Review Article

Yonsei Med J 2023 May;64(5):301-308
https://doi.org/10.3349/ymj.2023.0048

Yonsei Medical Journal
YMJ
pISSN: 0513-5796 · eISSN: 1976-2437

Health Effects of Microplastic Exposures: Current Issues and Perspectives in South Korea

Yongjin Lee[1], Jaelim Cho[1,2,3], Jungwoo Sohn[4], and Changsoo Kim[1,2,3]

[1]Institute for Environmental Research, Yonsei University College of Medicine, Seoul;
[2]Department of Preventive Medicine, Yonsei University College of Medicine, Seoul;
[3]Institute of Human Complexity and Systems Science, Yonsei University, Incheon;
[4]Department of Preventive Medicine, Jeonbuk National University Medical School, Jeonju, Korea.

Microplastics are environmental pollutants that prevail in the oceans, remote islands, and polar regions. Exposure to microplastics presents a major emerging threat to the ecosystems due to their potential adverse effects. Herein, we reviewed the literature to provide an up-to-date synopsis of the current understanding of the sources, compositions, and adverse effects of microplastics in humans and the environment. Most studies on microplastics have focused on developing standardized methods for monitoring the occurrence, distribution, and movement of microplastics in the environment, as well as developing microplastic substitutes; however, although humans are exposed to microplastics via various routes, research on the adverse effects of microplastics in humans remains limited. Little is known about the impact of microplastics on human health and the toxic effects that may vary depending on the type, size, shape, and concentration of microplastics. Therefore, more research is needed to understand the cellular and molecular mechanisms of microplastic toxicity and related pathologies.

Key Words: Microplastic, environmental pollutants, human exposure, multipathway, health effect, waste management

INTRODUCTION

Microplastics are found in the oceans, remote islands, and polar regions and are emerging as a major threat to ecosystems due to their direct and indirect potentials as environmental pollutants. No international consensus has been reached regarding the definition of microplastics, such as the size cutoff and materials involved. Microplastics are usually produced intentionally or generated when large synthetic polymer products, such as plastic packaging, are not properly disposed of or treated. Once formed, microplastics are often exposed to the environment, where they can decompose. In general, microplastics are synthetic polymer compounds that form when large plastic materials are fragmented and micronized to a size ≤5 mm.

Currently, accurate statistics are unavailable regarding the sources of microplastics and the total amount of microplastics deposited in the land and sea. Various human activities and products, such as washing, worn tires, city dust, road paint, ships, and cleaning products, have been reported as sources of microplastics;[1] however, the main sources of microplastics have not been clearly identified. Although various cases of microplastic pollution have been reported globally, such as in marine ecosystems, freshwater, air, and human bodies, additional research is needed to accurately understand the origins and spread of microplastics and their impact in each situation.

Microplastics are easily ingested due to their micro-level sizes. They also move easily through the food chain and persist in the environment since they are refractory to biodegradation. In addition, as microplastics exist in micro-level to nano-level sizes, they are virtually impossible to remove once released into the environment. Due to these characteristics, microplastics pose potential hazards to humans and the environment. As a representative example of the risk posed by microplastics, they can cause physical and mechanical harm (e.g., cause ab-

Received: March 21, 2023 **Revised:** March 23, 2023
Accepted: March 27, 2023 **Published online:** April 20, 2023
Corresponding author: Changsoo Kim, MD, MPH, PhD, Department of Preventive Medicine, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea.
E-mail: preman@yuhs.ac

•The authors have no potential conflicts of interest to disclose.

normalities in internal organs) to marine organisms when they mistakenly ingest microplastics. Ecotoxicity may be caused by the polymer itself, unreacted monomers, impurities (e.g., residual catalysts or reaction by-products), additives (e.g., stabilizers), or other substances in the polymer matrix (e.g., dyes, lubricants, or plasticizers). In addition, microplastics can enter the human body when they are not filtered out during sewage-treatment processes, or they can flow into the sea, thereby posing risks for the ecosystem and humans. Various examples of damage caused by microplastics have been reported, such as microplastic accumulation in the bodies of marine and aquatic organisms (leading to malnutrition), inflammation, reduced fertility, and mortality. The threats that microplastics present to the human body have not yet been clearly identified. However, previous reports have shown that ultrafine microplastic absorption resulted in complex toxicity in zebrafish,[2] and that microplastics under 100 nm in size can reach almost all organs after entering the human body.[3] Therefore, concerns exist regarding the negative effects of continuous microplastic accumulation in the human body.

To counteract the harmful effects of microplastics, the South Korean government has begun establishing and promoting plastic waste-management measures that promote the effective management of microplastics. The Korean Ministry of Environment prepared a comprehensive plan for recycling microplastic waste in 2018 and a plan for managing microplastics in 2019, and the Ministry of Oceans and Fisheries prepared a comprehensive plan for reducing marine plastics in 2019. Globally, general solutions to the problem of microplastics include direct regulations (such as banning the use of microplastics in some emission sources) and indirect regulations (such as restricting the use of single-use or disposable plastics and encouraging the collection and recycling of plastics). The United States and France introduced regulations banning the intentional use of primary microplastics in cleaning products, and the European Union (EU) expanded the list of products and items that are regulated (e.g., agriculture/horticulture products, cosmetic products, air fresheners, paints and coatings, oil and gas products, construction equipment, medications, medical devices and supplies, food, synthetic detergents, and adhesives) (ref). In particular, the EU adopted the "European Plastics Strategy" in January 2018 (ref), which included promoting increased recycling of plastic products and a reduction of plastic waste, and the United Kingdom and France have made efforts to strengthen regulations on the use of single-use and disposable plastics (ref).

Recently, various studies on microplastics have focused on developing standardized methods for monitoring the occurrence, distribution, and movement of microplastics in the environment, as well as developing microplastic substitutes; however, research on the adverse effects of microplastics in humans remains limited. International organizations such as the International Organization for Standardization and the Group of Experts on the Scientific Aspects of Marine Environmental Protection, which provide advice to the United Nations Environment Programme, have promoted the development of standardized investigation and analysis guidelines for microplastics. Furthermore, the Netherlands and Germany have promoted mid- to long-term research to obtain an integrated understanding of terrestrial microplastics (e.g., to determine where microplastics occur, their routes of dissemination, their loads in different settings, and treatment strategies).

The proposed Korean and international regulations of microplastics are based on current scientific knowledge and available information on the intentional uses and risks of microplastics. To obtain further information and take additional measures regarding the use of microplastics in the future, it is necessary to continue research on market adaptation to regulation, ascertain the performance of biodegradable polymers in related applications, and obtain new information on the harmfulness of microplastics to the human body and the environment.

STUDY OF MICROPLASTICS

Definition of microplastics and international regulations

Microplastics are synthetic, high-molecular weight compounds that have been micronized into plastic particles smaller than 5 mm in size. Such materials have a low biodegradation rate and, thus, mostly remain in the environment and adversely affect the human body, the final consumer in the food chain.

Microplastics can be classified according to their source and fragment size. In general terms, microplastics can be categorized as primary and secondary microplastics. Primary microplastics are intentionally created plastic particles, such as consumer-care products (e.g., detergents and cosmetics) or industrial products. Microplastics are also referred to as "microbeads." Currently, microbeads are prohibited for use both domestically in South Korea and internationally (Table 1). Secondary microplastics are products containing plastics, such as plastic waste and fibers, or plastic products that have decomposed after being exposed to the environment.

Lee, et al.[4] investigated correlations between the distribution of large plastics (which are easily seen with the naked eye) and microplastics in plastic debris on the beach near the Nakdonggang River estuary, based on their sizes, i.e., micro (1–5 mm), medium (5–25 mm), and large (>25 mm). In addition, the chemical constituents of environmental microplastics are diverse and include polymers, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), PE terephthalate, polyvinyl chloride, and polyvinyl alcohol. Microplastics can exist as fragments, films, fibers, and foam.

Microplastics in South Korea

Research conducted by the Seoul Institute of Health and En-

Table 1. Domestic and International Statuses of Regulating or Banning the Use of Microbeads and Microplastics

Country	Effective date (year)	Regulations
United States of America	2014	First ban on the use of microbeads in personal care products (Illinois)
	2015	Ban on the use of microbeads in cosmetic products (California, New Jersey, New York, etc.)
Canada	2016	Announcement of a ban on the use of microbeads for exfoliation and cleansing products
New Zealand	2018	Prohibition of the manufacture and sales of personal care products containing microbeads
Northern Ireland	2019	
Italy	2020	
UK	2021	
Sweden	2019	Announcement of amendments to acts regarding the use of microbeads in cosmetic products
Taiwan	2020	Announcement of amendments to acts regarding the use of microbeads in cosmetic products
Korea	2017	Designation of microbeads as raw materials that cannot be used in cosmetic products
	2019	Preparation of a test method for detecting microbeads in cosmetic products by the Ministry of Food and Drug Safety in Korea
	2021	Specific regulations for microplastic contents in some household chemical products : cleaning solutions, deodorant agents, laundry detergent, bleach, and fabric softener

vironment showed that the concentrations of microplastics suspended in indoor and outdoor air ranged from 0.45 to 6.64 [mean±standard deviation (SD): 2.51±1.77] pieces/m^3. Specifically, the concentration of microplastics suspended in indoor air ranged from 0.49 to 6.64 (mean±SD: 3.02±1.77) pieces/m^3, whereas that in outdoor air ranged from 0.45 to 5.16 (mean±SD: 1.96±1.65) pieces/m^3, indicating that 1.5 times more microplastics were floating in indoor air than in outdoor air. The size distributions of microplastics varied from 20.1 to 6801.2 μm indoors and from 20.3 to 4497.4 μm outdoors, and microplastics with a size of 20 to 100 μm accounted for 48% to 96% of the total microplastic particles. The most abundant type of microplastics detected was PE, followed by PP, polyamide (nylon), polyester, acrylic, and others. PE and PP components accounted for approximately 67% of all microplastics. The percentages of microplastics detected indoors were particularly high for synthetic fibers, such as polyester.[5]

According to research reported by the Ministry of Environment in Korea in 2017, a mean concentration of 0.05 pieces/L of microplastics was detected in 24 water-treatment plants that mainly received surface water from the four major river-water systems in South Korea (i.e., Hangang River, Nakdonggang River, Geumgang River, and Yeongsangang River). Kwon, et al.[6] investigated microplastics during the dry season (May) and rainy season (July) along the eastern coast of Geoje Island, adjacent to the Nakdonggang River estuary. Their study showed that in the May, manta trawl nets (pore size: 330 μm) and hand nets (pore size: 50 μm) caught 0.62–57 pieces/m^3 and 260–11410 pieces/m^3 of microplastics, respectively. In July, manta trawl nets and hand nets caught 0.64–860 pieces/m^3 and 210–15560 pieces/m^3 of microplastics, respectively. In addition, the most abundant type of microplastic particles detected was paint particles (48.9%), followed by Styrofoam (19.6%) and fibers (17.5%).

Since bivalves (which are one of the most widely consumed seafoods obtained from marine environments) are generally eaten whole without removing the intestines, they can be regarded as a main food source for human exposure to microplastics. According to a 2020 press release by the Ministry of Food and Drug Safety in Korea,[7] the mean concentration of microplastics detected in highly consumed marine products (including seafoods) in South Korea was 0.47 pieces/g. Microplastic concentrations according to the types of analyzed marine products were 0.07–0.86 pieces/g for shellfish, 0.03–0.04 pieces/g for cephalopods, 0.05–0.30 pieces/g for crustaceans, 1.03 pieces/g for dried anchovies, and 2.22 pieces/g for sea salt. Microplastics were mainly detected in marine products as fragments of 20 to 200 μm, and their major chemical components were PP, PE, and PS. Cho, et al.[8] found 0.15 (range: 0.07–0.34) pieces/g of microplastics in commercial bivalve shellfish (e.g., oysters, mussels, clams, and scallops) in fish markets of major cities in South Korea (Seoul, Gwangju, and Busan), and that the annual concentration of microplastics ingested through crustacean consumption by Koreans was 521 (range: 243–1182) pieces/person. The microplastics detected were mainly composed of PP, PE, Styrofoam, and PE vinyl acetate as fragments ranging from 100 to 200 μm in size.

Choi, et al.[9] analyzed the concentration of microplastics in soil samples from 100 sites in South Korea, including forests, suburbs, and agricultural lands in Yeoju-si, Gyeonggi-do, South Korea. Their analysis showed that the mean microplastic concentration in soil was 700 pieces/kg, and more microplastics were detected in upland soil than in urban soil. In addition, the microplastic concentrations differed depending on the agricultural soil type with orchard soil samples showing the highest microplastic concentrations, followed by upland, greenhouse, and rice paddy soil samples. These findings indicate that microplastic concentrations differ according to the type of land use (Table 2).

Table 2. Types and Concentrations of Microplastics in South Korea in Different Environmental Media

Medium	Types of microplastics	Sampling	Concentration(s)	Reference
Air	PE, PP, polyamide (nylon), polyester, acrylic, etc.	Capture of indoor and outdoor air	0.45 to 6.64 pieces/m^3 (mean±SD: 2.51±1.77)	5
Water	-	Water-treatment plants for surface water from the four major rivers in South Korea	Mean: 0.05 pieces/L	35
	Paint, Styrofoam, and fiber particles	Eastern coast of Geoje Island, adjacent to the Nakdonggang River estuary	Dry season (may) - Manta trawl nets (330 μm), 0.62–57 pieces/m^3 - Hand nets (50 μm), 260–11410 pieces/m^3 Rainy season (july) - Manta trawl nets (330 μm), 0.64–860 pieces/m^3 - Hand nets (50 μm), 210–15560 pieces/m^3	6
Seawater	Fragments 20 to 200 μm in size, consisting of PP, PE, or PS	Marine products that are highly consumed in South Korea, including seafoods	Shellfish: 0.07–0.86 pieces/g Cephalopods: 0.03–0.04 pieces/g Crustaceans: 0.05–0.30 pieces/g Dried anchovies: 1.03 pieces/g Sea salt: 2.22 pieces/g	7
	Fragments 100 to 200 μm in size, consisting of PP, PE, Styrofoam, or PE vinyl acetate	Commercial shellfish in fish markets in Seoul, Gwangju, and Busan, South Korea	Oysters, mussels, clams, and scallops: 0.15 (0.07–0.34) pieces/g Concentration of microplastic intake through crustacean consumption by Koreans: 521 (243–1182) pieces/(person · year)	8
Soil	-	Forests, suburbs, and agricultural lands in Yeoju-si, South Korea	Mean: 700 pieces/kg (more microplastics detected in upland soil than in urban soil)	9

PE, polyethylene; PP, polypropylene; PS, polystyrene; SD, standard deviation.

TYPES AND ROUTES OF MICROPLASTIC EXPOSURE AND THE EFFECTS ON HUMAN HEALTH

Types and routes of human exposure

Humans are mainly exposed to microplastics by using various plastic products (i.e., plastic packaging containers, decomposing plastic materials, fishing nets, textiles, and personal hygiene products) and being exposed to paint fragments (e.g., abrasion of paint) that have flowed into the environment (i.e., air, water, seawater, or soil). As such, humans can be exposed to microplastics through direct ingestion, direct contact, and inhalation.[10]

Most investigations of microplastics have been based on observations of synthetic microbeads (i.e., primary microplastics) intentionally manufactured for industrial or household use. However, unintentional causes of microplastic pollution should also be paid attention to, such as secondary microplastics that comprise a relatively large proportion of plastic particles in the environment. It is also well known that the physicochemical properties of nanomaterials play important roles in their toxic properties and lethality. Primary microplastics currently used in toxicology studies are mostly uniform in size and shape, whereas secondary microplastics exist in a variety of sizes and shapes, making it difficult to assess their actual health risks.[11]

Microplastics have irregular shapes, such as cubic, spherical, and rod shapes depending on their morphological characteristics, which should be considered when assessing risks to humans and the environment. Sharp microplastic particles can cause toxicity by physically stimulating the human body. In addition, various chemicals are used when synthesizing plastic polymers, depending on the end use, most of which are endocrine disruptors. Endocrine disruptors, also referred to as hormonally active agents, can harm the human body by causing various cancers and reproductive-system disorders. Microplastics can also affect the human body by stimulating the release of endocrine disruptors. In addition, microplastics can carry other toxic chemicals such as heavy metals and organic pollutants during adsorption, which can adversely affect the human body (i.e., the final consumer).

The toxicity of microplastics inhaled by humans was addressed in a study performed by Prata.[12] The results of that study suggested that microplastics were present in the atmosphere, and that humans could be exposed to microplastics through inhalation. Thus, chronic exposure to low concentrations of microplastics in the air could be associated with respiratory and cardiovascular diseases depending on an individual's susceptibility and the particle characteristics.

Choi, et al.[13] assessed the harmfulness of microplastic accumulation in marine zooplankton and found that such accumulation can affect the overall marine ecosystem as well as the human body. They exposed marine zooplankton to microplastics (size: 50 nm or 10 μm) for 24 h and 48 h, respectively, using PS microplastics found in disposable cups and snack packaging, and then they analyzed expression differences in

https://doi.org/10.3349/ymj.2023.0048

antioxidant genes and enzymes involved in generating active oxygen and oxidative stress. Although the gene-expression differences were not significant over time, it was found that smaller microplastics were more toxic. In addition, both sizes of microplastics accumulated in the bodies of plankton and in the oocytes of some female plankton, implying the possibility of intergenerational transmission. Such a finding raises the possibility of that microplastics can eventually enter the human body through the food chain, as microplastics accumulate in plankton (lowest level of the food chain) and then migrate into higher predators.

To date, no method has been established to accurately assess the risks posed by microplastics; therefore, further research is needed, particularly since microplastics can act a medium for adsorbing persistent organic pollutants or transporting bacteria.

Effects of microplastics on human health

The results of cellular and animal experiments have shown that microplastics can affect various systems in the human body, including the digestive, respiratory, endocrine, reproductive, and immune systems. First, the digestive systems are affected when microplastics are ingested, and physical irritation to the gastrointestinal tract may eventually cause inflammation, resulting in various gastrointestinal symptoms.[14] Microplastics may cause changes in the intestinal microbiome, resulting in an imbalance between beneficial and harmful bacteria, which can lead to various gastrointestinal symptoms, such as abdominal pain, bloating, and changes in bowel habits.[15] In addition to their physical effects on the digestive system, microplastics can cause chemical toxicity, which involves the absorption and accumulation of environmental toxins such as heavy metals and polycyclic aromatic hydrocarbons. These toxic substances can enter the body through the gastrointestinal tract when microplastics are ingested orally, leading to various gastrointestinal symptoms including nausea, vomiting, and abdominal pain.[16]

Regarding the effects on the respiratory system, microplastics may cause oxidative stress in the airways and lungs when inhaled, leading to respiratory symptoms such as coughing, sneezing, and shortness of breath due to inflammation and damage, as well as fatigue and dizziness due to a low blood oxygen concentration.[17] A recent study showed that nano-sized plastics were associated with mitochondrial damage in human respiratory cells.[18] Microplastics can act as carriers of other environmental toxins, such as PS, and exposure to high concentrations of PS are detrimental to human lung cells, increasing the risk of chronic obstructive pulmonary disease.[19]

In addition, microplastics interfere with the production, release, transport, metabolism, and elimination of hormones, which can cause endocrine disruption and lead to various endocrine disorders, including metabolic disorders, developmental disorders, and even reproductive disorders (i.e., infertility, miscarriage, and congenital malformations).[20] Microplastics can act as a medium for environmental toxic substances such as bisphenol A, which are absorbed into the body and cause various diseases of the endocrine system and reproductive system.[21] In a recent study, microplastics were also found in the placentas of six pregnant women by Raman microspectroscopy.[22] The potential negative effects of microplastics on the human immune system warrant further research. Accumulated exposure to microplastics induced chronic inflammation and homeostasis changes in animal experiments,[23] and a study on human lung cells showed that microplastics can activate innate immunity by regulating the expression of genes and proteins involved in the immune response.[24]

In vitro experiments with human cells and in vivo data generated with mice showed that microplastics elicit adverse health effects mainly by causing inflammation, oxidative stress [increased reactive oxygen species (ROS) production], lipid metabolism disturbances, gut microbiota dysbiosis, and neurotoxicity. Exposing human gastric adenocarcinoma cells to 44 nm PS nanoparticles strongly increased the expression of the IL-6 and IL-8 genes, which are major inflammatory substances in the body.[25] Exposing human glioblastoma multiforme cells (T98G cells) and human cervical carcinoma cells (HeLa cells)[26] to PE microplastics only increased ROS production in the T98G cell line, whereas exposure to PS microplastics increased ROS production in both cell lines. As such, microplastic exposure not only increases ROS production in cerebral and epithelial cells, but it also increases oxidative stress in colon and small intestine epithelial cells[27] and lung epithelial cells.[19,24] The results of animal experiments reported to date have shown that exposing mice to PS microplastics caused lipid-metabolism disturbance in the liver, increased oxidative stress and acetylcholine esterase activity,[28] and induces microbiota dysbiosis in the intestine.[29]

Choi, et al.[30] fed PS microplastics to mice for 2 weeks and found that inflammatory-response proteins, such as inducible nitric oxide synthase and cyclooxygenase-2, increased significantly in the liver, kidneys, and intestines of mice, and that ROS production and superoxide dismutase activity increased significantly. Lipid-metabolism disturbances and inflammatory reactions caused by microplastic exposure were more severe in diabetic mice than in healthy mice.[31] Microplastic neurotoxicity has also been reported in a small number of animal experiments. Shan and colleagues[32] exposed PS nanoparticles orally to mice for 7 days, and found that the nanoparticles accumulated in the central nervous system and caused microglia activation and neuron damage. Additional data have shown that exposure to PS microplastics caused cognitive dysfunction in mice,[33] along with changes in locomotor function and anticholinesterase activity.[34]

As discussed above, the detrimental health effects of microplastics have been observed in many experimental studies, suggesting that the risks for various inflammatory-related diseases in the human body is increasing. However, few epidemiological or etiological studies have been performed to examine the occurrence of symptoms or diseases caused by microplastic exposure.

Microplastic-exposure routes

Recently, microplastics have been recognized as important pollutants that cause environmental problems. Microplastics have been detected in food consumed by humans or in the air. Therefore, they may affect human health through food consumption or inhalation.

Ingested or inhaled microplastics may accumulate in the body and trigger an immune response or cause local particle toxicity. In addition, chronic exposure may cause more problems through accumulation in the body. However, to date, no definitive evidence has been reported regarding exposure levels, due to a limited number of studies on the exposure doses.

Therefore, it is necessary to evaluate the threshold exposure levels and loads of microplastics that affect human health in the future.

Ingestion

Target-food and microplastic-size considerations based on Korean dietary characteristics reviewed 134 food items after considering common Korean dietary patterns and heavy metals that might be found in such foods. After considering Korean eating habits, we classified the foods studied into different group (muscles, intestines, and other organs) and analyzed each food group. The foods were further subclassified as domestic Korean, ocean fishing, and imported marine products and investigated. Each product type (e.g., organic, salt dried, or dried) was analyzed separately. To estimate the internal dose of microplastics in foods sold in South Korea, obtaining information on the unit intake for each food group was essential, and it was necessary to analyze the contents of microplastics in each organ based on the dietary characteristics of Koreans (Table 3).

Inhalation

The synthetic fiber industry is a representative example of potential workplace exposure to microplastics through inhalation. The results of many studies have demonstrated that microplastic inhalation can lead to respiratory and lung diseases among workers in factories using synthetic fibers.

In addition, sea salt aerosols can be transmitted by sea waves and wind to urban environments close to the coast.

A previous report showed that microplastics exist in fertilizer components that are used in agricultural fields, and that they remain in the land for approximately 15 years and are eventually released to the atmosphere.

The results of most previous studies showed that ingestion was the main route of microplastic exposure in humans, although recently developed detection and quantification methods has provided mounting evidence that humans are exposed to microplastics through the air. However, a consensus on sampling and analysis methods for microplastics in the air is currently lacking, and this issue should be resolved soon. The main sources of microplastics in indoor and outdoor air are synthetic fibers, plastic fibers, building materials, waste-incineration byproducts, and landfills. Recent human-biomonitoring data have revealed the presence of plastic fibers in lung tissue, suggesting that airborne microplastics can be deposited or accumulate in the lungs.

DISCUSSION AND CONCLUSION

Previous estimates indicated that humans are exposed to between tens of thousands and millions of microplastics each year, or several milligrams per day. The main exposure route could be the inhalation of indoor air and drinking water in plastic bottles. Exposure to microplastics through food intake is likely the main exposure source, although it remains difficult to provide a detailed estimate due to the lack of research on the con-

Table 3. Major Seafood Items with High Consumption of Microplastics

Food group	Selection criteria	Target marine products
Fish (20 species)	Intestines consumed (muscles or intestines)	Yellow corvina, stingray, pike eel (liver), halibut, perch, cod, flounder, croaker, rockfish, conger eel, monkfish, and skate
	Whole fish consumed (whole fish, muscles, or intestines)	Snakehead, crucian carp, and carp
	Specific organs consumed (muscles, intestines, or specific organs)	Sandfish (roe), pollack (roe), frozen pollack (roe), and conger eel (liver)
Shellfish (8 species)	Conches (muscles or intestines, including reproductive organs)	Conch, triton snail, abalone, big snail, and rice paddy snail
	Larger shellfish among invasive shellfish (muscles or intestines, including reproductive organs)	Scallops, cockles, and razor shell
Crustaceans (6 species)	Marine decapods (muscles or intestines)	Blue crab, snow crab, red crab, stone crab, king crab, and lobster
Mollusks (4 species)	Cephalopods (muscles or visceral mass, including reproductive organs and ink)	Cuttlefish, squid, small octopus, and octopus
Echinoderms (1 species)	Specific organs consumed (edible parts or intestines)	Sea cucumber
Deep-sea fish (2 species)	Large marine animals or fish (muscles, intestines, tails, fins, or eggs)	Whale, shark (eggs)

https://doi.org/10.3349/ymj.2023.0048

tents and internal doses of microplastics in different foods.[17]

A recent report showed that microplastics exposure in newborns and infants could increase due to the use of feeding bottles and medical devies, and biomonitoring data provide indirect evidence of microplastics exposure in infants and children. The results of animal studies have shown that maternal exposure to microplastics affects offspring and subsequent generations and that the toxicity levels and effects in humans can vary depending on the size, shape, chemical composition, surface charge, and hydrophobicity of microplastic particles.

Microplastics exist everywhere, and humans are exposed to microplastics through various routes. To assess the toxicity and adverse effects in humans caused by such exposure, various exposure and toxicity evaluations are needed. Moreover, in the past 50 years, the global production of plastics has increased, as has the prevalence of overweight and obesity in the general population, and research is ongoing to test the hypothesis that microplastics are responsible.

Humans are exposed to microplastics through various routes, and the associated health effects are complex and variable. Little is known regarding the impact of microplastics on human health and the toxic effects that may vary depending on the type, size, shape, and concentration of microplastics, as well as other factors. Therefore, further research is needed to understand the cellular and molecular mechanisms of microplastic toxicity and related pathologies. In addition, the composition of microplastics and relevant additives variably introduce additional toxicity and health effects, so it is necessary to conduct additional research on these topics.

Considering the ubiquitous nature and long persistence of microplastics, it is necessary to make efforts to mitigate their exposure given their effects on entire generations and multiple generations.

Plastic, which has become inseparable from human life, has given various benefits to mankind, but is naturally or artificially divided into various sizes and affecting the natural ecosystem. When the size of the plastic becomes smaller and microplastics are formed, they can be absorbed, ingested, or inhaled into the human body through the skin, gastrointestinal system, or lungs. These microplastics can physically block the digestive system, stimulate the mucous membrane, and injure it. Also, when the size of microplastics becomes smaller than 1 micrometer to form nanoplastics, which are ultrafine plastics, they can pass through the primary tissue barrier in the body and penetrate the capillary blood vessel through the blood stream, which can be dispersed throughout the body. In addition, ultrafine plastics have hydrophobic properties that do not dissolve in water and can be dispersed, resulting in various properties.

Microplastics are so small that they are almost impossible to recover once they are released into the ecosystem. As a result, countries around the world are strengthening related laws on primary microplastics. For example, the EU is taking various measures to recycle plastics, develop biodegradable plastics, distinguish harmful substances in plastics, and prevent marine waste generation.

Research and development is needed to thoroughly identify and analyze the potential impact of microplastics on the environment, the distribution of waste plastics in the ocean, and chemical composition. In the future, in-depth research on the pollution status and hazards of marine microplastics, as well as the correlation between exposure to microplastics and diseases in humans, should be conducted; and based on these findings, human health should be protected by preventing and managing microplastics.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science and ICT and Ministry of Education) and (No.2019M3E7A111308322) and Korea Environment Industry & Technology Institute (KEITI) through Core Technology Development Project for Environmental Diseases Prevention and Management, funded by Korea Ministry of Environment (MOE) (grant No. 2022003310011).

AUTHOR CONTRIBUTIONS

Conceptualization: Changsoo Kim. Funding acquisition: Changsoo Kim and Jaelim Cho. Investigation: Yongjin Lee, Jaelim Cho, and Jungwoo Sohn. Methodology: Yongjin Lee and Changsoo Kim. Supervision: Changsoo Kim. Writing—original draft: Yongjin Lee, Jaelim Cho, and Jungwoo Sohn. Writing—review & editing: Yongjin Lee and Changsoo Kim Approval of final manuscript: all authors.

ORCID iDs

Yongjin Lee	https://orcid.org/0000-0002-2868-2221
Jaelim Cho	https://orcid.org/0000-0002-4524-0310
Jungwoo Sohn	https://orcid.org/0000-0002-5084-8670
Changsoo Kim	https://orcid.org/0000-0002-5940-5649

REFERENCES

1. IUCN. IUCN 2017: international union for conservation of nature annual report 2017 [accessed on 2023 February 20]. Available at: https://portals.iucn.org/library/node/47536.
2. Lei L, Wu S, Lu S, Liu M, Song Y, Fu Z, et al. Microplastic particles cause intestinal damage and other adverse effects in zebrafish Danio rerio and nematode Caenorhabditis elegans. Sci Total Environ 2018;619-620:1-8.
3. Food and Agriculture Organization. Microplastics in food commodities. A food safety review on human exposure through dietary sources [accessed on 2023 February 20]. Available at: https://www.fao.org/documents/card/en/c/cc2392en.
4. Lee J, Hong S, Song YK, Hong SH, Jang YC, Jang M, et al. Relationships among the abundances of plastic debris in different size classes on beaches in South Korea. Mar Pollut Bull 2013;77:349-54.
5. Seoul Institute of Health and Environment. Microplastics detected in the air [Internet] [accessed on 2022 May 10]. Available at: https://

news.seoul.go.kr/welfare/archives/533438.
6. Kwon OY, Kang JH, Shim WJ, Hong S. Distribution characteristics of floating microplastics in the Eastern Coast of the South Sea in Korea [Internet] [accessed on 2023 February 20]. Available at: https://sciwatch.kiost.ac.kr/handle/2020.kiost/25159.
7. Ministry of Food and Drug Safety. Microplastics in domestic distributed food. [accessed on 2023 February 20]. Available at: https://www.mfds.go.kr/brd/m_99/view.do?seq=46221&srchFr=&srchTo=&srchWord=&srchTp=&itm_seq_1=0&itm_seq_2=0&multi_itm_seq=0&company_cd=&company_nm=&page=1.
8. Cho Y, Shim WJ, Jang M, Han GM, Hong SH. Abundance and characteristics of microplastics in market bivalves from South Korea. Environ Pollut 2019;245:1107-16.
9. Choi YR, Kim YN, Yoon JH, Dickinson N, Kim KH. Plastic contamination of forest, urban, and agricultural soils: a case study of Yeoju city in the Republic of Korea. J Soils Sediments 2021;21:1962-73.
10. Enyoh CE, Shafea L, Verla AW, Verla EN, Qingyue W, Chowdhury T, et al. Microplastics exposure routes and toxicity studies to ecosystems: an overview. Environ Anal Health Toxicol 2020;35:e2020004.
11. Fadare OO, Wan B, Guo LH, Zhao L. Microplastics from consumer plastic food containers: are we consuming it? Chemosphere 2020;253:126787.
12. Prata JC. Airborne microplastics: consequences to human health? Environ Pollut 2018;234:115-26.
13. Choi JS, Hong SH, Park JW. Evaluation of microplastic toxicity in accordance with different sizes and exposure times in the marine copepod Tigriopus japonicus. Mar Environ Res 2020;153:104838.
14. Bouwmeester H, Hollman PC, Peters RJ. Potential health impact of environmentally released micro- and nanoplastics in the human food production chain: experiences from nanotoxicology. Environ Sci Technol 2015;49:8932-47.
15. Jin Y, Lu L, Tu W, Luo T, Fu Z. Impacts of polystyrene microplastic on the gut barrier, microbiota and metabolism of mice. Sci Total Environ 2019;649:308-17.
16. Abbasi S, Moore F, Keshavarzi B. PET-microplastics as a vector for polycyclic aromatic hydrocarbons in a simulated plant rhizosphere zone. Environ Technol Innov 2021;21:101370.
17. Wright SL, Kelly FJ. Plastic and human health: a micro issue? Environ Sci Technol 2017;51:6634-47.
18. Lin S, Zhang H, Wang C, Su XL, Song Y, Wu P, et al. Metabolomics reveal nanoplastic-induced mitochondrial damage in human liver and lung cells. Environ Sci Technol 2022;56:12483-93.
19. Dong CD, Chen CW, Chen YC, Chen HH, Lee JS, Lin CH. Polystyrene microplastic particles: in vitro pulmonary toxicity assessment. J Hazard Mater 2020;385:121575.
20. Vandenberg LN, Luthi D, Quinerly DA. Plastic bodies in a plastic world: multi-disciplinary approaches to study endocrine disrupting chemicals. J Clean Prod 2017;140:373-85.
21. Campanale C, Massarelli C, Savino I, Locaputo V, Uricchio VF. A detailed review study on potential effects of microplastics and additives of concern on human health. Int J Environ Res Public Health 2020;17:1212.
22. Ragusa A, Svelato A, Santacroce C, Catalano P, Notarstefano V, Carnevali O, et al. Plasticenta: first evidence of microplastics in human placenta. Environ Int 2021;146:106274.
23. Détrée C, Gallardo-Escárate C. Single and repetitive microplastics exposures induce immune system modulation and homeostasis alteration in the edible mussel Mytilus galloprovincialis. Fish Shellfish Immunol 2018;83:52-60.
24. Chiu HW, Xia T, Lee YH, Chen CW, Tsai JC, Wang YJ. Cationic polystyrene nanospheres induce autophagic cell death through the induction of endoplasmic reticulum stress. Nanoscale 2015;7:736-46.
25. Forte M, Iachetta G, Tussellino M, Carotenuto R, Prisco M, De Falco M, et al. Polystyrene nanoparticles internalization in human gastric adenocarcinoma cells. Toxicol In Vitro 2016;31:126-36.
26. Schirinzi GF, Pérez-Pomeda I, Sanchís J, Rossini C, Farré M, Barceló D. Cytotoxic effects of commonly used nanomaterials and microplastics on cerebral and epithelial human cells. Environ Res 2017;159:579-87.
27. Zhang Y, Wang S, Olga V, Xue Y, Lv S, Diao X, et al. The potential effects of microplastic pollution on human digestive tract cells. Chemosphere 2022;291(Pt 1):132714.
28. Deng Y, Zhang Y, Lemos B, Ren H. Tissue accumulation of microplastics in mice and biomarker responses suggest widespread health risks of exposure. Sci Rep 2017;7:46687.
29. Lu K, Qiao R, An H, Zhang Y. Influence of microplastics on the accumulation and chronic toxic effects of cadmium in zebrafish (Danio rerio). Chemosphere 2018;202:514-20.
30. Choi YJ, Park JW, Lim Y, Seo S, Hwang DY. In vivo impact assessment of orally administered polystyrene nanoplastics: biodistribution, toxicity, and inflammatory response in mice. Nanotoxicology 2021;15:1180-98.
31. Liu S, Wang Z, Xiang Q, Wu B, Lv W, Xu S. A comparative study in healthy and diabetic mice followed the exposure of polystyrene microplastics: differential lipid metabolism and inflammation reaction. Ecotoxicol Environ Saf 2022;244:114031.
32. Shan S, Zhang Y, Zhao H, Zeng T, Zhao X. Polystyrene nanoplastics penetrate across the blood-brain barrier and induce activation of microglia in the brain of mice. Chemosphere 2022;298:134261.
33. Estrela FN, Guimarães ATB, Araújo APDC, Silva FG, Luz TMD, Silva AM, et al. Toxicity of polystyrene nanoplastics and zinc oxide to mice. Chemosphere 2021;271:129476.
34. Liu X, Zhao Y, Dou J, Hou Q, Cheng J, Jiang X. Bioeffects of inhaled nanoplastics on neurons and alteration of animal behaviors through deposition in the brain. Nano Lett 2022;22:1091-9.
35. Ministry of Environment Korea. Press release: microplastic announcement of the results of the survey on microplastics in tap water [accessed on 2023 February 10]. Available at: http://www.me.go.kr/home/web/board/read.do?menuId=286&boardMasterId=1&boardCategoryId=39&boardId=826090.