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Polychlorinated Biphenyl (PCB) in Environment: Contamination, Toxicity, and Carcinogenicity

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ABSTRACT

Polychlorinated Biphenyl (PCB) compounds which are widely used in industry have become a widespread and sustainable environmental problem for decades. PCB is chemically stable, low volatility, non-flammable, and high dielectric constant. Its main uses include heat exchange and dielectric fluids in transformers and capacitors, hydraulic fluids and lubricants, diffusion pump oils, plasticizers for plastics, and so on. PCBs are biologically magnified in the food chain and found in fish, wildlife, and human tissues. PCBs have been identified as contaminants in water, air, and soil, and are distributed up to the polar regions. According to epidemiological studies reporting blood levels of PCBs, the higher the level of exposure, the higher the blood concentration of PCBs, and the higher the environmental concentration or the longer the exposure period (or both), the longer the blood levels of PCBs remain elevated. PCB levels also correlate with race, place of residence (geographical), age, and dietary intake of fish in humans. PCBs have a very low potential to produce acute toxic effects. PCB exposure has been linked to having a particular skin rash commonly referred to as "chloracne". Liver damage was the most consistent finding among the many laboratory animal species tested. Yusho refers to the epidemic of poisoning by consumption of cooking oil contaminated with PCBs and polychlorinated dibenzofuran. Mothers with Yusho experience stillbirth, abnormal skin pigmentation, or babies tend to be small when compared to the national average. Some PCB compounds are carcinogenic in a number of rodent bioassays, producing liver tumors. Based on the available animal data, PCBs should be considered potential carcinogens for humans.

Keywords: Polychlorinated Biphenyl, pollution, contamination, toxicity, carcinogenicity.

INTRODUCTION

PCB (Polychlorinated Biphenyl) contamination in the environment has been a widespread and then ongoing problem for decades (1–3). PCBs are a group of industrial chemicals widely used in the 20th century in a variety of applications, including electrical appliances, paints and plastics. Despite their widespread use, PCBs were eventually banned in many countries because of their presence in the environment and their potential to cause harmful health effects in humans and animals (3,4)

PCBs are highly resistant to degradation and can remain in the environment for long periods of time. PCBs can be found in air, water, and soil, and can accumulate in plant and animal tissues, including humans (5,6). PCBs can also be transported over long distances by air and water, causing widespread contamination in many areas (4,7,8). PCB exposure can have a variety of harmful effects on human health and has thus been considered a probable human carcinogen and has been linked to a variety of health problems, including cancer, immune system dysfunction, and developmental and reproductive problems (3,9).

CONTAMINATION OF POLYCHLORINATED BIPHENYL (PCB) IN THE ENVIRONMENT

PCBs were first introduced to the industry in the early 1930's. This compound has been widely used because of its chemical stability, low volatility, non-flammability and high dielectric constant. Its main uses include heat exchange and dielectric fluids in transformers and capacitors, hydraulic fluids and lubricants, diffusion pump oils, plasticizers for plastics and coatings, putty agents, printing inks, paints, adhesives, carbonless paper, flame retardants and as extenders for pesticides (3).

Theoretically, PCBs contain 209 congeners, which are among the initial twelve Persistent Organic Pollutants (POPs) listed under the Stockholm Convention as having adverse effects on humans and ecosystems. PCBs are widely used in transformers and capacitors (4,5,8). Industrially produced commercial PCBs are usually mixtures, which involve the chlorination of biphenyls in the presence of a catalyst. These compounds have various trade names, for example Arochlors (Monsanto, USA), Clophens (Germany), Kanechlors (Kanegafuchi, Japan), and Pyroclors (UK). Of these, Arochlors is responsible for 50% of the total PCB product (10).

Until its ban in the 1970s, around 1.3 million tonnes of PCBs had been produced worldwide, with 10,000 tonnes produced in China (2,6). Although PCBs have been banned for decades, they are still detectable in the environment and continue to be a contaminant of great concern. Until now, volatilization from the past use of commercial products containing PCBs is still recognized as the main source of PCBs (11).

PCBs are biologically magnified in the food chain and found in fish, wildlife and human tissues. PCBs have been identified as contaminants in water, air, soil, and are dispersed as far as the polar regions away from disposal sites. Due to biomagnification in the food chain, trace amounts of PCBs in human blood have been documented in more than 50 percent of people sampled in all geographic areas of the United States. Reported levels of adipose tissue are in the range of 1-2 ppm, and residues measured in human milk range from 40-100 ppm in whole milk. Much higher levels have been documented in people who are active in sport fishing (1,7).

PHARMACOKINETICS

From the available PCB pharmacokinetic data, it is still considered insufficient to draw conclusions. There are generalizations that can be made with experimental data on animals according to (9), namely: (1) Absorption occurs via all routes (skin, gastrointestinal, inhalation) (2) Distribution mainly into fat (3) Liver is the main site of biotransformation via hydroxylation and conjugation with glucuronic acid (4) Metabolism and excretion depend on the structure of the particular molecule (5) Excretion is generally slow enough that bioaccumulation occurs even at low levels of exposure (6) There are essentially no pharmacokinetic data in humans.

There are several generalizations that can be made based on epidemiological studies reporting blood levels of PCBs. The higher the level of exposure, the higher the blood concentration of PCBs; and the higher the environmental concentration or the longer the exposure period (or both), the longer blood levels of PCBs remain elevated (7). PCB levels also correlate with race, place of residence (geographical), age, and dietary intake of fish in humans (12).

TOXICOLOGY

Studies on the health effects of PCB exposure have several challenges. Most of the studies reported were characterized by one or more of the following drawbacks: (1) small study population, (2) lack of accurate exposure data, (3) simultaneous exposure of workers to other hazardous chemicals and (4) lack of controls for confounding variables, such as alcohol consumption (3).

Acute Toxicity

PCBs have a very low potential to produce acute toxic effects. In rodents, the acute oral LD50 ranges from 1-10 g per kg body weight. According to the American Industrial Hygiene Association (AIHA) for acute toxicity, PCB is classified as "slightly toxic to practically non-toxic." The low degree of acute toxicity in experimental animals is consistent with the lack of acute effects observed in workers exposed to PCBs. Symptoms reported in the workplace include slight irritation to skin and eyes at airborne levels above 0.1 mg per cubic meter with intolerable irritation occurring above 10 mg per cubic meter (3).

In a comparison study in animals, (13) showed that acute PCB exposure decreased the survival rate of *Cyclina sinensis* mussels compared to controls. Acute PCB exposure regulates the enzymatic activities of superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GSH-Px) and malondialdehyde (MDA) content in *C. sinensis* hemolymph, while decreasing nonspecific enzymatic regulation of alkaline phosphatase (AKP). For the hepatopancreas, exposure to 1 ng/L PCB increased SOD enzyme activity while decreasing C. sinensis CAT enzyme activity. For the hepatopancreas, exposure to 1 ng/L PCB increased SOD enzyme activity while decreasing CAT enzyme activity. Histological observations showed that acute exposure to PCBs causes loss of gill filaments and lateral cilia as well as shortening of their length, in the organisms studied, as shown in Figure 1.

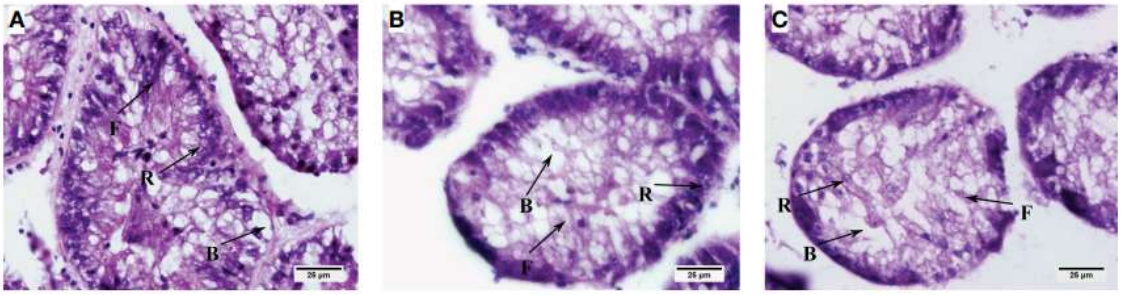

Figure 1. Histological changes in the hepatopancreas of C. sinensis clams under different PCB concentrations: (A) control (B) 1 ng/L PCB group (C) 10 ng/L PCB group. B: blister-like cells; F: fibrillar cells; R: resorptive cells (13).

Dermatological Effects

Exposure to PCBs (as well as certain other halogenated cyclic compounds, including dibenzofurans and dibenzodioxins) has been associated with a certain skin rash commonly referred to as “chloracne”. While it may resemble typical teenage acne, there are certain features that are different. The most characteristic lesion is cystic, skin-colored, and 1-10 mm in size. Another prominent lesion is the Blackheads. Blackheads and cysts can become inflamed and secondarily infected with large pustules. Unlike teenage acne, chloracne can occur at any age and may involve the trunk, arms, and legs as well as the face, neck, and back. It can be very persistent and refractory to treatment. Skin lesions similar to those of chloracne have been observed in a number of animal species experimentally exposed to PCBs (14). Further research is needed to better understand the mechanisms by which PCBs cause these effects and to develop strategies to reduce the risks associated with exposure to these chemicals.

Liver Damage

Liver damage, as documented histologically, was the most consistent finding among the many laboratory animal species tested. The effects of low-level chronic exposure do show considerable variation among species, but liver damage has been observed in all species and is usually the most sensitive indicator of PCB exposure. The fact that liver dysfunction has been inconsistently observed in humans may be a relative insensitivity of the standard liver function

tests (SGOT and SGPT), compared with biopsy and histological analysis (15).

Yusho

In Japanese, Yusho means "rice oil disease" and refers to an epidemic of poisoning caused by the consumption of cooking oil contaminated with PCBs and polychlorine dibenzofuran. The episode occurred in western Japan in 1968, affecting more than 1,600 people (16). An epidemiological survey of affected people identified a certain brand of rice oil produced in early February 1968 as the causative agent. Subsequent analysis of the rice oil confirmed that it was contaminated with large amounts of Kanechlor 400 (a Japanese brand of PCB with 48 percent chlorine content), and the component Kanechlor 400 was also found in various patient tissues (17).

The study of (18) obtained data on all Yusho patients for the period 1968–2017 and calculated the standardized mortality ratio (SMR) for all causes and specific deaths over a 50-year follow-up period compared to the general population in Japan. A total of 1,664 Yusho patients out of 63,566 people examined at follow-up were included in the analysis. Among male patients, increased mortality was observed for all cancers. Among female patients, increased mortality was observed for liver cancer. No significant increase was seen in non-cancer-related mortality compared with the population The study concluded that the carcinogenic risk to humans after exposure to PCBs and polychlorinated dibenzofurans (PCDF) remained higher among Yusho patients and the findings demonstrated the importance of engaging in optimal care and management to address Yusho's disease burden.

Reproduction

The Yusho incident is also important because it clearly documents the potential for reproductive and fetotoxic effects in humans. Two of the mothers with Yusho experienced fetal death. There are 10 out of 13 babies with abnormal skin pigmentation, 9 out of 13 have eye discharge, and 12 out of 13 babies tend to be small when compared to the national average. Despite various other effects observed in these infants, follow-up of these children showed no persistent morphological or behavioral abnormalities. Adverse reproductive effects of PCBs have also been found in many mammalian and avian species (19–22).

CARCINOGENICITY OF PCB

Some PCB compounds are clearly carcinogenic in a number of rodent bioassays, resulting in liver tumors (hepatocellular carcinoma). Because high doses of PCBs are known to cause extensive damage to liver tissue, it is important to consider the dose level at which liver carcinoma occurs in rodent bioassays. In two rat studies, significant improvement in hepatocellular carcinoma occurred at doses that did not produce obvious histological changes. Hepatocytes are moderately enlarged, but there is no extensive fatty infiltration or necrosis, which is characteristic of bioassays at higher dose levels (23).

None of the PCB compounds were active in short-term tests for mutagenicity, a finding that holds true for most chlorinated carcinogens. Nonetheless, substantial confirmatory evidence for carcinogenicity was provided by a positive cell transformation test using this same PCB mixture (24,25). Both the International Agency for Research on Cancer and the Environmental Protection Agency has concluded that on the basis of available animal data, PCBs should be considered a potential human carcinogen (3).

Most of the genotoxicity tests indicate that PCBs act as indirect nongenotoxic carcinogens. Decreased thyroid hormone levels after PCB treatment have been suggested to play a role in the development of thyroid neoplasms in mice; however, other mechanisms may also be involved. In epidemiological studies, increased mortality from cancer of the liver, gallbladder, bile duct, gastrointestinal tract, and from brain cancer and malignant melanoma was

observed in workers exposed to a series of technical PCB mixtures. A significant relationship between PCB concentrations in adipose tissue and non-Hodgkins lymphoma was found in another study (26).

Declaration by Authors

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