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Forever Chemicals:

An Essential PFAS Guide for Functional Medicine Providers

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PFAS GENERAL INFORMATION

WHAT ARE PFAS CHEMICALS?

The PFAS term encompasses thousands of per-and polyfluoroalkyl chemicals which are industrially produced for surface tension lowering or "non-stick" properties. PFAS offer water, oil, and stain repellent capabilities and other friction reduction benefits. PFAS are broadly used in industries such as aviation, automotive and electronics as well as in consumer goods such as cosmetics, paints, fast food packaging, carpets, floor polishes, herbicides, cookware, outdoor gear, and firefighting agents. Due to widespread applications, humans are often chronically exposed to PFAS in day-to-day life.

PFAS chemicals have a unique physicochemical structure. All PFAS chemicals contain a chain of carbon atoms which are chemically bonded to fluorine atoms. The carbon-fluorine bond is one of the strongest chemical bonds known and it is difficult to break. As a result of this chemical property, PFAS can remain in the environment, humans, and wildlife for a very long time and therefore have become known as the "forever chemicals".[1-2]

HOW ARE PFAS CATEGORIZED?

PFAS chemicals include a wide variety of substances with a carbon-fluorine structure but with varying forms, such as liquids, gases, surfactants, and solids. Due to this diversity, PFAS are grouped into families with similar physical and chemical characteristics. PFAS are first categorized into polymers and non-polymers, as seen in **Figure 1**. Then, nonpolymer compounds are further categorized into subgroups of PFAS, such as perfluoroalkyls and polyfluoroalkyls. Common subgroups of perfluoroalkyls include perfluoroalkyl carboxylic acids, PFCA's, and perfluoroalkane sulfonic acids, PFAS's.

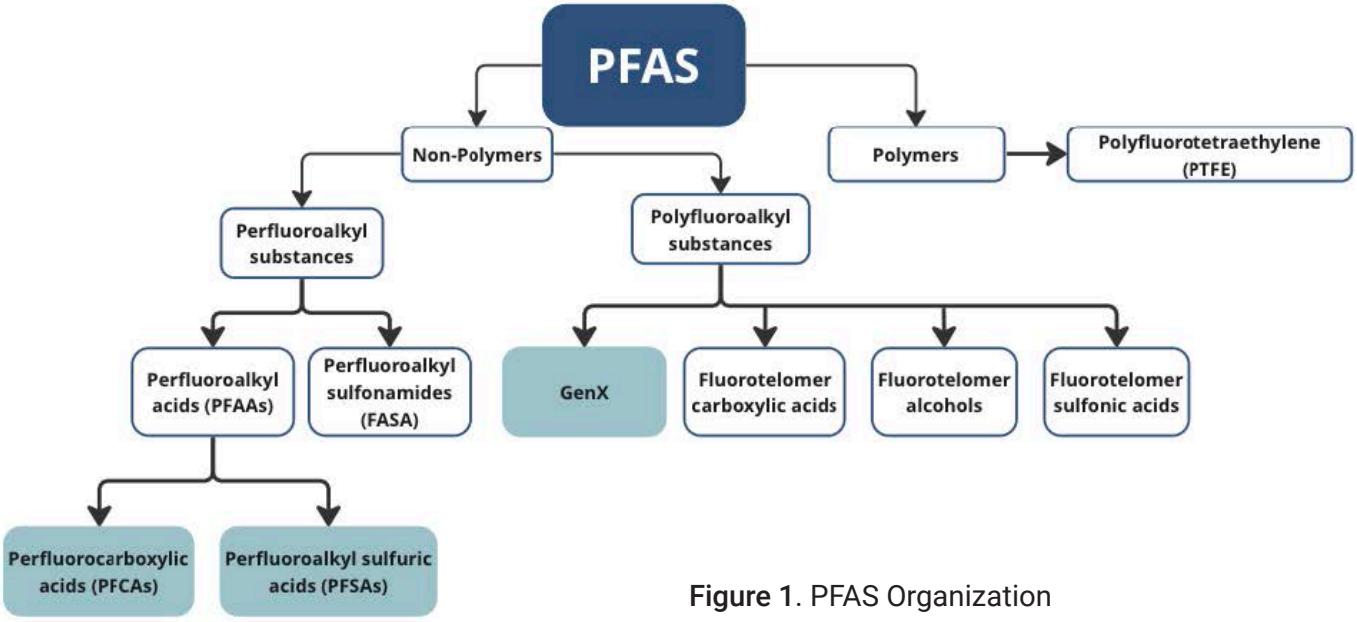
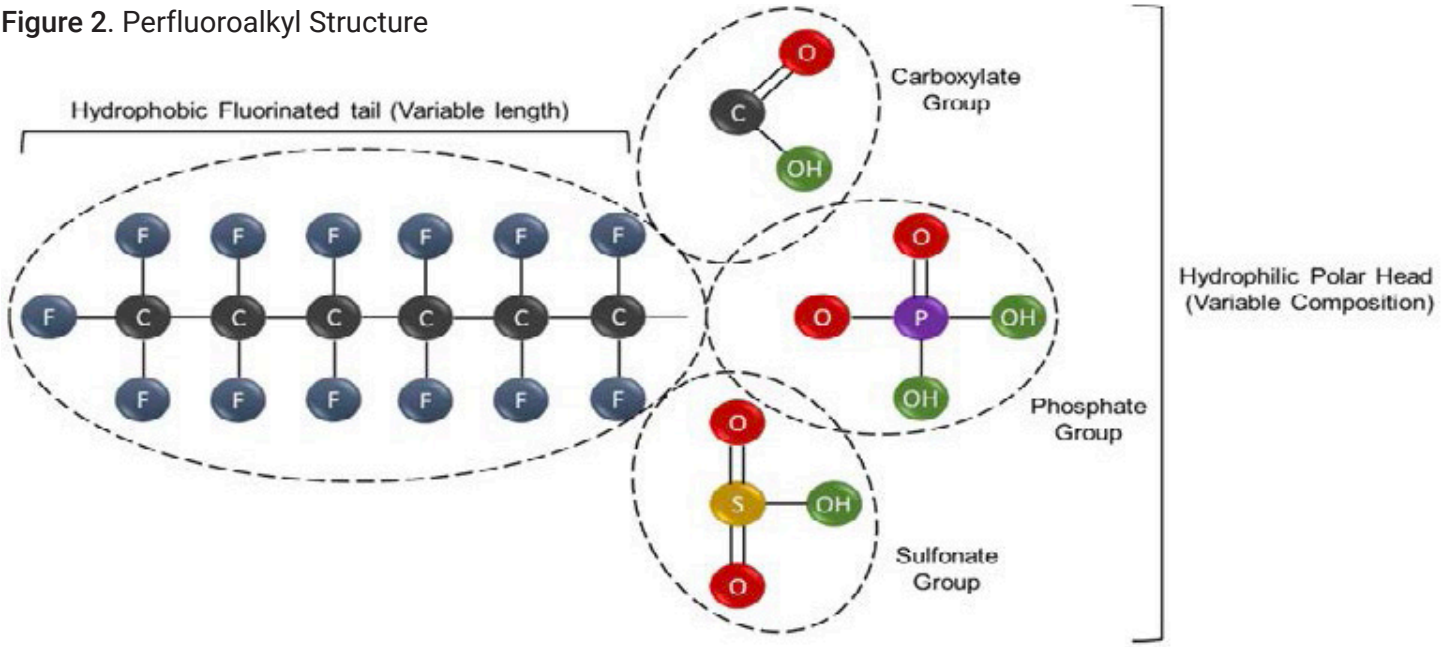


Figure 1. PFAS Organization

Figure 2. Perfluoroalkyl Structure



Sourced from: Panieri E, Baralic K, Djukic-Cosic D, Buha Djordjevic A, Saso L. PFAS Molecules: A Major Concern for the Human Health and the Environment. *Toxics*. 2022; 10(2):44. https://doi.org/10.3390/toxics10020044

THE IMPORTANCE OF CARBON CHAIN LENGTH IN PFAS

The length of the carbon chain in PFAS can range from C4-C17 and the number of carbons can generally predict physical and chemical properties, bioaccumulation tendencies, protein-binding, and environmental distribution.[3] Until 2000, long-chain PFSA's (Carbon ≥ 6) and PFCA's (Carbon ≥ 7) were predominantly used. These are termed "legacy" PFAS.[4] The most well-known legacy PFAS are PFOS and PFOA. After 2000, due to widespread bioaccumulation and health concerns, production of these were phased out in the US, and were replaced by short chain PFAS or other alternatives. Examples of these "next generation" (next gen) PFAS include GenX, PFBA, and PFBS.

Long chain PFAS tend to persist in humans, wildlife, and the environment for a long time. Legacy PFAS chemicals have been found in 95-100% of blood samples when tested across varying populations, despite reduction of production decades ago.[5-6] Short-chain PFAS and other next-gen PFAS tend to have shorter half-lives in humans, however, can persist in the environment and can disperse to greater areas. Short chain, next-gen, and long chain PFAS all have potential health harms from chronic or high exposure in humans.

SHORT CHAIN PFAS	LONG CHAIN PFAS
Perfluorobutanoic acid (PFBA)	Perfluorooctanoic acid (PFOA)
Perfluorohexanoic acid (PFHxA)	Perfluorohexane sulfonic acid (PFhxS)
Perfluoropentanoic acid (PFPeA)	Perfluorononanoic acid (PFNA)
Perfluoroheptanoic acid (PFHpA)	Perfluorodecanoic acid (PDFeA)
2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (GenX/HPFO-DA)	Perfluoroundecanoic acid (PFUnA)
Dodecafluoro-3H-4,8-dioxanoate (NaDONA)	Perfluorododecanoic acid (PDFoA)
	Perfluorotridecanoic acid (PFTrDA)
	Perflurotertradecanoic acid (PFTeDA)
	Perfluorooctane sulfonic acid (PFOS)
	Perfluoro-n-(1,2-13C2) hexanoic acid (MPFHxA)
	Perfluoro-(1,2-13C2) octanoic acid (M2PFOA)
	Perfluoro-(1,2,3,4-13C2) octanesulfonic acid (MPFOS)
	Perfluoro-(1,2-13C2) decanoic acid (MPFDA)
	Perfluoro-1-heptane sulfonic acid (PFHpS)
	9-chlorohexadecafluoro-3-oxanonane-1-sulfonate (9CLPF3ONS)

METABOLISM AND HALF-LIFE OF SHORT AND LONG CHAIN PFAS

Estimations of half-life are used in toxicology studies to help assess rates of excretion and predict toxicity induced harms. The half-life of a compound is defined as the length of time it takes to reduce the amount of the compound in the body by 50%.[7] Half-life determinations are typically based on elimination pathways. In the case of PFAS, the elimination pathways are not well clarified and/or have significant individual variations. Thus, different sources can cite widely different rates for clearance of the same PFAS compounds.[8]There are some theories for the discrepancies. It is known, for example, that renal elimination is a large factor in determination of total body clearance of PFCA's. Renal elimination rates, however, may be affected in individuals with SNP's (single nucleotide polymorphisms) in kidney transporter proteins and other gender and age-related renal function variations.[9]The biliary and fecal routes of elimination also provide some elimination of compounds; however, these can be affected by individual intake of fiber,[10] GI permeability, and GI inflammation.[11] Another pathway of excretion is through blood loss and breastfeeding. Thus, women who are of reproductive age excrete more compounds through pregnancy, breast feeding, and menstrual blood loss than other demographics. Lastly, ongoing, and unpreventable exposure to PFAS compounds can make it difficult to assess true clearance in studies and this exposure is also variable.

Despite the discrepancies in the data, there are some big picture concepts to keep in mind regarding PFAS and half-life elimination. Individuals with younger age, more recent time since initial exposure, and better renal function demonstrate faster clearance of PFAS than in those with the opposing traits.[11] Furthermore, regardless of individual elimination variables, the type of PFAS largely affects rate of clearance. As seen in Table 1, long-chain PFAS, such as PFOA, PFOS and PFHxS, tend to have half-life elimination times of years. In contrast to this, most short-chain PFAS, such as PFBS, PFBA and PFHxA, have half-life elimination times of hours, days, or weeks. Lastly, there have been studies showing greater amounts of short chain PFAS in the urine versus legacy compounds which are observed in greater amounts in serum.[12]

TABLE 1. MEAN ELIMINATION HALF-LIVES OF SELECTED SHORT & LONG CHAIN PFAS

SHORT-CHAIN PFAS		LONG-CHAIN PFAS	
PFBA	3-4 days	PFOA	2.1-3.9 years
PFBS	26 days	PFOS	3.3-27 years
PFHxA	14-49 days	PFHxS	7.7-15.5 years

Note: Values in table are sourced from: Russell MH, Nilsson H, Buck RC. Elimination kinetics of perfluorohexanoic acid in humans and comparison with mouse, rat and monkey. *Chemosphere*. 2013 Nov;93(10):2419-25. doi: 10.1016/j.chemosphere.2013.08.060.

PFAS HEALTH HARMS

WHERE DO PFAS CHEMICALS ACCUMULATE IN HUMANS?

Humans absorb the highest amounts of PFAS chemicals through ingestion and inhalation of airborne particulate and contaminated dust. PFAS are quickly and efficiently absorbed into the alimentary tract and respiratory system. Once inside the body, PFAS have a strong binding affinity to plasma and serum proteins and bioaccumulate in the blood. Studies also show bioaccumulation of PFAS in the lungs, kidney, liver, and bone.[1]

WHAT ARE THE GENERAL HEALTH HARMS OF PFAS?

Research on the health harms of PFAS are widely available for many long chain PFAS, with much of the focus on PFOA and PFOS. Long-term and other health effects of next-gen PFAS have been studied less. Increasing research indicates PFAS demonstrate potential for harm across endocrine, neurological, respiratory, immune, urinary, gastrointestinal, reproductive, and cardiovascular systems.[1] The following table highlights some specific conditions that have been studied in relationship to general PFAS exposure.

Conditions	Evidence
Asthma	There is limited evidence that in utero and early life exposure to PFAS increases risk of infections, allergies, asthma, and atopic dermatitis.[13]
Cancer	The International Agency for Research on Cancer (IARC) classified perfluorooctanoic acid, PFOA, a legacy PFAS, as a possible human carcinogen. The most evidence-based associations with PFOA and cancer are for kidney and testicular cancer. There are also associations in the literature with PFAS and prostate cancer. Several other types of cancer and PFAS are currently being investigated.[14]
Diabetes	Studies show PFAS appear to behave as potential diabetogens. They can affect PPAR (peroxisome proliferator-activated) receptors which act as regulators of adipocyte differentiation and lipid and glucose homeostasis. One recent study showed high exposure to PFAS in midlife women more than doubled the risk of developing diabetes.[15]
Hyperlipidemia	There have been over[20] studies that show a positive association between elevated PFAS levels and serum lipids, notably LDL and total cholesterol. Most studies have only studied PFOS and PFOA, though a few also support this association with other PFAS.[16]
Infertility	In males, preclinical studies and epidemiological studies suggest PFAS exposure affects testosterone levels and semen quality, potentially due to toxicity to Leydig cells and changes in levels of steroidogenic enzymes.[17] In females, studies suggest that PFAS, which are found in follicular fluid, may contribute to fertility issues, and affect oocyte development. Additional studies support an association between elevated PFAS levels and decreased fertility and increased time to pregnancy.[18]
Kidney Disease	Numerous epidemiological studies report an association between exposure to PFAS and reduced kidney function or kidney cancer. Toxicology studies demonstrate structural alterations in the proximal tubules of the nephron and dysregulated metabolic pathways, amongst other mechanisms.[19]
Liver Disease	Several epidemiological studies report an association between increased PFOA and elevated transaminases.[20] Additional studies on multiple PFAS report changes with liver biomarkers including transaminases, bilirubin and GGT.[21]
Lower infant birth weight	Low birth weight is a consistently reported adverse pregnancy outcome in epidemiological and animal studies relating to gestational PFAS exposure. Studies have found this result in PFOA as well as several other legacy PFAS.[22]
Obesity	At least 15 studies have reported positive associations between overweight or obesity and the exposure to at least one PFAS. The studies span many geographic regions and diverse age groups, including maternal exposure and childhood obesity, as well as adults. Mechanisms underlying this may relate to altered leptin levels and other metabolic dysregulations.[23–24]
Pre-eclampsia	Several epidemiologic studies have found positive associations between maternal exposure to PFAS and pre-eclampsia. Some research suggests this is related to the impairment of placental function, though the exact mechanism has yet to be fully elucidated.[22]
Thyroid disease	Studies have found associations with elevated PFOS and PFOA and an increased risk of thyroid disease, also associated alterations in TSH and thyroid hormone levels.[25] In vitro and animal studies support a thyroid-disrupting effect of both old and new generation PFAS.[26]
Ulcerative Colitis	PFOA has been shown to have a significant, positive association with ulcerative colitis in highly exposed individuals though mechanisms remain unclear.[27]

Clinical Screening

As seen in the above table, the evidence is accumulating regarding PFAS and correlations to human health risks in a variety of systems. One part of a prevention strategy is to consider increased clinical screening in highly exposed individuals for PFAS associated conditions. In the C8 Health Study, a landmark study of over 69,000 people exposed to PFOA in the Mid-Ohio Valley communities and monitored over decades, the medical panel suggested ongoing health screenings for the study population. These tests included screening for cholesterol, uric acid, thyroid hormones, and liver function.[25,28]

VIBRANT PFAS TEST ANALYTES AND POTENTIAL HEALTH RISKS

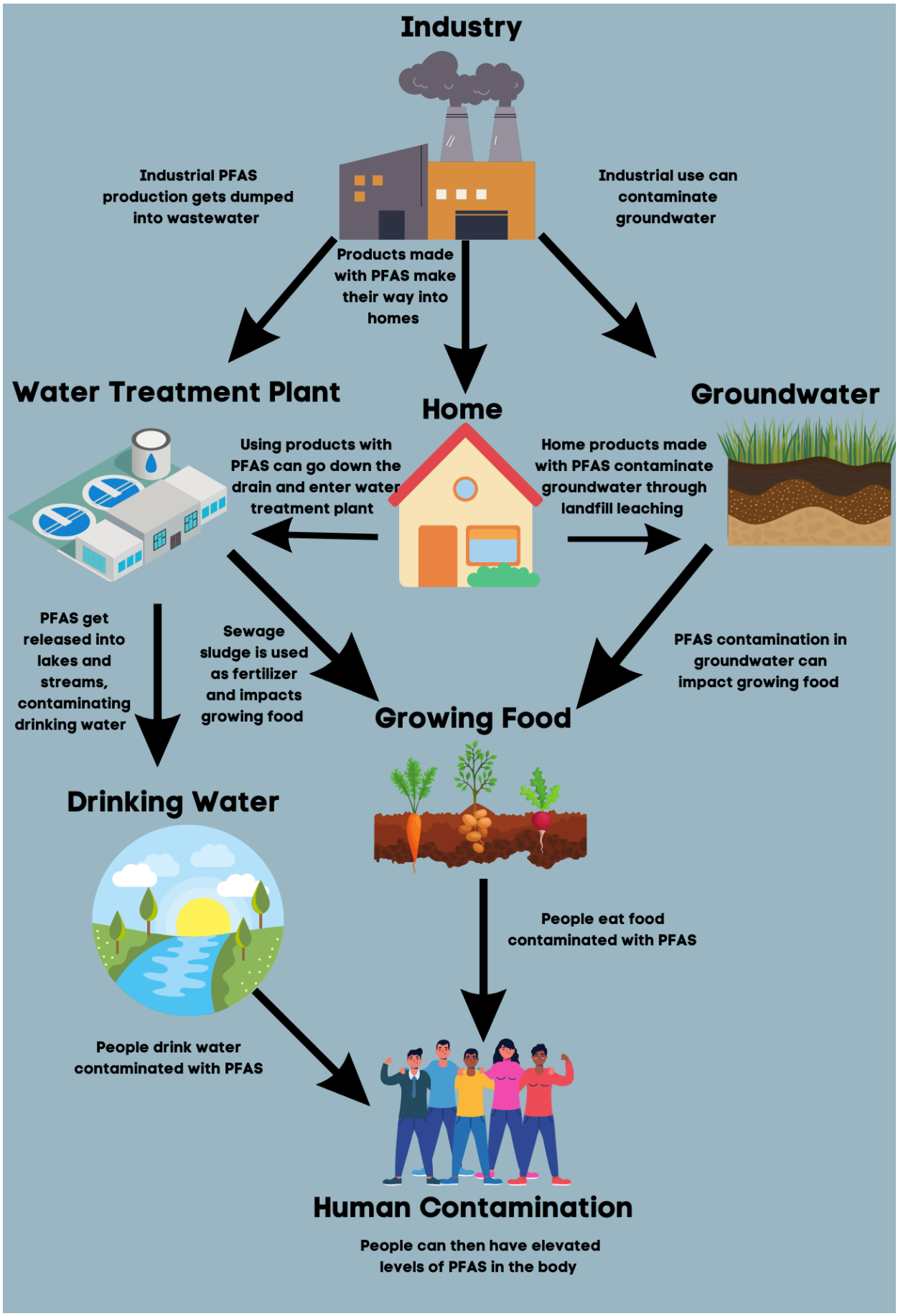
An excerpt of potential health harms of individual PFAS test analytes is offered below. For a more comprehensive look at studies relating specific PFAS to human health, please refer to PFAS-TOX Database at https://pfastoxdatabase.org.

SHORT CHAIN PFAS	
VIBRANT PFAS TEST ANALYTE	POTENTIAL HEALTH RISKS
Perfluorobutanoic acid **(PFBA)**	Negative effects on liver (hepatomegaly), thyroid, hypertension, hematological alterations, peroxisome proliferation, induction of peroxisomal fatty acid oxidation[29-30]
Perfluorohexanoic acid **(PFHxA)**	Decreased birth weight, hematological changes, hepatotoxicity, inreased risk cardiovascular disease, thyroid abnormalities, Gilbert syndrome[29,31]
Perfluoropentanoic acid **(PFPeA)**	Carcinogenicity, developmental toxicity, endocrine toxicity, hepatotoxicity, digestive system toxicity, immunotoxicity, reproductive toxicity[32]
Perfluoroheptanoic acid **(PFHpA)**	Liver and heart diseases, asthmatic and rhinitis problems in girls, lower respiratory tract infections, developmental toxicity, hepatotoxicity, digestive system toxicity, reproductive toxicity[32-33]
2,3,3,3-tetrafluoro-2- (heptafluoropropoxy) propanoate **(GenX/HPFO-DA)**	Negative effects to the liver, blood, and cancer of the liver, pancreas and testicles[34]
Dodecafluoro-3H-4,8-dioxanoate **(NaDONA)**	Cancer, endocrine disruption, accelerated puberty, liver and immune system damage, and thyroid changes[35]

LONG CHAIN PFAS	
VIBRANT PFAS TEST ANALYTE	POTENTIAL HEALTH RISKS
Perfluorooctanoic acid **(PFOA)**	Hepatic and metabolic toxicity, reproductive and developmental toxicity, immunotoxicity, endocrine disruption[36]
Perfluorohexane Sulfonic Acid **(PFHxS)**	Immunotoxicity, liver damage, endocrine disruption, developmental harm[29,36]
Perfluorononanoic acid **(PFNA)**	Hepatotoxicity, immunotoxicity, negative developmental effects, reproductive harm[29]
Perfluorodecanoic acid **(PFDeA)**	Decreased body weight, immunotoxicity, developmental toxicity, digestive system toxicity, reproductive toxicity[29,32]
Perfluoroundecanoic acid **(PFuNA)**	Osteoporosis, decreased RBC folate, dyslipidemia, ER+ breast cancer and others [37-39]
Perfluorododecanoic acid **(PFDoA)**	Endocrine disruption, reproductive toxicity, affects thyroid homeostasis [40-41]

Perfluorotridecanoic acid **(PFTrDA)**	Endocrine disruption, affects thyroid homeostasis, immunosuppressant, cancer, liver damage, and others[42-43]
Perfluorotetradecanoic acid **(PFTeDA)**	Dyslipidemia, hepatotoxicity, pneumonia, affects immune function and response to syncytial viral infections[44]
Perfluorooctane sulfonic acid **(PFOS)** and **(MPFOS)**	Hepatotoxicity, neurotoxicity, reproductive toxicity, immunotoxicity, thyroid disruption, and cardiovascular toxicity. Testosterone production may be compromised in individuals with high PFOS exposure[45]
Perfluoro-n-[1,2-13C2] hexanoic acid **(MPFHxA)**	Gilbert Syndrome (a mild genetic liver disorder in which the body cannot properly process bilirubin)[31]
Perfluoro-[1,2-13C2] octanoic acid **(13C2- PFOA) (M2PFOA)**	Thyroid disease, high cholesterol, ulcerative colitis, pregnancy-induced hypertension, changes in liver function, cancer and reduced immune response[46]
Perfluoro-1-heptane sulfonic acid **(PFHpS)**	Dyslipidemia, cardiometabolic disturbances, hormone disruption and deterioration of thyroid and renal function[44]
9-chlorohexadecafluoro-3-oxanonane-1- sulfonate **(9Cl-PF3ONS)**	Endocrine disruption,[47] dyslipidemia[48]

PFAS EXPOSURE



HOW DO HUMANS GET EXPOSED TO PFAS?

Humans are exposed to PFAS from environmental contamination from PFAS manufacturing as well as from direct exposure from products containing PFAS. PFAS chemicals from manufacturing plants and aqueous fire-fighting foams make their way to wastewater and into outdoor air. From there, PFAS enter surface and groundwater systems and then are ultimately transferred to drinking water, fish, and soil. Sewage sludge contaminated with PFAS is also used as fertilizer for agriculture, which is then used for human consumption. Further, humans are directly exposed to PFAS from transfer into food from non-stick food packaging containers and cookware. There can be transfer of these stored PFAS chemicals, through umbilical cord blood and breastmilk, from mothers to offspring. Also, humans can breathe and ingest contaminated dust from indoor air in homes with PFAS chemicals present from non-stick products. Lastly, humans are topically exposed to products with PFAS chemical treatments on them, however systemic absorption through dermal exposure is thought to be low.[2]

MAIN SOURCES OF EXPOSURE

PFAS are 'everywhere.' They are used widely in products due to their inert and repellant properties for product surfaces. Even though exposure occurs through multiple different means, dietary intake and drinking water are the main routes of exposure.[49]

While most Americans are exposed to PFAS, increased exposure risks occur in those with residential or occupational exposure to PFAS such as:

- Firefighters and military personnel routinely exposed to firefighting foam
- People who live or work near airport, military, wastewater, or PFAS production complexes
- People who live near contaminated water sites (https://pfas-exchange.org/connecting-communities/)
- People who work with water, oil, or grease repellant chemicals in production or application
- Furniture production, textile and upholstery workers who work with treated fabrics
- Carpet related occupations (installers, store personnel, carpet cleaners)
- People who work in chemical manufacturing and automotive industries

Some of the main sources of exposure that are discussed below include food sources, migration to food, household and personal exposures, and water.

FOOD SOURCES

There are many foods that are highly contaminated with PFAS. Fish and seafood are some of the highest foods in PFAS, based on studies conducted all around the world.[49] This is likely due to water contamination from industrial use and water treatment plants impacting water sources. Many other foods are also commonly contaminated with PFAS, including animal products and produce, particularly items grown in fertilizer from sewage sludge high in PFAS.

Fish and seafood

Fish and seafood can contain very high levels of PFAS, especially in areas next to contaminated sites. The European Food Safety Authority (EFSA) concluded that up to 86% of PFAS exposure in adults occurs from fish and other seafood.[2] Studies conducted in countries throughout the world have consistently shown that fish and seafood are the highest food sources of PFAS. One country showed that there's a dose-dependent relationship between fish consumption and internal exposure of PFOS.[2] The study showed the highest levels in seafood across many countries include perches, eel mollusks, crustaceans, prawns, hake.[2] Another interesting finding was that PFAS levels in freshwater fish (PFOS highest) were higher than those in marine fish and seafood.

Animal products

Animal products are another category of foods containing a potentially high level of PFAS. The European Food Safety Authority (EFSA) found that meat and meat products may account for up to 52% of PFOS exposure in humans.[2] They found that eggs and egg products may account for up to 42% of infant exposure of PFOS[2] while milk and dairy products were found to be chronic sources of PFOA for toddlers.

Agriculture

Many PFASs used for industrial purposes enter the wastewater streams and end up in wastewater treatment plants.[2] Sewage sludge from wastewater treatment plants is commonly used for fertilizer to grow different types of produce. This may increase crop contamination and increase levels of PFAS in many foods.

RECOMMENDATIONS TO DECREASE PFAS EXPOSURE FROM FOOD

- Consider decreasing consumption of fish and seafood overall
- Limit intake of fish from freshwater sources

MIGRATION TO FOOD

PFAS are ubiquitously used in food contact materials because the carbon-fluorine bonds protect them from degradation even at high heat. They increase exposure indirectly because the packaging contents can migrate into the food. They are used in the packaging of so many different products and unfortunately, they are not listed on any ingredient labels because it's not actually an ingredient in the food. Therefore, it can be difficult to identify which food packages contain PFAS and which do not.

Migration Factors

The migration of PFAS into food can vary depending on different circumstances. For example, PFAS are more likely to migrate into fatty foods compared to non-fatty foods. Researchers also found that there is a 50x higher migration in emulsified foods (butter) compared to non-emulsified fats (oil).[50] PFAS are more likely to migrate into acidic foods, compared to those with a higher pH (more alkaline). This is likely why research has shown an increased migration into alcoholic beverages. PFAS are more likely to migrate into food when they are stored for a long period of time. Studies have shown that PFAS levels may be 4.8 higher in long storage food products.[51] PFAS are more likely to migrate into food when there's a high storage temperature, which can increase levels up to 7.3 times.[51]

FOOD PACKAGING	COOKWARE & KITCHEN EQUIPMENT
• Microwave popcorn bags • Candy wrappers • Baking Paper • Box of chips • Sandwich wrap • Takeout containers/fast food packaging • Pizza boxes • Ice cream containers **Contains PFAS, such as PFOA, PFHxA, PFHpA, PFNA, PFDA, PFUA[50]*	Non-stick cookware containing polytetrafluoroethylene (PTFE) • Prior to 2013 PFOA was used in manufacturing of PTFE. Newer PFAS have been used after 2013 to manufacture PTFE • Pots, pans, oven racks, griddles, waffle makers, sandwich makers, muffin and cake pans, kitchen utensils • Even if non-stick cookware is not used in the home, restaurants may be a source of exposure if they are using them **Note: companies may specify that they do not contain PTFE, but may add different variations of PFAS that aren't as well known*

RECOMMENDATIONS TO DECREASE PFAS MIGRATION TO FOOD

- Decrease intake of packaged foods (even healthy packaged foods)
- Avoid packaged foods with very long shelf lives
- Choose food products stored in glass jars (tomato sauce from a glass jar instead of a can)
- Limit the amount of take out/fast food consumed
- Avoid heating foods in original packaging that may contain PFAS
    - o Example: do not heat popcorn in the microwavable bag, cook on the stovetop instead
- When purchasing foods in packaging, transfer to a glass storage container at home

- Choose cookware that does not use PTFE for non-stick properties
    - o Opt for cast iron or ceramic coated cast iron
- Use parchment paper or wax materials in the kitchen when packaging/wrapping is needed

PFAS IN HOUSEHOLD AND PERSONAL ITEMS

Household exposure accounts for a significant level of PFAS exposure due to the ubiquitous nature of PFAS in manufacturing. There are many items in the house that are commonly made with PFAS that can increase the toxic load in humans through ingestion, inhalation of dust or fumes, and through indirect means of water contamination. Some common sources are listed below.[50,52]

HOUSEHOLD AND PERSONAL ITEMS WHICH CONTAIN PFAS	
Household exposures	• Anti-stain coatings • Upholstery • Furniture paints and varnishes • Cleaning and impregnating agents o Floor polishes • Carpets and carpet shampoo • Leather (personal use or cars)
Clothing & Waterproof fabrics	• Water repellant outdoor jackets, gloves, boots
Personal Care Products	• Shampoo • Dental floss • Cosmetics such as nail polish and eye makeup
Dust	• PFAS can accumulate in household dust
Other	• Fire extinguisher: mostly an occupational hazard but exposure can occur from anyone using it • Ski waxes

RECOMMENDATIONS TO DECREASE HOUSEHOLD & PERSONAL EXPOSURE

- Avoid purchasing furniture with anti-stain coatings
- Limit wearing fabrics that may be coated in PFAS to waterproof them
- Choose non-toxic cleaning products in the house
- Avoid installing carpet in the house, consider removing existing carpet
- Use a water flosser instead of dental floss or ensure dental floss does not contain PFAS
- Dust house often with a damp cloth
- Use high quality air HEPA air filtration unit to filter dust particles.

WATER

Water is a predominant source of PFAS exposure. When products are produced with PFAS, nearby water sources can be contaminated from industrial contamination. Areas that tend to be higher risk include locations near manufacturing facilities, air force bases, airports, fire training facilities and landfills.[2] Industrial PFAS use affects water quality by leaching into groundwater sources as well as contaminating drinking water sources. Areas near industrial sites can contaminate drinking water, accounting for roughly 75% of PFAS exposure.[2]

One of the most important and actionable steps to take to evaluate PFAS exposure is to assess local water quality. This can be done in two ways:

1) View a map of PFAS contamination sites to assess individual risk
    - o https://pfas-exchange.org/connecting-communities/
2) View local water quality: Enter city's Zip code to view local contaminants in water supply
    - o https://www.ewg.org/tapwater/

Since PFAS can leach into streams and fresh drinking water sources, drinking water tends to be a major source of exposure. One study found that drinking water concentrations of PFOS and/or PFOA directed to about 6 million Americans, exceeded the US EPA 2016 health advisory levels, which is extremely concerning.[2] The first statewide assessment of PFAS levels occurred in New Jersey where PFOA levels were detected in 59% of public water supplies, therefore impacting a large percentage of the population.[2]

Drinking water exposure can affect all humans and animals. One study found that formula-fed infants were highly exposed to PFAS due to increased water intake compared to body weight ratio.[53]

RECOMMENDATIONS TO DECREASE PFAS WATER EXPOSURE

Residential Water Filtration

Reverse osmosis filtration is considered the best filtration method for PFAS. Reverse osmosis reliably removes PFAS compounds, both short and long chain, averaging to below detection limits for most compounds.[54]

A dual stage, under the sink, filter (pre-filter plus activated carbon filter) can be significantly beneficial in reducing both long and short chain compounds. These filters had similar effectiveness to reverse osmosis in one residential use study.

Single stage activated carbon filters (point of use pitcher, faucet and refrigerator filters) are somewhat helpful in removing variable amounts of PFAS, studies showed a 50-70% reduction depending on the system.[54] These filter long chain compounds more reliably than short-chain compounds, which showed only 41% reduction in one study.[54]

Whole house carbon filtration has markedly varying results in removing PFAS. Some tested models helped somewhat, while others showed an increase in PFAS in water due to saturation of media with compounds, followed by release of the adsorbed chemicals back into water.[54]

DETOXIFICATION & INTERVENTIONS

CLINICAL CONSIDERATIONS FOR REDUCING PFAS BURDEN

Improving excretion of PFAS presents unique challenges compared to detoxification of other toxicants such as heavy metals, pesticides, phthalates, or other environmental toxins. Due to the stability of the carbon-fluorine bond, most long chain PFAS are not conventionally biotransformed or metabolized by the body.[25] PFAS are largely bound to blood plasma proteins. This binding plays a critical role in bioaccumulation for many long chain PFAS, as only free (unbound) perfluoroalkyls are available for excretion.[29] Thus, as indicated previously, legacy, and long chain PFAS are only gradually eliminated through urine, blood loss and breastfeeding. Biliary excretion occurs; however, compounds are largely reabsorbed through enterohepatic circulation.

From a wellness perspective, as well as conventional medicine guidelines, intentional avoidance of PFAS substances, as outlined in previous sections, is the primary step to reduce PFAS burden. Studies on lifestyle, supplement, and pharmaceutical interventions that are shown to enhance excretion of PFAS are limited, and more research is strongly needed. From available evidence at the time of this writing, enhancement of PFAS biliary excretion through interruption of enterohepatic recirculation holds promise. Mitigation of harms through antioxidant and polyphenol intake also offers a low-risk strategy to consider. These studies, and others currently available regarding PFAS excretion and mitigation of risk, are summarized below.

INTERVENTIONS TO SUPPORT EXCRETION

ROUTE	GENERAL INFO & CONSIDERATIONS
Bile-Bowels	Perfluorinated compounds (PFCs) may persist in the body partially due to enterohepatic recirculation. One potential approach to decrease PFCs includes blocking the reabsorption of toxins in the enterohepatic pathway to increase excretion.[55] **Bile acid sequestrants** One study in humans found that cholestyramine resulted in significantly elevated levels of three different PFAS in the stool, whereas prior to cholestyramine the levels were mostly undetectable.[55] **Fiber** Foods rich in fiber have been associated with lower levels of perfluoroalkyl substances (PFAS). One study found that dietary fiber increases the excretion of PFOA, PFOS, and PFNA through the GI tract.[56] **Zeolite and Chlorella** (not shown effective) Zeolite and chlorella were shown to be ineffective at increasing PFAS in stool excretion in a case study and small human study, respectively.[55,57]
Breastmilk	One study estimated that breast milk contributed to more than 94% of PFOS and 83% of PFOA exposure in infants 6 months of age.[58] One longitudinal human study found that breastfeeding for one year resulted in a decrease of PFOA and PFOS from 95% to 37%. Even though breast milk is the optimal nourishment for infants, it is also a means of perfluoroalkyl acid (PFAA) excretion by the mother. **Breastfeeding** If levels of PFAS are markedly elevated in a mother, it may be important to discuss breastfeeding pros and cons with a doctor or healthcare practitioner.
Blood	A study in Australia found that individuals undergoing intermittent blood draws showed significantly lower PFAA levels.[59] The mechanism likely relates to the PFAA storage component in the body, which is predominantly proteins in blood, and in organs heavily perfused by blood (liver and kidney). **Blood or Plasma donation** Research has shown that regular phlebotomy may significantly increase perfluroalkyl acid (PFAA) clearance.[59] Since PFAS are highly protein bound with significant levels found in the plasma, plasma donation may be preferred.[60] **Menstruation** Since menstruation results in blood loss, menstruating women may be excreting PFAS at a higher rate than those who do not menstruate.[61] Epidemiological studies have shown a higher level of PFAS in men, menopausal women, and those with a history of hysterectomy compared to premenopausal women.[61]

Sweat (Not shown effective)	A human study assessed the elimination of long chain perfluorinated compounds (PFCs) through sweat. The study concluded that induced perspiration though sauna or exercise was not effective in clearing legacy PFC's, specifically, PFHxS, PFOS, and PFOA.[62]

MITIGATE RISK FROM EXPOSURE

It is well established that PFAS compounds are present in the human body for long periods of time and pose risks of single and additive health harms. Thus, dietary strategies for potential mitigation of harms or chemoprevention are a worthwhile approach to consider. It has been shown that PFAS toxicity across multiple systems relates to oxidative stress. It has also been shown that PFAS exposure increases the formation of reactive oxygen species in both animals and humans as an activation of the antioxidant defense system.[63] However, this activation from PFAS exposure is only somewhat effective in reducing damage to biomolecules. Supplemental antioxidants, vitamin C and polyphenols in particular, have limited evidence of mitigation of PFAS toxicities. Increasing intake of antioxidants and other compounds that may mitigate the risk from PFAS exposure, therefore, may be beneficial.

FOOD/ SUPPLEMENT	SELECTED RESEARCH
Vitamin C	One study showed that 1000mg/day of vitamin C supplementation can protect against the adverse effects of perfluorinated compounds (PFOS and PFDoDA) on insulin resistance.[64]
Resveratrol-Glucan-Vitamin C (RVB)	Research has shown that perfluorinated compounds (PFOA and PFOS) exhibit significant immunosuppressive effects on cellular and humoral immunity. A combination of RVB supplementation decreased the immunotoxic effects from perfluorinated compounds.[65]
Blueberry Anthocyanins	Research has shown that PFOA's induce mitochondrial dysfunction and decrease antioxidant capacity and enzyme activities. An animal study found that anthocyanin supplementation showed an improvement in PFOA induced mitochondrial toxicity, antioxidant capacity and enzyme activity.[66]
Curcumin	Research has found that PFOS can strongly induce DNA damage and promote biomarkers of oxidative stress and inflammation. One animal study found that curcumin supplementation prevented PFOS induced DNA damage.[67]
Green Tea	Research has found that perfluorodecanoic acid (PFDA) can induce liver damage and inflammation. An animal study showed that intake of green tea polyphenols and epigallocatechin-3-gallate (EGCG) improved multiple parameters of liver dysfunction, including hepatic oxidative stress, cell apoptosis, necrosis, steatosis, edema and hepatic inflammation.[68]

REDUCE TOTAL TOXIC BURDEN

In addition to avoidance, and other potential interventions described above, another important recommendation is to reduce the total toxic burden of additional chemicals that may be impacting the body. As stated in previous sections, due to high stability and lack of biotransformation in the body, PFAS can be difficult to efficiently eliminate. Typical methods of toxin removal such as enhancement of Phase 1 and Phase 2 hepatic detoxification pathways, sauna, etc., either have unknown or negative efficacy in specific reduction of PFAS levels. Nonetheless, typical detoxification methods may have a net benefit in addition to specific PFAS support. Reduction of body burden of overall toxins would likely help decrease total physiological damage and preserve cellular resources. To focus on reducing the total toxic burden, the following recommendations may be considered:

1) Assess and remediate high levels of other toxins through the **Vibrant's Total Tox Bundle** test, which includes the **Heavy Metal Test, Environmental Toxin Test and the Mycotoxin Test.**

2) Avoid exposure to other common toxicants.

3) Support excretion pathways to eliminate toxins from the body.

4) Upregulate Phase 1 and Phase 2 detoxification and support elimination to decrease total toxic burden.

5) Consume a nutrient dense diet high in antioxidants to offset the potential risk from exposure.

6) For an in-depth guide to the above detoxification steps, please see Vibrant's Environmental Toxin Guide.

CONCLUDING REMARKS

According to the Agency for Toxic Substances and Disease Registry (ATSDR) guidelines entitled, *An Overview of the Sciene and Guidance for Clinicians on Per- and Polyfluoroalkyl Substances (PFAS)*, there are no currently established methods advised for PFAS removal in conventional medical settings. There are also no established PFAS values in urine or blood that can predict current or future health problems.[25]

Despite this, and the fact that PFAS are 'everywhere' and are considered 'forever chemicals,' there are ways to reduce our exposure to decrease the potentially negative impacts they may have on the body. While some typical detoxification recommendations may not apply to PFAS, there are indeed actionable steps that may help decrease the total body burden from combined, accumulated chemicals. Given the scientific uncertainty and lack of scientific agreement about screening, monitoring and treating abnormal levels of PFAS, these are our conclusions:

- First and foremost, avoidance of PFAS wherever possible can help reduce PFAS body burden over time. Avoidance strategies include water filtration, air filtration and utilizing PFAS free cookware and packaging materials.
- Secondly, blocking toxin resorption in enterohepatic circulation through fiber or other bile sequestration may increase fecal excretion of PFAS compounds.
- Thirdly, a healthy, high nutrient diet and supplementation with Vitamin C and polyphenols, may provide a mitigation of oxidative stress harms from PFAS.
- Fourth, reducing the exposure and improving excretion of other, non-PFAS, toxicants can reduce overall body burden and prevent additive chemical harms.
- Fifth, screening for PFAS related conditions in highly exposed individuals can aid with early detection and treatment. See the "What are the Health Harms?" section of this guide for a table of potential conditions associated with high PFAS exposure.

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