Freshwater Harmful Algal Blooms: Toxins and Children's Health

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Massive accumulations of cyanobacteria (a.k.a. "blue-green algae"), known as freshwater harmful algal blooms (FHABs), are a common global occurrence in water bodies used for recreational purposes and drinking water purification. Bloom prevalence is increased due to anthropogenic changes in land use, agricultural activity, and climate change. These photosynthetic bacteria produce a range of toxic secondary metabolites that affect animals and humans at both chronic and acute dosages. Children are especially at risk because of their lower body weight, behavior, and toxic effects on development. Here we review common FHAB toxins, related clinical symptoms, acceptable concentrations in drinking water, case studies of children's and young adults' exposures to FHAB toxins through drinking water and food, methods of environmental and clinical detection in potential cases of intoxication, and best practices for FHAB prevention.

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Case Report

In July 2002, several previously healthy teenage boys swam in a blue-green algae scum-covered golf course pond in Dane County, Wisconsin. All became ill with mild to severe symptoms of nausea and diarrhea. The most severe symptoms occurred in boys who had reportedly swallowed water. Approximately 48 h after exposure, one of the boys suffered a seizure and died of heart failure.[1] Tests of stool and blood samples were negative for certain pesticides, parasites, and other pathogens. Given no other obvious explanation, exposure to algal toxins was considered, and based on the symptoms, anatoxin-a was implicated. Tests of stool and stomach contents were positive for the toxin and the toxin-producing species, *Anabaena flos-aquae*.[1] After a year of research, the coroner eventually identified anatoxin-a as the most likely underlying cause of death.

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Introduction

An increasing number of waterways in the United States support frequent and intense freshwater harmful algal blooms (FHABs). Decaying algae release noxious odors and reduce dissolved oxygen levels resulting in fish die-offs and a loss of biodiversity.[2] Additionally, large accumulations of cyanobacteria (often called blue-green algae) contain toxins harmful to humans, pets, fish, birds, and other wildlife. As the incidence of FHABs increases, there is greater probability that humans may be exposed to FHAB toxins in recreational environments through accidental ingestion of natural waters or intended ingestion of drinking water and food (e.g., sport fish) containing the toxins. Exposure through skin contact with the algae may also result in dermatitis.[3,4] The toxicology of the most common FHAB toxins is well known, and most algal toxins are acutely effective at very low doses (e.g., parts per billion). Multiple cases of acute illness, primarily in children and young adults, have been reported.[5,6] Frequent low-level exposures are associated with chronic illnesses such as liver cancer.[7–10]

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developmental stage. Compared to adults, children spend more time in the water and swallow more water per body weight than adults. A study by Dufour et al.[11] used breakdown products of chlorine stabilizers as a tracer in urine to determine that children swallow about twice as much water as adults in absolute volume (37 and 16 ml, respectively) during a 2-h swim. Children may ignore posted warnings of FHABs or may not be aware of the hazards posed by waters containing FHAB toxins. Swimming at night is another risky behavior, which is probably more prevalent among young men in their 20s.[12] In previous community-wide outbreaks of algal toxin poisoning, children have had a higher incidence rate of illness and mortality than adults.[13]

Besides lower body weight and risky behavior, developmental effects of FHAB toxins must also be considered.[14] Exposure of fish embryos and larvae to microcystins causes changes in embryonic hatching, a decrease in survival and growth rate, and histopathological effects (as reviewed by Malbrouck and Kestemont[15]). Zebrafish embryos exposed to saxitoxin developed edemas of the eye, pericardium, and yolk sac; curvature of the spine; and sensorimotor deficits.[16] Developmental effects have also been observed for anatoxin-a and cylindrospermopsin in mouse models.[2,17] Whether these studies translate to perturbations in human development is not yet known. Although FHAB poisonings are likely rare compared to other diseases, the actual rate of FHAB-related illnesses is unknown. Anecdotal reports of FHAB poisonings are common in the United States and elsewhere, particularly during the summer months.

The apparent increase in FHAB events in the U.S. waterways is due to a variety of factors including increased agricultural productivity, land use change, and global climate change. Algal productivity in freshwater environments is most often limited by phosphorus and sometimes nitrogen. Addition of these nutrients allows the algae to replicate in the presence of other optimal conditions (temperature, lack of predators, etc.). Thus, runoff from fertilizers used on croplands is a major contributing factor to the occurrence of FHABs.[18] Agricultural pressures on the U.S. lands have increased in recent decades, and farmers are now getting more food from the same amount of land. For example, the U.S. farm output has grown at a steady rate of 1.63% per year since 1948, yet from 1945 to 2002, the total cropland in the United States decreased from 451 to 442 million acres.[19] At the same time, annual phosphorus and nitrogen application to these lands increased by 1.5 and 9.5 million pounds, respectively, from 1960 to 2010.[20] The result is greater fertilization per acre of cropland, making it more difficult to stem the tide of non-point source nutrient runoff.

While agricultural productivity and fertilizer usage has increased, so too have pressures for residential development around lakes and rivers. Lakefront property values continue to increase. For example, in 2002, adding a view of Lake Erie to a home added over $250,000 to the sale price.[21] Development around lakes has also increased. Between 1992 and 2001, 33.5% and 7.5% of lands in the U.S. Great Lakes watershed were converted to residential property and roads, respectively.[22] Similar levels of development have been observed to degrade nearshore habitats.[23] Residential housing development and creation of roads decreases vegetation in nearshore habitats that would otherwise reduce nutrient runoff.[24]

There are no laws requiring regular testing for FHAB toxins in recreational settings, drinking water, or fish in the United States, and only recent laws in a few states (e.g., Oklahoma Senate Bill 259, 2012)[25] require posting advisories at recreational areas warning of the presence of FHAB toxins, but without any mandate for regular testing of recreational waters. The Clean Water Act (section 303(d)) requires states to identify water bodies that are unsafe, meaning they do not meet current water quality standards, and take action to clean them up. This especially applies to non-point source pollution such as nutrient runoff that is responsible for FHABs. Although largely ignored by states, a reduction in nutrient loading to lakes and rivers from non-point sources is required in order to be in compliance with the Clean Water Act. A variety of best management practices (BMP) have been employed to control storm water and agricultural runoff. These BMPs are aimed at reducing nutrients and other contaminants in the storm water before it enters lakes and rivers. These include diverting runoff into grasslands or wetlands, retention ponds, water treatment systems, trenches, rain barrels, constructed wetlands, and many others (reviewed in Refs. 26 and 27).

In agriculture, the implementation of buffer strips, ~50-foot wide strips of grass, reduces nutrient runoff from croplands.[28] A reduction in nutrient runoff may also be achieved by maintaining proper manure storage areas and reducing liquid manure spreading and spreading of manure on hard or frozen soils.[29]