Cognitive Vitality Reports® are reports written by neuroscientists at the Alzheimer's Drug Discovery Foundation (ADDF). These scientific reports include analysis of drugs, drugs-in-development, drug targets, supplements, nutraceuticals, food/drink, non-pharmacologic interventions, and risk factors. Neuroscientists evaluate the potential benefit (or harm) for brain health, as well as for age-related health concerns that can affect brain health (e.g., cardiovascular diseases, cancers, diabetes/metabolic syndrome). In addition, these reports include evaluation of safety data, from clinical trials if available, and from preclinical models.

Plastics

Evidence Summary

Plastic particles can accumulate in human tissues, where they may induce an inflammatory response that exacerbates other pathologies. The plastic associated chemicals likely pose the greatest safety risk.

Brain health risk: Plastic particles may enter the brain, provoking oxidative stress, leading to metabolic dysfunction and an inflammatory response that exacerbates pathophysiological processes driving neurodegenerative disease.

Aging and related health risk: Plastic particles may disrupt the intestinal microbiome, resulting in systemic inflammation and metabolic dysfunction. They can also carry carcinogenic compounds into the body which accumulate in tissues.

Safety: The risks vary with plastic composition, size of the particles, and exposure level. Young children and those with compromised barriers may be at higher risk. The long-term effects of chronic exposure are largely unknown.

What is it?

Plastics are made of polymers, generally organic (i.e. carbon-based) polymers, which can be shaped or molded into a wide variety of forms [1]. They are conventionally made from fossil fuel-based chemicals, such as petroleum, but can also be made from biological-derived sources, including carbohydrate-rich plants, such as corn and potatoes. The latter form is called bioplastic, and unlike conventional plastics, many of these are biodegradable, usually under industrial conditions. Plastic tends to shed particles into the environment. Microplastics are smaller than 5 mm in size, while nanoplastics are less than 1 µm in size. These plastic particles have become a ubiquitous feature of the environment, reaching all areas of the globe, and have been detected in the bodies of humans and animals. Recent efforts have begun examining the potential health consequences of the exposure to these plastic particles.

Brain health risk: Plastic particles may enter the brain, provoking oxidative stress, leading to metabolic dysfunction and an inflammatory response that exacerbates pathophysiological processes driving neurodegenerative disease.

Types of evidence:

- 1 real world study in wild fish
- Numerous laboratory studies

Human research to suggest negative impacts to dementia incidence, or worsened cognitive function:

The impact of plastic exposure on human brain health and cognition has not yet been characterized. Preclinical animal studies suggest that plastic exposure may have the most profound impacts on brain function during the period of neurodevelopment ranging from embryonic development to early childhood [2; 3]. This could also be relevant for human brain development, since microplastics have been detected in appreciable quantities in the human placenta, breast milk, and infant formula, as well as in meconium and infant feces, suggestive of maternal-fetal transfer [4].

Human research to suggest harm to patients with dementia:

The ability of plastics to contribute to disease progression in the context of dementia has not yet been established. However, many of the mechanisms associated with the neurotoxicity of plastics in preclinical models have also been associated with the exacerbation of cognitive decline, such as

oxidative stress, metabolic dysfunction, lysosomal dysfunction, and inflammation [5]. Additionally, amyloids can interact with plastic surfaces in the laboratory, and it has been hypothesized that plastic particles in the brain could facilitate amyloid aggregation [6].

Mechanisms of action for neurotoxicity identified from laboratory and clinical research:

Brain uptake of plastic: Plastic particles have been detected in the brains of plastic-exposed animals, though there is currently no direct evidence that plastic particles can enter the human brain [7]. The degree of brain uptake varies in relation to particle size, such that smaller particles (i.e. nanoparticles) can more readily enter the brain. Orally administered plastic particles can enter the blood and brain of rodents [7; 8; 9; 10]. While the levels of polystyrene reaching the brain are much lower than in the intestine, liver, and kidney in response to oral exposure, the levels of potentially toxic chemicals carried by those plastic particles can accumulate to a high level in the brain, due to slow elimination [10]. For example, the phthalate DHEP and its associated metabolite MHEP were found at the highest levels in the brain, following oral exposure to DHEP and polystyrene beads in mice, despite lower uptake of the polystyrene particles into the brain compared to other organ systems [10]. The presence of polystyrene also enhanced the uptake of arsenic into the brain of zebrafish, leading to worse mitochondrial and structural damage, relative to arsenic alone [11]. These studies highlight that the transport of toxic chemicals or pathogens to the brain via nanosized plastic particles may be more of a concern than the presence of the plastic itself. While most laboratory studies use naked virgin plastic beads, typically polystyrene, most environmental exposure will come from fragmented, irregular, mixed composition plastic particles containing a variety of chemicals as well as a host of other environmental substances, such as bacterial biofilms and pollutants [12]. Within the body, the plastic particles can also interact with biomolecules, such as lipids and proteins, forming a corona [8]. The composition of the surrounding biomolecular corona can impact the behavior of the plastic particles within the body, such as their ability to cross or interact with cell membranes. Cholesterol coating can enhance the uptake of the plastic particles into the membrane of the BBB, where they can get lodged in the lipid bilayer and potentially get stuck inside neural tissue [8]. In contrast, the transport of protein-coated plastic particles across the BBB is thermodynamically unfavorable. The surface charge of the plastic particles can also impact neuronal uptake. NH2-modifed polystyrene was found to have enhanced cellular uptake, leading to a higher neuronal load relative to COOH-modified polystyrene [13]. In addition to oral ingestion, nanoplastic particles have also been shown to reach the brains of mice following intranasal inhalation [13; 14]. The majority of nanoplastic particles are likely to be removed from neurons via clearance mechanisms, such as retrograde transport and exocytosis, but the remaining plastic particles can trigger

oxidative stress and a chronic inflammatory response [14]. Brain uptake of plastic has also been seen in fish within the natural environment. A study examining wild fish from an estuary of the Douro River off the coast of Portugal found that 5% of the fish (9/180) contained plastic in their brains [15]. Notably, all of the affected fish were collected during summer, which may be related to increased plastic contamination during the boating season in that region.

Neurotransmitter disruption: Once inside the brain, various preclinical studies suggest that plastic particles can interfere with neurotransmission. A meta-analysis of 35 studies examining the neurotoxic effects of microplastic at environmentally realistic concentration levels for aquatic animals (≤1 mg/L; median = 0.100 mg/L) found a significant effect on levels of acetylcholine esterase (Effect size = −0.1769, 95% CI −0.2235 to −0.1305; $p < 0.05$) [16]. Effects on levels of GABA and dopamine were also seen, but these neurotransmitter systems were only examined in a small subset of studies [3; 16]. Although not seen across all species or studies, the impact on the cholinergic system has been the most consistent finding regarding the impact of microplastic exposure on aquatic organisms [5]. In mice, acetylcholine levels were found to be reduced in response to neuronal uptake of plastic particles, along with the inhibition of the CREB/BDNF pathway, resulting in learning and memory deficits [7; 17].

Oxidative stress: Mitochondrial damage appears to be a key mechanism by which plastic particles exert cellular toxicity [18]. Brain levels of reactive oxygen species (ROS) were increased while levels of the endogenous antioxidant glutathione were decreased in mice exposed to polystyrene microplastics. Exposure to 0.25–250 mg/kg body weight polystyrene nanoplastics (50 nm) induced a Parkinson's like neurodegenerative state and motor impairments in male mice stemming from an energy metabolism disorder in the substantia nigra and striatum [19]. These nanoplastic-exposed mice showed altered mitochondrial function, leading to deficits in ATP metabolism. Elevated markers of oxidative stress have also been seen in aquatic animals exposed to environmentally realistic concentrations of plastic particles [16].

Disruption of gut-brain axis: Oral exposure is the primary method by which plastic particles enter the body [20]. As a result, the intestine is subjected to some of the highest loads of plastic particles, which can lead to a disruption of the gut microbiota [10; 21]. Changes in the composition and functionality of the microbiome can alter the profile of secreted microbe-derived metabolites. Via the gut-brain axis, these metabolites can influence brain function and behavior [22]. Ingestion of polystyrene microplastics and nanoplastics was found to shift the composition of the gut microbiome in mice towards less beneficial commensals and more pathogenic bacteria, which was coupled with a shift in the biosynthesis

of secondary bile acids and metabolites, including altered neurotransmitter metabolites [23]. The plastic particle exposure also reduced intestinal mucus secretion and increased the permeability of the intestinal barrier, leading to greater systemic exposure of these microbe-derived metabolites [23]. These metabolite changes were then associated with altered transcriptional patterns of rhythmically expressed genes, leading to a disruption in circadian rhythms [7]. The profile of gut metabolites was found to alter the profile of neurotransmitters and metabolites in certain brain regions, such as the amygdala, which may underlie the observed increase in anxiety-like behaviors in the plastic-exposed mice [22]. Plastic particle exposure can also induce an immune response within the gut, which then drives a systemic inflammatory response [22]. A study testing the effect of 10 mg/kg microplastics and nanoplastics, which approximates the estimated dose of plastic particles ingested by humans on a daily basis, for up to two months, found the presence of the plastic particles led to the activation of IL-1 producing intestinal macrophages, and that the released IL-1 impacted brain immunity and cognition [24]. Nanoplastics (i.e. smaller particles) were more effectively taken up by the macrophages, but incompletely broken down within the cells, thereby inducing lysosomal dysfunction. Within the brain, IL-1 promoted the activation of microglia and the differentiation of Th17 T cells, and cognitive impairment, which could be mitigated through the use of an IL-1r antagonist or NLRP3 inhibitor.

APOE4 interactions: Not established.

Aging and related health risk: Plastic particles may disrupt the intestinal microbiome, resulting in systemic inflammation and metabolic dysfunction. They can also carry carcinogenic compounds into the body which accumulate in tissues.

Types of evidence:

- Report of the Minderoo-Monaco Commission on Plastics and Human Health
- Several observational studies detecting plastic particles in human fluids/tissues
- Numerous laboratory studies

Metabolic syndrome: PLASTICS MAY DAMAGE MITOCHONDRIA AND IMPAIR METABOLISM
Microplastics/nanoplastics have been characterized as 'obesogens' due to their capacity to harbor endocrine disrupting chemicals, and to negatively impact glucose and lipid metabolism [25]. Following uptake of plastic particles by intestinal cells and into the blood, plastic particles preferentially accumulate in the liver, where they can impact metabolic processes [26]. Due to the gut-liver axis, plastic accumulation in the intestine and liver can have bidirectional effects. Bile acids produced in the

liver can regulate the function and composition of the microbiome, whereas secondary bile acids and metabolites produced by the microbiota can induce inflammation and impact liver function [25]. As a result, the accumulation of plastic particles in both of these organ systems can act as a feedforward system in the exacerbation of metabolic dysfunction. In response to plastic particle-driven mitochondrial damage and oxidative stress, hepatic lipid metabolism is altered, leading to an increase in lipid synthesis coupled with an accumulation of triglycerides and lipid droplets within the liver, due to impaired lipid utilization [26]. Chronic inflammation can lead to insulin resistance, such that there is a metabolic shift leading to reduced glucose metabolism. Oxidative stress-driven lipid accumulation and inflammation-driven fibrosis stemming from plastic particle exposure may accelerate the development of non-alcoholic fatty liver disease (NAFLD) in the context of a high fat/sugar diet [25]. Mice on a high-fat diet exposed to polystyrene microplastic in their drinking water had more activated pro-inflammatory intestinal immune cells, an altered gut microbial taxa profile, an altered composition of microbial-derived metabolites, including short-chain fatty acids, and an accumulation of hepatic lipids [27]. They also upregulated intestinal expression of the sodium-glucose cotransporter, leading to increased glucose absorption and reduced glucose tolerance. These effects were most prominent in the context of both the plastic and high-fat diet, which is consistent with the multi-hit hypothesis of metabolic dysfunction [25]. Adipose tissue has also been observed as a site of nanoplastic accumulation in mice, due to its lipophilicity [9]. Within the adipose tissue, plastic particles may also disrupt energy metabolism, and serve as a reservoir of plastic-associated toxic chemicals. Sulfate-modified polystyrene nanoplastic was shown to stimulate the accumulation of lipid droplets in cultured human macrophages driven by oxidative stress and lysosomal dysfunction [28]. The combination of oxidative stress and lipid accumulation induced the transformation of the macrophages into foam cells, potentially resulting in fatty plaque deposits in vessels and organs. The type of metabolic alterations may be influenced by the type of plastic. One study examined the impact of polystyrene or mixed plastic (polystyrene, polyethylene, and poly-lactic-co-glycolic acid) on the metabolome in mice, and found that the plastics significantly impacted pathways involved in amino acid biosynthesis and metabolism, although there were differences in the specific pathways affected [29].

Cancer: PLASTIC ASSOCIATED CHEMICALS MAY ACT AS CARCINOGENS

A direct association between cancer and plastic exposure has not been established in humans, but some chemicals found in plastics, such as plasticizers, have been associated with cancer risk [30]. Some of these, such as phthalates, have been shown to act as endocrine disruptors, which may preferentially affect reproductive cancers [31; 32]. Due to their ability to act as carriers, plastic particles may also lead to the accumulation of other carcinogenic environmental pollutants within the body [33].

Intestinal dysbiosis: PLASTICS MAY NEGATIVELY IMPACT GUT MICROBIOME
Microplastic particles have been found in the stool of healthy adults [20]. Based on the plastic profiles, the plastic packaging of food and water were considered the major sources of microplastic exposure. Compared to healthy adults, a higher concentration of microplastic particles (~1.5X) was found in the stool of patients with inflammatory bowel disease [34]. It is unclear whether a higher intestinal microplastic load contributes to increased intestinal inflammation, or if intestinal inflammation promotes the accumulation of plastic particles, or it's a combination of both. Microplastics were also detected in colon tissue from patients with colorectal cancer [35]. The ingestion of plastic particles has also been shown to induce alterations in the composition and function of the gut microbiome in preclinical models, which is associated with intestinal inflammation, reduced intestinal mucus production, and decreased intestinal barrier integrity [23]. A study examining the stimulation of polyethylene terephthalate (PET) particles through the human digestive system found that the presence of the plastic particles altered the composition of microbes in a colonic fermentation model that was inoculated with fecal samples from healthy human volunteers, leading to a reduction in taxa associated with protective properties and an increase in taxa associated with pathogenic properties [36]. A similar shift in microbiome composition was seen in cultures derived from human fecal samples incubated with polyethylene microplastic particles [37].

Safety: The risks vary with plastic composition, size of the particles, and exposure level. Young children and those with compromised barriers may be at higher risk. The long-term effects of chronic exposure are largely unknown.

Types of evidence:

- Report of the Minderoo-Monaco Commission on Plastics and Human Health
- Several observational studies detecting plastic particles in human fluids/tissues
- Numerous laboratory studies

Plastic particle composition: RISKS ASSOCIATED WITH DIFFERENT TYPES OF PLASTICS REMAIN UNCLEAR
The vast majority of laboratory studies examining the health effects of microplastics and nanoplastics on animal health use commercial spherical polystyrene beads [20]. However, studies assessing the plastics found in human tissues and biofluids have detected a variety of plastic types. In general, humans appear to have more exposure to polypropylene (PP) and polyethylene (PE), relative to polystyrene (PS) [4]. Other commonly detected plastics include polyvinylchloride (PVC), polyurethane (PU), polyethylene vinyl acetate (PVA), polyethylene terephthalate (PET), and polyamide (PA). The abundance of the

different plastic types varies across studies depending on the tissue/fluid type and the population, which may be related to differential exposure across individuals depending on environmental and lifestyle factors, as well as different propensities of different types of plastics to accumulate within a given tissue/fluid depending on chemo-physiological interactions. Environmental microplastic exposure occurs largely through the weathering of larger plastic objects due to thermal and mechanical forces, resulting in particles with irregular shapes and sizes [1]. Weathering, such as UV exposure, has been shown to alter the composition of the hydrocarbon bonds in the plastic and induce photochemical oxidation [12]. These weathered plastic particles were found to induce a stronger pro-inflammatory response in mice [12]. The weathering process increases the propensity of these plastic particles to interact with environmental molecules, such as pollutants and pathogens, as well as physiological biomolecules such as serum proteins, which can influence their ability to interact with and be taken up by cells in the body [1; 12]. Microplastics detected in the human digestive tract were found to be primarily of fiber or filamentous shape [35]. These studies suggest that humans are generally exposed to irregularly shaped, weathered plastic particles in a range of sizes from a mix of different plastic compositions, carrying a variety of different chemicals or biological molecules. As a result, the laboratory studies using naked, single-origin, virgin plastic beads may not be representative of the impact of real-world plastic exposure [20]. The use of extremely high doses may overestimate some risks, however, the use of potentially less immunogenic plastic particles may underestimate other risks, such that the true impacts to human health remain unclear.

Chemicals: PLASTIC PARTICLES CARRY TOXIC CHEMICALS INTO THE BODY

As foreign objects, the plastic particles themselves can elicit immune responses and structural damage, however, the toxicological risks associated with plastic exposure stem primarily from their ability to transport toxic chemicals into the body [1]. The transformation of plastic polymers into a wide variety of objects with different properties and functionalities requires the use of thousands of chemicals, such as solvents, plasticizers, and stabilizers, many of which are toxic to humans and animals. Some of the most widely studied include chemicals that can act as endocrine disruptors, such as phthalates and bisphenol A. However, the safety profile for many of these chemicals is unclear. This is problematic because some of the chemical replacements for established endocrine disrupting compounds also have deleterious properties, which only come to light after evidence of harm following widespread use. As a result, claims that a plastic object does not contain an established toxic compound, such as bisphenol A, does not mean that it does not contain other compounds with as yet unknown toxic properties. Moreover, the exposure risk to these chemicals from everyday plastic products is also unclear. When bound up within an intact plastic object, these chemicals are largely sequestered and do not pose a risk, however, when

the plastic starts breaking down and shedding particles, it begins leaching these chemicals into the environment. The chemical additives do not form strong chemical bonds with the plastic polymers, and thus can readily leach from the plastics over time [1]. Additionally, recycled plastics tend to leach out higher quantities of chemicals relative to virgin plastic [1]. Within the body, these plastic particles can serve as vectors to transport the chemicals, which can then accumulate in tissues. Due to the hydrophobic nature of plastic, the particles and associated chemicals tend to bioaccumulate in lipid-rich tissues, such as adipose tissue, reproductive tissue, and the brain [9].

Bioplastics: NOT NECESSARILY BETTER FOR HEALTH THAN CONVENTIONAL PLASTICS

Plastic products derived from renewable carbon-based sources, such as plants, have emerged in recent years in response to environmental concerns regarding fossil fuel-based plastics. Many of these bioplastics are also touted as being biodegradable. However, the potential environmental benefits of bioplastics appear to have been overestimated, as they pose their own health risks to ecosystems [38]. The starting polymer material for bioplastics, often in the form of starches, tend to have worse thermal and mechanical properties relative to conventional plastic polymers, and thus require a higher degree of processing with chemical additives to reach the desired properties [38]. As a result, the chemical footprint of bioplastics tends to be higher. Thus, even though the raw materials for bioplastics tend to be non-toxic, the final products can be as toxic or even more toxic than conventional plastic products [39]. A study assessing the *in vitro* toxicology profiles of a wide variety of bioplastics from 43 consumer products found that the chemical footprint and toxicology profiles varied widely across the products, in some cases in relation to the same bioplastic, depending on the properties of the final product [39]. Endocrine disrupting chemicals were most commonly found in poly(butylene adipate) (PBA) and Bio-PE9-containing products, with Bio-PE9 containing the highest levels of anti-androgenic compounds. Starch and cellulose-based products tended to have the highest overall toxicity profiles, due to the high numbers of chemicals needed to transform these biopolymers into plastics with desirable properties. In this sampling, there were products that had minimal or no toxic effects on *in vitro* assays, including bamboo-based products, and products from several forms of Bio-PE (bio-polyethylene). Polylactic acid (PLA), is one of the most commonly used bioplastics [38]. In mice, polylactic acid oligomers and their nanoparticles were found to bioaccumulate in the liver, intestine and brain [40]. The PLA was hydrolyzed by stomach and intestinal lipases, resulting in acute intestinal damage and inflammation.

Another concern with bioplastics is their so-called biodegradability. Many of these bioplastics only fully break down under the conditions of extremely high heat and humidity found in industrial composting facilities [36]. As a result, most of the bioplastics in the environment will not fully degrade, but rather will fragment and accumulate in ecosystems, like conventional plastic. An additional concern is that

bioplastics in compost that is not fully broken down may continue to leach chemicals into the compost, which is then used on crops, and can work its way through the food supply.

Plastic particle size: SMALLER PARTICLES CAN MORE EASILY GET INTO THE BODY
There is generally a consensus across studies that smaller plastic particles have a higher capacity to traverse barriers, enter into cells, and accumulate within bodily tissues [20]. However, harmful effects have been seen in studies using a wide size range of microplastics and nanoplastics, as larger particles can induce structural damage and some small particles may have increased propensity to aggregate with themselves or other substances in the body, which may alter their physiochemical properties [5]. The exposure level and associated risks of very small nanoplastic particles have not yet been established due to technical detection limit reasons, thus human exposure studies have largely been restricted to the detection of microplastics [20].

Temperature: HIGH TEMPERATURES INCREASE PLASTIC SHEDDING
Chemical, thermal, and mechanical stresses can all promote the weathering of plastic [1]. As a result, conditions that promote weathering can induce the generation of plastic particles, and may weaken chemical bonds, thereby accelerating the leaching of chemical additives. In marine animals, signs of neurotoxicity stemming from plastic exposure become more apparent in warmer water [5]. A study examining the plastic exposure risks associated with plastic (polypropylene and polyethylene) baby food containers and reusable food pouches found that the release of plastic depended on the storage and usage conditions [41]. High temperature storage and use, such as microwaving food or water in the containers resulted in the highest rates of plastic particle shedding.

Sources and dosing of exposure:

Studies estimate that the average American consumes ~74,000 to 121,000 plastic particles per year, or about 5 grams of plastic per week [42; 43]. The major sources of plastic particle exposure are through the ingestion of plastic-contaminated food and water, as well as the inhalation of plastic particle-containing dust (9.80 particles/m^3), usually in the form of microfibers [44]. Plastic contamination has been detected in a variety of foods, including sugar (0.44 particles/g), honey (0.10 particles/g), salt (0.11 particles/g), and alcohol (32.27 particles/L) [44]. Seafood is one of the most plastic contaminated food sources. It is estimated that an individual may consume over 53,000 microplastic particles per year from the consumption of seafood alone [45]. Dermal exposure is another common route of exposure, particularly through cleansing and beauty products [4]. A recent report suggests that contact lenses

serve as a source of microplastic exposure, with lenses worn up to 10 hours per day shedding around 90,000 microplastic particles over the course of a year [46].

Mitigation strategies:

Water filtration devices

Plastic particles are ubiquitous in the environment, including in water systems. Although it can be mitigated through filtering that takes place in water processing facilities, the majority of water used by humans will contain microplastic and nanoplastic particles [1]. While many people turn to bottled water to avoid contaminants that can be found in tap water in some areas, the shedding of plastic particles can leach chemicals into the water. Home filtration devices (point of entry filters), such as a reverse osmosis filtration system (pore size as small as 0.0001 microns) can be installed to filter out plastic and other contaminants. The smaller the filter pore size, the greater the capacity to remove microplastic particles. A more accessible option includes point of use filtration devices, typically in the form of water pitchers or countertop filtration devices. Unfortunately, the current rating system for water filtration devices is designed for chemicals, and does not include plastics. Currently, the highest level of particle filtration, the NSF-52 certification is class 5, meaning it removes particles >30-50 µm [47]. As a result, these devices still allow for the passage of nanoparticles. A study compared the plastic filtered effects of three different types of point of use water filtration products [47]. The first device used granular activated carbon and ion exchange, the second device used granular activated carbon, ion exchange, and non-woven membranes, while the third device used microfiltration, granular activated carbon, and ion exchange. Both of the latter two devices performed well, though the third device was the best, likely due to the smaller membrane pore size (0.2 µm vs. ≥ 1 µm). Fibers may be the most common source of microplastic in drinking water, and all three devices showed superior capacity in removing nylon fibers relative to PVC and PET fragments.

Store and cook food using non-plastic materials

Food can serve as a major source of plastic particle exposure [4]. Heating plastic accelerates its shedding of particles [1], thus food and beverages should not be heated in plastic containers; it is better to use metal, glass, ceramic, or food-grade silicone containers for cooking and heating, depending on the method (i.e. stove vs. microwave). Additionally, plastic particles may be transferred to food via the use of plastic cutting boards, cooking utensils, and cutlery. Transferring hot food into plastic containers for storage can also promote transfer, thus it is best to use glass, ceramic, or food-grade silicone for storage. If using plastic storage containers, both the food and the container should be cold or room

temperature and not used for long-term storage, as studies have found that even refrigeration and room temperature storage in plastic containers result in the shedding of millions to billions of plastic particles over a six-month period. Reusable beeswax wraps can be used in place of plastic cling wrap. Many brands of tea bags are made of plastic components, and can leach millions of plastic particles when submerged in hot water [48]. Alternatives include using loose tea with metal infusers or cloth reusable sachets. Additionally, some brands indicate that they do not use plastic in their tea bags. The shedding of plastic into beverages from plastic bottles increases with temperature, including when stored in hot locations such as in vehicles or outside in hot weather.

Natural fabrics

Clothing made from synthetic fabrics can serve as a major source of microfibers shed into the environment, which can then be inhaled as dust [1]. The use of natural fiber fabrics, such as cotton, wool, and linen can help reduce exposure. Machine washing and drying of clothing facilitates the shedding of microfibers. Air drying synthetic fabrics, such as fleece, can reduce the degree of microfiber shedding. Dryer lint is heavily enriched in microfibers, thus one should take caution when cleaning lint traps, such as wearing a protective face mask to avoid breathing in the microfiber dust.

Antioxidants

Mitochondrial damage and oxidative stress have been established as major mechanisms by which the intake of plastic particles can damage cells [18]. Several preclinical studies have found that the use of antioxidants, such as vitamin E, anthocyanin, or melatonin can mitigate the harmful effects of plastic exposure on cellular function [7; 17; 49].

Probiotics

Gut microbiome dysbiosis has been identified as one of the major mechanisms by which plastic consumption can exert harmful effects on the body, including systemic inflammation and metabolic dysregulation [49]. Preclinical studies have found evidence that the consumption of probiotics can help mitigate some of the deleterious systemic effects stemming from the ingestion of plastic particles by helping to restore populations of beneficial microbial species and mitigate disruptions to the microbiome ecosystem [7; 50].

Research underway:

There are efforts underway to develop plastics that are readily biodegradable under real-world conditions. One example includes embedding enzymes into bioplastics to facilitate their degradation [51]. This work has been spun off into the company Intropic Materials.

Search terms:

Pubmed, Google: Microplastics; Nanoplastics

- Alzheimer's disease, brain, cancer, toxicity, metabolism

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