The Detrimental Effects of Forever Chemicals

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Introduction

A normal day in the life may include making eggs for breakfast in the morning, filling up a water bottle from the sink, popping some popcorn before a movie, and if it is a rainy day, it is a good idea to to throw on that rain jacket. Many are entirely unaware of the fact that each of those activities involves an extremely harmful and toxic chemical, poly- and perfluoroalkyl substances, or PFAS. PFAS has posed a risk to human health because these chemicals are not decomposing, and in fact, are building up in the environment and in people.

Many everyday products contain PFAS. The nonstick pan used to make breakfast and that popcorn bag are lined with a nonstick substance that is resisting water. Those chemicals can seep into the food and then into the body where they will persist and build up. Depending on where one lives, it is possible for water sources to be contaminated. The U.S. Environmental Protection Agency (EPA) has set safety levels for PFAS in drinking water supplies, and with testing it was found that there are an estimated six million U.S. residents that have their drinking water supplies contaminated above the level set by the EPA (Stohler, 2021). Outside of food and water consumption that may be contaminated, PFAS are also in other water-resistant products such as rain jackets.

The problem with this is PFAS can leave the material in a dust form which then travels through the air contaminating it. PFAS are found in products that are marketed as water and stain resistant. Other PFAS-containing products include food wrappers and bags; mostly with fast food, stain-resistant materials such as carpets, and personal care items such as shampoo, shaving cream, dental floss, and cosmetics. While PFAS appear to be very convenient, the exposure to these chemicals is causing numerous health issues, including hormone disruption of thyroid hormone and estrogen, immune system harm, low infant birth weights, and several other

concerns to organ systems. The prominence of PFAS compounds in everyday products is harming humans and the environment. It is imperative that there is an attempt to fix this.

PFAS Effects on the Body

These artificial chemicals have an extremely strong bond, making them take thousands of years to break down and therefore having detrimental effects on the body. The effect on the body is seen through the chemicals compromising immunity, hormonal imbalances, fetal development, and fertility. PFAS can weaken the immune response, making people more susceptible to illnesses and less responsive to vaccines and disrupt hormone homeostasis, as well as cause pregnancy complications and reduce fertility.

While every system in the body serves an important purpose, the immune system is responsible for being the defense against outside invaders such as certain viruses and bacteria. Without good immunity, it would be extremely difficult, if not impossible, to recover from certain illnesses. We can look specifically at how PFAS affect the efficacy of vaccination compared to PFAS levels in the blood. Philippe Grandjean, an environmental epidemiologist of the University of Southern Denmark, conducted a study in 2008 about PFAS and PFOA[1] exposure at birth, through analyzing the mother's blood serum. He tracked the PFAS levels in about 600 children and was specifically looking at antibodies against tetanus and diphtheria. What is expected is that after one gets vaccinated, they have an adequate level of antibodies that will protect them from being infected. This was not the case in Grandjean's study. He found that an increased exposure of PFAS at birth was correlated to an approximate 40% drop in diphtheria antibody concentration at five years old (Beans, 2021). This is concerning because with a low

[1] PFAS is an umbrella term that includes numerous chemicals with slightly different chemical structures. Throughout the following studies PFOA and PFOS are examples of PFAS that will be used interchangeably with the term PFAS.

antibody response level, the immune system will have a decreased ability to respond to certain infections and diseases. This will the lead to greater hospitalizations for those who need treatment.

Another recent study had shown that increased prenatal PFAS exposure would affect children's probability of becoming infected with common communicable diseases. It was found that increased PFAS exposure was linked to higher rates of gastric flu by the age of seven (Beans, 2021). For younger children, around the age of three, increased exposure led to increased rates of bronchitis and pneumonia (Beans, 2021). The alterations in the immune system performance have a great effect on the economy. A decreased immune response will cause someone to be sicker for longer and will result in decreased workdays due to illness, school absences, and increased visits to the doctor.

An adequate immune response has recently shown its importance during the COVID-19 pandemic. Recent studies are looking to see how impaired immune systems from PFAS exposure is contributing to a more deadly pandemic. In another study by Grandjean, it was shown that there is a strong correlation between a more negative outcome of a COVID-19 infection and a form of PFAS called perfluorobutanoic acid (PFBA). This form of the PFAS molecule specifically builds up in the lungs, a bad sign when it comes to respiratory infections. In a group of 300+ samples, the existence of PFBA was connected to almost double the chance of one needing to be hospitalized from COVID-19 (Beans, 2021). This is a great concern because although PFBA will reside in the blood for less time due to it only being a four-carbon chain, compared to PFAS, an eight-carbon chain, this compound is still being used by several companies and contaminating food, soil, and water (Lerner, 2020). More data expresses that the accumulations of PFBA in the lungs has also shown its negative impact with the coronavirus

infection. In a study of 323 COVID-19 patients where 215 were hospitalized, more than half of the patients had high levels of PFBA in their blood plasma, while less than 20% who experience mild sickness has high levels of PFBA (Lerner, 2020). It is clear that in areas of high PFBA accumulation, hospitals are more likely to be overwhelmed with patients.

In order for the body to remain in a state of homeostasis, hormones are essential. Thyroid hormone is one in particular that regulates multiple systems in the body. Thyroid hormone is important for metabolism regulation, fertility, fetal neurodevelopment, and affects cardiovascular function (Kim et al., 2018). In a study on rats, treating them with PFAS caused hypertrophy or hyperplasia of thyroid follicular cells. That is enlargement of the cells. This enlargement could further stimulate thyroid dysfunction and thyroid disease. Disturbing the normal function of the thyroid can lead to hyperthyroidism or hypothyroidism. Hyperthyroidism will cause the body to go into overdrive, causing more energy being used leading to weight loss, anxiety, and increase heart rate (Kim et al., 2018). Whereas hypothyroidism or too little thyroid hormone will lead to lethargy, weight gain and cold intolerance (Kim et al., 2018).

Another area of concern that is negatively being affected by PFAS is the reproductive system. Exposure to PFAS chemicals have been shown to lower infant birth weight, harm the male reproduce system and induce hypertension in pregnant women (Amarelo, 2021). An issue with PFAS is that they are targeting the placenta which is vital for a fetus to get its nutrients and eliminate waste. PFAS exposure has shown to increase pregnancy duration, cause hypertensive disorders, preeclampsia, gestational diabetes, and low infant birth weight (Blake & Fenton, 2020). These negative pregnancy outcomes can all be contributed to placental insufficiency which harms the baby and the mother. PFAS passively pass from the maternal blood to the developing fetus. It is of great concern if what is acting as the liver, lungs, and kidneys of the

fetus is the target of PFAS toxicity. A study on mice has shown that there were placental changes after exposure to PFAS. Including decreased fetal and placental weight, placental lesions and tissue changes in the placenta including congestion and atrophy (Blake & Fenton, 2020). Exposure of PFAS to the placenta has also been shown to increase placental oxidative stress, leading then to preeclampsia, a condition where there is a sudden rise in blood pressure, which can lead to kidney and liver damage (Blake & Fenton, 2020). Preeclampsia can be fatal to the mother and baby and often the mother will have to be induced in order to avoid complications.

Gestational hypertension has developed in numerous women who are exposed to PFAS. At 13 weeks gestation, maternal arteries begin to remodel themselves to support the growing embryo. Disturbance in the placental vascularization can lead to impaired fetal growth and hypertensive disorders of pregnancy (Blake & Fenton, 2020). A study in mice has shown that PFAS toxicity of the placenta has led to an increased placental weight. In an 87,600 Canadian single birth study, fetuses born that had abnormally large placentas had the risk of seizures, respiratory morbidity, and low Apgar score, a test that shows how well a baby is doing shortly after birth. Another U.S. study of about 30,000 births has found that large placentas are associated with high blood pressure during childhood (Hemachandra et al., 2006). A Norwegian study shown that large placentas at birth has a correlation with increase cardiovascular disease, increasing one’s risk of death (Risnes et al., 2009).

PFAS exposure has been correlated with a low infant birth weight. This association has been supported in humans through numerous studies on increased exposure of PFAS on birth weight and placental insufficiency (Blake & Fenton, 2020). A recent study has used a stem cell differentiation model that mimics 3D human embryonic development in order to ethically find the effects of PFAS on early development in vitro. The model, human induced pluripotent stem

cells, are able to go through the early stages of embryonic development and eventually turn into beating cardiomyocytes. Cardiomyocytes are the cells in the heart responsible for generating the contractions that allow the heart to beat. After conducting the study, significant data was found that PFAS can disturb early organ development (Davidsen et al., 2021). To make the study the most accurate, the PFAS concentration levels were the same of those found in mothers and newborns that have a reduced birth weight. The results found that PFAS have disrupted cardiomyocyte differentiation (Davidsen et al., 2021). It was also revealed that PFAS in higher concentrations decreased embryo size and that GenX, a PFAS alternative, has also shown to disturb early embryonic development.

PFAS have shown their negative impact on human development through toxicity of the placenta. It is also important to look at the paternal side as well and if PFAS are influencing fertility. In order to determine this, a study was done on couples who used in vitro fertilization. Urine samples from men were provided to test for flame retardant metabolites that contain PFAS. This was then compared to the IVF outcomes. The organophosphate flame retardant exposure has increased greatly over the past few years due to it being used in upholstered furniture. The organophosphate flame retardants or PRFs are not chemically bonded to the foam in the furniture and are able to travel into the air and dust inside the house (Carignan et al., 2017). This dust can then be ingested. Through this study it was found that paternal urinary concentrations of bis(1-chloro-2-propyl) phosphate, a metabolite in flame retardant, was correlated with reduced fertilization (Carignan et al., 2017). Not only are there harmful pregnancy outcomes from PFAS but exposure is now affecting successful oocyte fertilization.

In another study, PFOA and PFOS were measured in maternal blood at week 30. The offspring of these women were then included in the study when they were around 19-21 years

old. Samples were taken to test for sperm concentration, total sperm count, motility, and morphology along with blood samples. What was found is that exposure in utero to PFOA was associated with lower sperm concentration and lower sperm count. Therefore, they found that exposure in utero also can affect male semen quality (Vested et al., 2013). It is very important for all organs to develop properly in utero and “forever chemicals” are beginning to show their impact on fertility. “The capacity for sperm production later in life is determined during sexual organ development in fetal life, whereas the morphology and motility of spermatozoa are determined during sperm production in adolescence and adulthood” (Vested et., 2013). This study continued to observe that the fetal male reproductive system is undoubtedly affected by the exposure of PFOA compounds.

How PFAS are Bioaccumulating

Understanding how PFAS compounds find their way into the environment is equally important as recognizing their effects on the body and is essential in finding ways to eliminate them. Being able to comprehend the risks of PFAS in the environment and what to look for is imperative. PFAS in the environment can be found and transported through soil, groundwater, water masses such as lakes and the air as well (ITRC, 2020). The Environmental Working Group had analyzed water supplies from around the nation and estimated that up to 110 million Americans could have their water contaminated with PFAS (EWG, 2018). This is an issue because uptake of PFAS can happen in plants, and plants are later consumed by humans and animals. Therefore, PFAS can bioaccumulate in the food chain. For example, increased amounts of PFAS in animals at the top of the food chain have been observed in animals such as polar bears and seals (ITRC, 2020). PFAS compounds have been detected in numerous water sources,

including tap water and bottled water and many levels of reported PFAS in water are also higher than what the Environmental Protection Agency deems as safe concentrations in the water.

To understand PFAS accumulation in the environment, it is important to look at how PFAS migrate. One way is through diffusion. This is a slow rate of migration where molecules will move in response to a concentration gradient. Diffusion happens with groundwater as it moves through soil and bedrock. Forever chemicals are finding their way into all parts of the environment. They have also shown their ability to diffuse into concrete. In a report from 2015, PFAS penetrated 12cm into a concrete pad at a fire training area through diffusion (ITRC, 2020). This shows that these chemicals will easily persist in the environment from many of the materials that contain PFAS.

Another mode of transportation for PFAS compounds is through the air. Specifically, aerosols are where particles are suspended and can travel as a solid or liquid droplet. Aerosols can come from a water surface contaminated with PFAS and transportation through aerosols is very concerning. After traveling through the air PFAS particles can naturally deposit onto surfaces through settling or diffusion. This presents a concerning method of PFAS transportation, now to aquatic and land environments. And after these materials settle, they can be absorbed into the ground (ITRC, 2020). It is also possible for these particles to settle indoors to on surfaces in one’s house, easily being breathed into the lungs. At any point, PFAS particles can be resuspended and redistributed somewhere else, making them hard to contain.

PFAS presence in the soil makes it easy for them to get into the human and other animals’ diets. Root systems will take the PFAS compounds which will then be dispersed through the stems, leaves and fruits of the plants. Plants that are specifically growing in highly contaminated soil or are irrigated with water contaminated with PFAS will eventually build up

high PFAS concentrations compared to a lowly contaminated area (ITRC, 2020). PFAS are presented to plants through soil, water, and air through emissions, biosolids put into land, and contaminated water irrigation. Biosolids fertilizer is often used in fields for farmers as it is cheap and good for growing crops. Unfortunately, this is often PFAS contaminated and eventually animals that are fed silage for these fields will have elevated PFAS in their tissues (ITRC, 2020). Contaminated feed and water will ultimately lead to accumulation of PFAS in beef products and then to humans. Wildlife will also consume plants from farming areas which will continue the accumulation of these compounds in animals.

Fish consumption is a part of many different diets. PFAS are bioaccumulating in fish as the water that they are in are contaminated, especially around areas with high population density. (Ssebugere et al., 2020). The issue of PFAS transferring from animal meats to humans now is evident and very concerning. Widespread exposure to plants and animals in leading to number unfavorable effects.

Another route of exposure is indoor dust. This is something that is encountered on a daily basis. Dust-containing PFAS compounds are easily inhaled in homes, vehicles and offices. A study was done in Boston, Massachusetts, that screened for nineteen different forever chemicals including PFOAs and PFOSs. Dust samples were collected from offices, homes, and vehicles of 31 people and their blood serum was collected as well. The highest concentration was found homes and vehicles (Fraser et al., 2013). Materials made to resist water and oil stains are now shedding harmful chemicals into the air for people to breathe in. Infants are especially at risk as they learn to crawl and are in close contact with carpets treated with PFAS. The increased uptake of the pollutant is from frequent hand-to-mouth contact as well (Ssebugere et al., 2020). Infants are known to be especially vulnerable to harmful chemicals. In California, it was found that there

is a two-fold risk for childhood leukemia from exposure of carpet dust (Ssebugere et al., 2020). Household contaminants also come from organochlorine pesticides, polychlorinated biphenyls or PCBs, often used to resist extreme temperature, and flame retardants.

Eliminating PFAS

With the prevalence of PFAS in the environment and the known harmful adverse effects of these compounds, it is important to look at ways to try to remove PFAS. There are many removal technologies that are still being developed, but there are some that are found to be working right now. For example, granular activated carbon (GAC), uses sorption where a hydrophobic "tail" absorbs to the carbon of PFAS to remove it from water systems (ITRC, 2020). Ion exchange resin works similar to sorption where it absorbs the hydrophobic "tail", and the "head" is ionized. These are very efficient as they work in 2-3 minutes to treat the water and requires a smaller footprint for the system. There is another method called reverse osmosis. This method requires a lot of energy but is efficient. The only problem with this method is that it removes other components in water that are beneficial to humans such as alkalinity which would have to then be added back to drinking water (ITRC, 2020). Often PFAS found in the environment can be found in foams that form on contaminated water. Foam fractionation can be used where air can be used to carry PFAS into a foam fraction to concentrate PFAS and are then removed from the foam (ITRC, 2020). This treatment has a limited application right now but does not require it to be fractioned multiple times, making it quick.

While it would be unreasonable and difficult to put a sudden ban on all PFAS containing materials, it is easy for it to be phased out in some products that contain it. For example, some dental floss is coated with PFAS for it to slip between teeth easily. However, there are many more brands on the market for consumers to switch to. While some products there are no

alternatives, for many there are. For workers that need to wear protective flame-resistant clothing for their jobs, there has not been found to be many useful alternatives. A professor of environmental science and analytical chemistry from Stockholm University, Ian Cousins, suggests using a phaseout plan by dividing PFAS into three different groups. That would be nonessential uses of PFAS that can easily be eliminated before they have no necessity for health or benefit society in any way, substitutable uses that would include products where there are non-PFAS alternatives or those alternatives can be easily available, and finally products where PFAS are essential and have no substitutes (Hogue, 2019). Along with the dental floss, other products that fit into this first category of nonessential PFAS include any finishes that are resistant to water, oil, and stains for clothes and carpets. Cousins also mentions that PFAS are not essential in waxes used for skis to help them move through snow, as PFAS from the wax has been found in soil, earthworms, and voles in a ski area (Hogue, 2019). Last, they are not essential in cosmetics and other personal care items. The second category includes items where there are current substitutes. That can include certain firefighting foams since there are now PFAS-free options available and waterproof jackets as well. The current issue is that some non-PFAS products are slightly more expensive. However, Cousins states “upon increased market uptake, the costs can be expected to decrease” (Hogue, 2019). Eventually, if non-PFAS alternatives were to become more popular, they would not be at a higher cost.

An issue that commonly comes up is that companies are opposing the idea that eradicating products that contain PFAS, saying that there is not a risk to people or the environment if their products are used properly (Hogue, 2019). Many products with PFAS are often bought by consumers because of the higher performance of the product. Cousins suggests that companies need to manufacture their products with molecules that are able to degrade after

their use, as it is the persistent chemicals that is causing harm (Hogue, 2019). If they are not eventually phased out, they will continue to build up in the environment, exposing current and future generations.

Recently the house had passed a bill requiring the EPA to regulate PFAS in drinking water this past July, the PFAS Action Act. It was introduced by Michigan representatives Debbie Dingell (D) and Fred Upton (R) (Udasin, 2021). They pushed for the EPA to regulate the most common forms of PFAS, PFOA, and PFOS and to consider these substances as hazardous. If the bill makes it all the way through, it will give the EPA five years to go through the thousands of PFAS and figure out which ones are hazardous and to give a review of their clean-up efforts. It would also limit industrial release of PFAS and dedicate a certain amount of money each year for treatment of wastewater (Udasin, 2021). While some Republicans oppose the act, saying that it is overwhelming and an “aggressive expansion of power”, others are showing their support for the bill, including President Biden (Udasin, 2021). While it may take a while for this to be approved, it is necessary for the future health of humans, animals, and the environment.

Ethical and Social Implications

It is vital to look at the ethics of chemical contamination when considering how to tackle the issue in the most suitable way. David Resnik, a bioethicist from the National Institutes of Health gave his opinion on this after a situation at Bradly International Airport. In 2019, a plane crashed at the airport and firefighting foam used has washed out of the airport into nearby communities leaving firefighting foam forming out of brooks. When asked if he sees a middle ground on PFAS firefighting foam he responded, “There is potentially a middle ground if we could agree that we should avoid PFAS most of time for things that are not so important for human health. We could still allow it to be used for firefighting where there are lives clearly at

risk" (Skahill, 2019). Cousins' ideas express that PFAS should only be considered when the lives of people are at stake. If their use is not necessary, then there is no point in continuing to use them. Finding a middle ground seems to be the best way to tackle this. For the Bradley airport situation, Resnik also mentioned the idea of something to keep the waste contained. He gives the example of how certain construction sites already have environmental protections like fencing to keep waste out of streams and a similar application could be used for PFAS. He urges us to find a way to contain the chemical if we are obligated to use it, in order to maintain environmental health (Skahill, 2019). Resnik also gives the example of BPA, where the effects of it are known and policy shifts have happened due to this enlightenment. While this chemical is only banned in baby bottles/products, the response of consumer demand has caused manufacturers to market BPA-free items. This example proves that through researchers identifying risks in certain products and through concerned citizens, companies will try to be environmentally friendly and cognizant to the public health. If consumers are to really demand change, then companies will respond. In fact, many use the internet or blog posts to spark change. The internet has allowed ethical discussion to be more common and for companies to be more willing to change their policies.

A big part of change is education. As of now, there are numerous studies and data being collected on PFAS and the harm that comes with using these products. A study was done in Australia about people's concerns with PFAS. Majority of the people reported that they are concerned about health and distrustful of government agencies because they are downplaying the dangers of PFAS. There was great concern by many regarding health adversities from exposure, including cancer clusters and inexplicable deaths (Banwell et al., 2021). It is hard for many to comprehend that the future health of their children is jeopardized from a chemical that could be

regulated. In the study in Australia, one participant stated, “This block of land has been my home, it’s where I brought up my kids, its everything to me and yet at the same time it’s a contaminated piece of land and you’re holding these two things in your hand, and the confusion of it, these two opposing truths, it drives you nuts” (Banwell et al., 2021). Living in these uncertain conditions is bringing more anxiety to families living in neighborhoods knowing the socio-economic impacts of these compounds in their communities (Banwell et al., 2021). However, the fact that these communities know about PFAS will motivate them to challenge it.

Due to the prevalence of PFAS in the environment, there are some health-related costs to society. Previously discussed examples included decreased fertility, pregnancy-induced hypertension, low infant birth weight, thyroid hormone issues, liver damage, and testicular and kidney cancer (Goldenman et al., 2019). People are exposed in their workplace depending on the work environment, such as the firefighters. Those who are living in communities contaminated with PFAS are affected as well. One can look health impact-related costs in Europe for example. Workers who have high exposure, for example at a chemical production plant are at risk for kidney cancer, and the annual cost for that would be about 12.7-41.4 million euros, or $14,731,809 to $48,023,379.00 U.S. dollars (Goldenman et al., 2019). Medium exposure would include populations with chemicals in their drinking water or those who live near chemical plants. This can cause low infant birth weights, hypertension, and infection mostly in children. The annual cost would be $47,559,385,000 to $56,839,265,000 and would result in about 3,300 low infant birth weights annually and for children an additional 1,500,000 days of fever a year (Goldenman et al., 2019). Looking at the overall costs of these chemical compounds is unfathomable and could be changed with societal push to get companies attention.

Beyond health, there are also environmental costs to society. These can include the cost of cleaning up PFAS chemicals in drinking water, monitoring PFAS levels, and upgrading treatments. Doing checks for contamination through water sampling would cost between $29,008 to $580,175 depending on how much contaminates are usually found in that area (Goldenman et al., 2019). Upgrading water treatment would cost about $350 and to excavate and treat contaminated soils would be an average of $324,898 for each kilogram of soil (Goldenman et al., 2019). Depending on the area and level of contaminations these numbers are subject to chance but provide an estimate on the costs of continuing to use PFAS in everyday products.

Conclusion

The persistence of PFAS compounds in products and the environment has proved to be detrimental to human health. In order for there to be change, there has to be a push from the people. To start, there needs to be research and education on what these compounds are and the effects of them. When people begin to understand the dangers of PFAS their concern will push them into action. As demonstrated with products containing BPA, it is plausible for there to be a change in products containing PFAS. There are some alternatives that are at a higher cost, but if we were to choose these over other PFAS-containing products, the price will eventually even out. PFAS are damaging the body, leading to issues such as infertility, low infant birth weight, and hormonal disruption. These concerns are proving to cause an unfavorable socioeconomic impact, including price of treatment and health related costs. The convenience of poly- and perfluoroalkyl substances does not outweigh the costs to human health and society and there must be change in order to stop the harmful consequences to humans and the environment. Everyone has the right to know what products or water sources are contaminated with PFAS and to recognize the alternatives available in order to prevent the devasting adverse health effects.

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