose, which are biodegradable and less likely to produce MPs when they decompose. However, it is important to note that not all surgical masks are made from natural materials, and some actually contain synthetic materials, such as N95 masks. Previous studies have reported that the release of MPs from both new and worn masks can range from hundreds to thousands of particles per piece per day (Chen et al. 2021; Morgana et al.2021). Environmental factors, such as weathering, exposure to light, and physical stress, can accelerate the release of MPs from mask (Saliu et al. (2021; Wang et al. 2021). Sun et al. (2021) and Rathinamoorthy and Balasaraswathi (2022 have demonstrated high emission rates of MPs from masks (Rathinamoorthy and Balasaraswathi 2022; Sun et al. 2021b). Pengfei Wu et al. (2022) reported that SMs release a higher abundance of microfibers in both aquatic and sediment environments compared to other types of masks (Wu et al. 2022). Chen et al. (2021) stated that microplastics (MPs) found in masks are the result of fiber breakage and shedding in non-woven fabrics (Chen et al. 2021).

Visual inspection of MPs

Microplastic particles were observed using an optical microscope with a 10× lens magnification, and the results are presented in Fig. 2. The analysis revealed that the microplastics generated by masks were primarily spherical, stringy, and irregular in shape, with the stringy type being the most prevalent in this study. Also, MPs were found in various colors, such as clear, blue, black, red, green, brown, and orange. This finding is consistent with the studies conducted

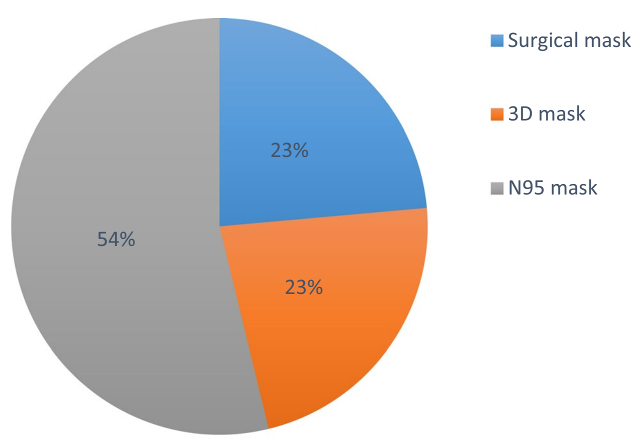

Fig. 1 Percentage of frequency of microplastics in different masks

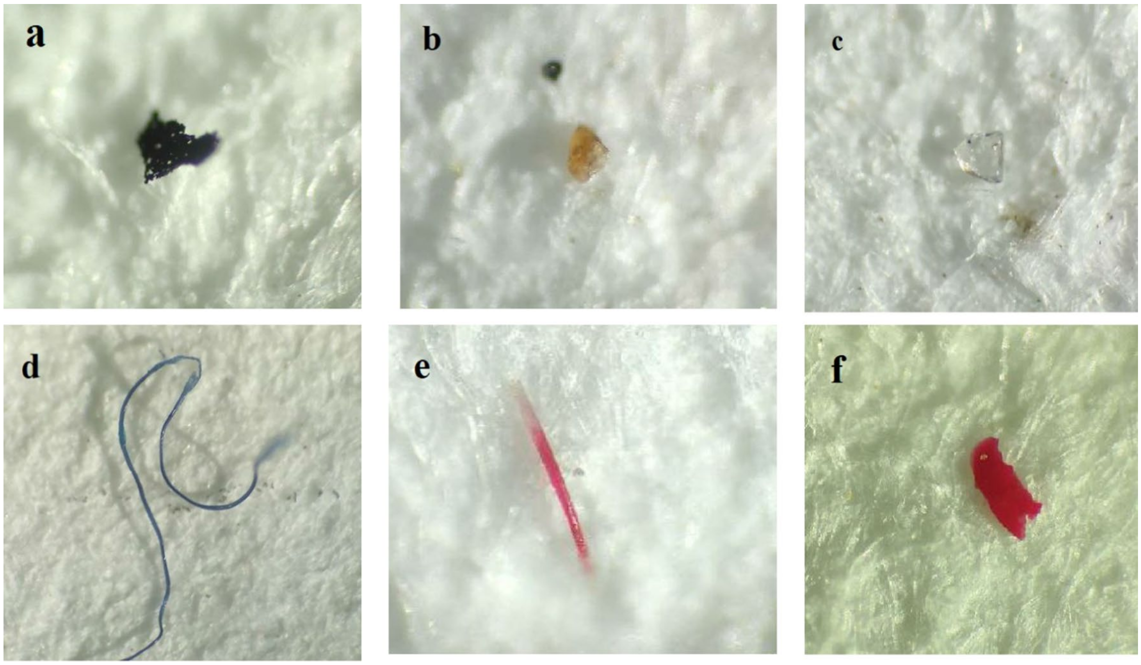

Fig. 2 The microplastic image on the microscope **a** black fragment, **b** orange fragment, **c** colorless fragment, **d** blue filament, **e** red filament, and **f** red fragment

by Chen et al. (2021) and Sullivan et al. (2021) and Pengfei Wu et al. (2022) (Chen et al. 2021; Sullivan et al. 2021; Wu et al. 2022).

Shape of MPs

Based on the findings illustrated in Fig. 3a, the frequency of microplastic shapes was ranked as follows: filament > spherical > irregular > fragment (*P*-value < 0.05). According to Fig. 3a, MPs in filamentous forms were the most common, while the fragmented form was the least common. The study conducted by Peng et al. in 2017 observed that the most common forms of MPs were fibrous and irregular (Peng et al. 2017).

Color of MPs

MPs exist in clear, black, blue, gray, green, red, purple, and yellow colors in both saltwater (Courtene-Jones et al. 2017; Dai et al. 2018; Okamoto et al. 2022) and freshwater and freshwater environments (Li et al. 2018; Okamoto et al. 2022; Wu et al. 2020).

Figure 3b displays the abundance of MPs observed in various colors, including white, black, blue, green, yellow, red, and brown (*P*-value < 0.05). The results of this research are consistent with other similar studies (Chen et al. 2021; Liang et al. 2022a; Sullivan et al. 2021). As shown in Fig. 4b, the combination of transparent and black accounted for 60% of the total colors. Other colors such as blue, red, green, brown, and orange accounted for approximately 40% of all colors. Chen et al. (2021) reported that the majority of microplastics (MPs) found in medium-sized transparent masks originated from non-woven fabrics (Chen t al. 2021).

Effect of mask weight on the release of MPs

Figure 3c shows the amount of MPs observed in 1 g of each type of mask. According to Fig. 3c, masks from the A3 brand release more MPs than masks from other brands. The release of MPs from discarded face masks can have adverse effects on aquatic life. A single worn mask can release more than 1.5 million MPs into the aquatic environment.

Size distribution of microplastics

Figure 4 illustrates that the majority (37%) of microplastics fall within the range of 1000–5000 µm, while only 26% are in the range of 100–500 µm (*P*-value < 0.05). A similar study found that medium-sized microplastics (100–500 µm) were the predominant type found in both fibers and fragments of used disposable face masks. A study found that the percentage distribution of microplastics emitting different colors was nearly identical in both new and used cloth, N95, and surgical masks (Bhangare et al. 2023). A study investigated the effects of microplastics from disposable medical masks

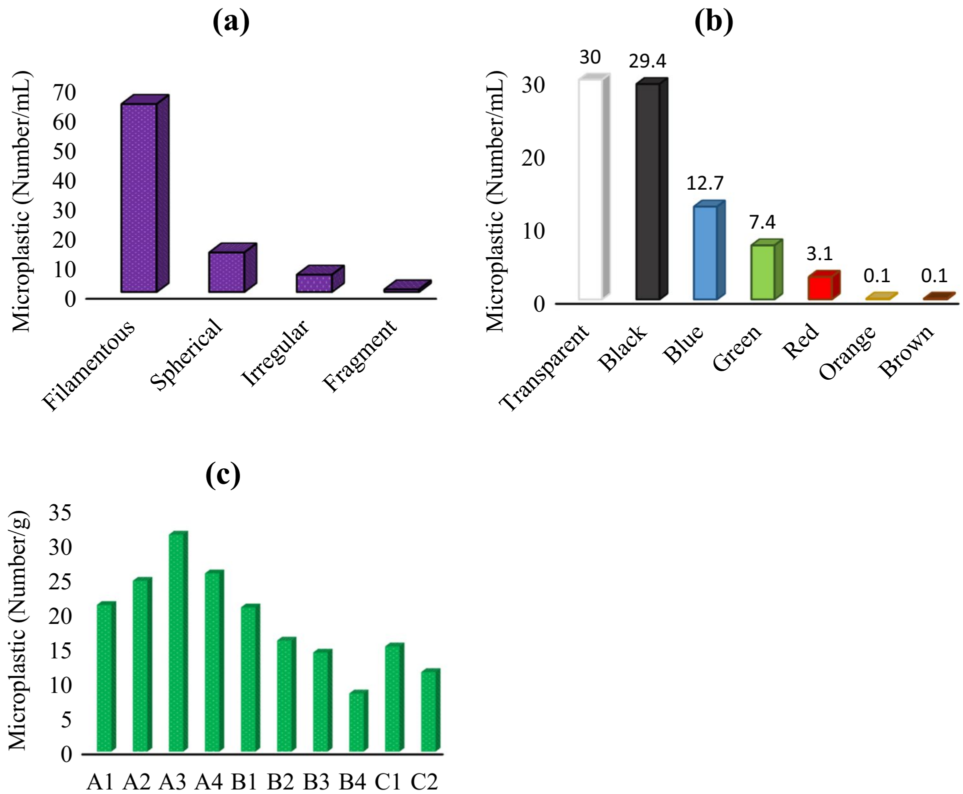

Fig. 3 Percentage of microplastics released from studied masks based on **a** shape, **b** color, and **c** weight

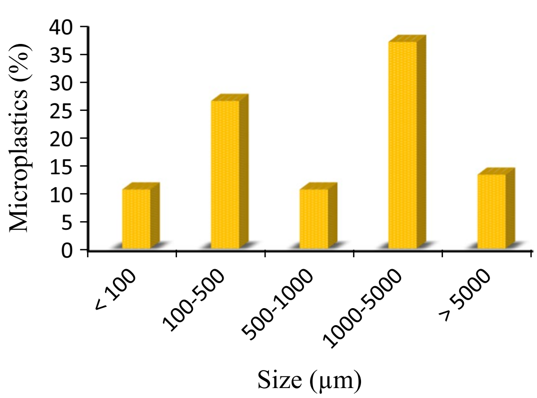

Fig. 4 Size distribution of microplastics from different masks

on terrestrial invertebrates. The study found that microplastics obtained from each layer of a medical mask differed in size and shape (Kokalj et al. 2022).

Conclusion

The use of face masks has resulted in a notable discharge of MPs into the environment, especially in aquatic ecosystems. The potential impact of microplastic contamination from masks on both the environment and human health is a cause for concern, and warrants further research. MPs were detected in all three types of masks examined in the study. N95 masks released the highest amount of MPs due to their synthetic material composition. The visual inspection of MPs revealed that they exist in spherical, filament, and irregular forms with varying colors. The frequency of microplastic shapes was ranked as follows: filaments were the most common, followed by spherical, irregular, and fragment shapes. Additionally, transparent, and black colors combined accounted for 60% of the total colors observed. The study also found that A3 brand masks release more MPs than other brands.

It is important to note that the quantity of MPs in the study results may be lower than what occurs in real environmental conditions because the masks examined were new and intact.

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Authors' contributions FB performed the experiments and wrote the paper; ZB wrote and edited the paper, and conceived and designed the experiments.

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Data availability All necessary data are included in the document.

Declarations

Conflict of interest The authors declare that they have no conflict of interests.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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