The Process of Microplastic Release from Personal Protective Equipment and Its Impact on the Environment

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Abstract: This study focuses on the significant issue of microplastic release from personal protective equipment (PPE), particularly face masks, during the COVID-19 pandemic. Microplastics, defined as synthetic particles smaller than 5 mm, have gained considerable attention due to their widespread environmental dissemination and potential impacts on ecosystems and human health. By employing a comprehensive set of detection techniques, including visual inspection, Fourier Transform Infrared Spectroscopy (FTIR), Raman spectroscopy, hyperspectral imaging, and thermal analysis, this research aims to provide a detailed understanding of the microplastic release process from PPE. The results highlight the scale of the problem and emphasize the need for urgent action to mitigate microplastic pollution. To this end, the study proposes a multifaceted approach that involves strengthened regulatory frameworks, improved PPE design that minimizes microplastic release, and increased investment in research to advance our knowledge and develop effective control strategies. This work serves to raise public awareness of the issue, enhances our comprehension of microplastic sources and transmission pathways, and lays a solid scientific foundation for environmental protection and public health initiatives aimed at preventing and controlling microplastic pollution.

1 INTRODUCTION

Microplastics, defined as synthetic solid particles or polymeric matrices with dimensions ranging from 1 mm to 5 mm, can originate from primary or secondary manufacturing processes and are characterized by their insolubility in water (Frias and Nash, 2019). These particles are categorized as primary or secondary microplastics based on their source. Primary microplastics predominantly originate from industrial products and personal protective equipment, whereas secondary microplastics are derived from the breakdown of larger plastic waste through various physical, chemical, and biological processes. The widespread environmental dissemination of microplastics and their adverse biological and ecological impacts are causes for concern. Notably, these particles can accumulate within the food chain; as the trophic level increases, the concentration of microplastics in organisms also escalates. Marine organisms, especially, may harbor significant amounts of microplastic particles due to their feeding habits (Laskar and Kumar, 2019). When consumed by humans, these microplastics can enter the body, leading to various health complications. Specifically, microplastics are not absorbed by the human body and may accumulate in the gut, causing constipation, irritable bowel syndrome, gut flora disruption, and altered intestinal permeability. Furthermore, microplastics can release chemicals that may damage the endocrine system, resulting in hormonal imbalances, impaired reproductive and developmental functions, and potential effects on the cardiovascular and nervous systems. Therefore, the investigation and mitigation of microplastics are of utmost importance.

With the heightened awareness of self-protection and the ongoing development of social industries, the use of masks has become increasingly prevalent. This trend has been further exacerbated by the outbreak of COVID-19 in Wuhan, China, in 2019, prompting widespread adoption of disposable masks globally to mitigate disease transmission. According to the World Health Organization, approximately 89 million procedural masks were required monthly to manage COVID-19 (Sommerstein et al., 2020). However, this widespread use has given rise to environmental concerns, particularly regarding discarded masks. Improper disposal of these masks, evident in locations such as Hong Kong beaches and Nigerian roads and

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drainage systems, not only detracts from the urban landscape but also potentially hinders tourism and economic progress, degrades air quality, undermines soil and microbial diversity, and harms ecosystems. The environmental impact of these discarded masks is intricately linked to their material composition. Disposable masks typically consist of three layers: an inner layer of standard hygienic gauze or non-woven fabric, a middle layer of ultrafine polypropylene fiber melt-blown material, and an outer layer of specialized antibacterial material. During decomposition, these materials release microplastics, posing significant environmental pollution and waste challenges.

This study aims to examine the process of microplastic release from personal protective equipment, identifying microplastics as an emerging contaminant and offering recommendations to enhance our understanding of the microplastic release process through advanced detection techniques. The significance of this research lies in its potential to enhance our comprehension of microplastic sources and transmission pathways, providing a scientific foundation for the development of effective microplastic pollution prevention and control strategies. By assessing the strengths and weaknesses of various detection methods, this study also paves the way for future microplastic detection and management efforts, thereby playing a pivotal role in environmental protection and public health advancement.

2 METHODS FOR DETECTING MICROPLASTIC RELEASE FROM PERSONAL PROTECTIVE EQUIPMENT (PPE)

2.1 Visual Inspection Method

Researchers primarily utilize the visual inspection method, which involves naked-eye observation and microscopic examination, to enumerate sample particles. Microscopy aids researchers in distinguishing microplastics by magnifying their surface texture and structure, thereby minimizing interference from other organic and inorganic substances adhering to the mask's surface. However, recent studies indicate a misidentification rate exceeding 20% for plastic-like particles using microscopy, with a notably high misidentification rate of up to 70% for transparent microplastics (Ho and Not, 2019). Such deviations can arise from various factors, including potential oversights during scientific observation or the inherently challenging nature of observing extremely small microplastic particles. To enhance accuracy, samples frequently undergo pretreatment, commonly involving staining with a Nile red solution. This staining process enables the particles to fluoresce green under a fluorescence microscope, facilitating easier detection by the observer.

2.2 Spectral Analysis Method

FTIR (Fourier Transform Infrared Spectroscopy) stands as a prevalent technique in chemical analysis, notably adept at detecting microplastics. IR spectroscopy operates by gauging the transitions between molecular vibrational energy levels through the absorption of radiation (Xu et al., 2019). Distinct materials exhibit unique absorption spectra, forming the scientific grounds for material differentiation. By referencing spectral databases, unknown materials can be accurately identified, and chemical images subsequently generated. Technological advancements have refined FTIR and spawned numerous derivatives. Notably, FTIR microspectroscopy boasts the capability to detect samples exceeding 10 µm. Additionally, focal plane array spectroscopy offers insights into the chemical and physical attributes of analyzed particles (Ramsperger et al., 2020).

Raman spectroscopy, another valuable tool, employs scattered light emerging from the interaction of light and matter to dissect the chemical structure of substances. Upon light's impact on a sample, the majority of it scatters at an unchanged frequency, a phenomenon known as Rayleigh scattering. However, a minor fraction of light, upon colliding with sample molecules, undergoes a frequency shift, termed Raman scattering. This frequency alteration correlates with the vibration and rotational energy levels of the sample molecules, enabling the identification of different species. Hyperspectral imaging, a cutting-edge technology, excels in spectral resolution and captures spectral data within narrow bands. This capability allows for the precise identification of spectral signatures among various materials, facilitating material resolution and identification.

2.3 Thermal Analysis Method

Thermal analysis, while being an effective technique, involves the decomposition of the sample. This process entails heating the plastic sample to high temperatures, leading to its decomposition and the formation of new products. Subsequently, the characteristic pyrogram of the microplastic is juxtaposed with a reference pyrogram derived from a known pure polymer. This comparison aids in determining the polymer type of the microplastic (Aragaw, 2020). By systematically varying the temperature, measuring the heat absorption and release differences between the sample and the reference, and mapping the correlation between temperature and these differences, the detection of microplastics and the identification of their substance type become feasible. Thermal investigations conducted on the inner and outer layers of the mask reveal distinct peak endothermic temperatures of 130, 125, and 175° C for the respective layers (Stubbins et al., 2021). When benchmarked against a reference, it becomes evident that the mask primarily consists of polypropylene plastic, highlighting the plastic composition as its main constituent.

Table 1 comprehensively outlines the strengths and weaknesses of the aforementioned five methodologies. Each method exhibits unique applicability and constraints. In practical applications, the choice of a suitable assay or the combination of multiple approaches may be necessary to achieve optimal analytical results. This selection should be guided by factors such as specific analytical goals, sample attributes, budgetary constraints, and ease of execution.

Table 1. Advantages and disadvantages of thermal analysis methods

Detection method	**Advantages**	**Disadvantages**
The visual inspection method	Low cost Simple operation Can directly see the shape and size of microplastics	Cannot directly detect the properties of microplastic samples High rate of incorrect identification Cannot directly detect properties The samples need to be pretreated
FTIR	Can detect the degree of oxidation of this type of microplastic Relatively high accuracy Ensure the integrity of the sample Small amount of sample is required.	Expensive High operational requirements High sample requirements: the samples must be infrared active, free of additives, not specially treated, larger than 20 μ m in size, and with a purity of over 98%.
Raman spectroscopy	Relatively high accuracy. Ensure the integrity of the sample. The required amount of sample is small Capable of detecting microplastic samples larger than 1 μ m The moisture content requirement for the sample is also relatively low	Prone to interference from fluorescent background signals of additives and pigment-like chemicals Susceptible to contamination by impurities, requiring sample pretreatment
Hyperspectral imaging method	Fast response High resolution Ensure the integrity of the sample	Unable to identify the polymers of microplastics Low accuracy
Thermal analysis method	High sensitivity with accuracy of mass change up to 10^-5 No special requirements for the sample Requires only a small amount of sample	Sample is destroyed during operation Operation technique is relatively complex Analysis of characteristic pyrolysis diagram requires corresponding theoretical knowledge

3 CHANGES IN MICROPLASTICS IN CHINESE SOIL BEFORE AND AFTER COVID-19

Before the epidemic in 2019, the abundance of microplastics in farmland soils of Shaanxi Province ranged between 1430 and 3410 items per kilogram (Ding et al., 2020). However, in 2024, post-epidemic data revealed a significant surge in the average abundance of microplastics in a representative agricultural region of Yan'an City, Shaanxi Province, reaching 4505 items per kilogram, indicating an increase of up to 50%. The primary driver behind this escalation in soil microplastics is attributed to the extensive utilization of personal protective equipment, particularly masks, during the epidemic. This increase poses numerous detrimental effects on soil ecosystems. Similar trends, albeit to varying degrees, have been observed across other regions of China. Currently, the nationwide average abundance of soil microplastics stands at 4536.6 items per kilogram. The notable rise in soil microplastics following the pandemic serves as a warning that plastic components from personal protective equipment may be leaking into the environment, demanding urgent attention. Therefore, it is imperative to enhance public awareness regarding microplastic pollution, comprehend the mechanisms through which microplastics are released, and implement measures to minimize the use of plastic in personal protective gear, thereby safeguarding the health of our soils and ecosystems.

4 MICROPLASTIC POLLUTION CONTROL STRATEGIES

4.1 Preventing Microplastic Pollution Through Laws and Regulations

The environmental impact of microplastics has garnered global attention, leading to the establishment of various regulations aimed at mitigating microplastic pollution. The first international initiative aimed at tackling this matter was the establishment of the 1973 International Convention for the Prevention of Pollution from Ships, which garnered support from 134 countries (Boyle, 1985). However, this convention failed to elicit widespread awareness regarding microplastic pollution and lacked enforceable measures to curtail the abandonment of personal protective equipment (PPE) in individual countries.

Subsequently, significant steps have been taken, such as the United Nations Environment Assembly's resolution on a legally binding international instrument addressing plastic pollution, and the European Union's legislative measures restricting microplastics under Annex XVII of the REACH Regulation. In a contrasting approach, certain countries like Sweden and some states in the United States have implemented regulations specifically targeting microplastics. These measures include prohibiting the use of microplastics in cosmetics and personal care products, thereby limiting their dissemination. These localized efforts serve as valuable references. In 2022, China officially recognized microplastics as emerging pollutants, and the "Management Measures for the Use and Reporting of Disposable Plastic Products by Business Operators" introduced in 2023 offers alternative strategies for reducing microplastic pollution.

Overall, while global unified regulations for microplastics control are still evolving, there exists a disparity in the stringency and scope of these regulations across different countries and regions. Future efforts should focus on enhancing international collaboration to establish a harmonized global framework for microplastic pollution control, thus collectively addressing this pressing environmental challenge.

4.2 Preventing Microplastic Pollution Through Laws and Regulations

During usage, various types of masks undergo damage, leading to the generation of distinct microplastics. Specifically, masks such as KN95 and regular disposable masks exhibit differences in the production of fine particles. Our observations indicate that, within the 0.3-1.0 mm particle size range, the concentration of particles from KN95 masks surpasses that of disposable medical masks. Conversely, in the 1.0-2.5 mm range, disposable medical masks shed a higher concentration of particulate matter. Interestingly, for particle sizes exceeding 2.5 mm, both mask types exhibit similar levels. These findings underscore the need for enhanced mask design considerations. Future research should focus on addressing the limitations of both mask types, exploring the feasibility of developing a novel mask that effectively prevents pollution while minimizing the release of microplastics. Additionally, improving production materials, such as the use of polylactic acid for biodegradable masks, represents a promising avenue for future developmental research.

5 CONCLUSION

This paper uncovers a significant source of microplastic pollution stemming from the widespread use of personal protective equipment (PPE), especially face masks, during the COVID-19 pandemic. Through analytical techniques including visual inspection, Fourier Transform Infrared Spectroscopy (FTIR), Raman spectroscopy, hyperspectral imaging, and thermal analysis, the release of microplastics from PPE was detected. While acknowledging the strengths and weaknesses of each method, this comprehensive approach allowed for a detailed examination of the issue.

Given the potential environmental and health risks posed by microplastics, this paper proposes several measures to mitigate the problem. Firstly, it advocates for stronger legislative frameworks to discourage improper PPE disposal and encourage globally harmonized regulations for microplastic pollution control. Secondly, it suggests improvements in PPE design to minimize microplastic release, such as exploring new eco-friendly materials and refining manufacturing processes. Lastly, it emphasizes the need for increased investment in microplastic pollution research. The significance of this study lies in its contribution to raising public awareness about microplastic pollution, particularly from PPE. The findings enhance our understanding of microplastic sources, transmission pathways, and their environmental and public health impacts. Furthermore, this paper lays a scientific foundation for developing effective strategies to prevent and control microplastic pollution, thereby playing a pivotal role in environmental protection and public health initiatives.

The limitations of this study include a potential lack of depth in analyzing certain detection techniques and an incomplete examination of the environmental behavior and biological effects of microplastics. Future research should aim for a more holistic investigation of microplastic pollution through interdisciplinary approaches, integrating insights from chemistry, biology, environmental science, and other relevant fields.

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