Emerging drinking water disinfection by-products and new health issues

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Abstract

Drinking water disinfection by-products (DBPs) are of concern because some epidemiologic studies have shown that some DBPs are associated with cancer or adverse reproductive/developmental effects in human populations, and other studies have shown that certain DBPs cause similar health effects in laboratory animals. As a result, the U.S. EPA has regulated several DBPs. However, more than 500 DBPs have been reported in drinking water for which little or no occurrence and health data exist. As a result, we recently conducted a nationwide study to obtain occurrence data for unregulated, high priority DBPs that were predicted to cause adverse health effects. The goal of this work was to determine how often and at what levels these DBPs occurred, so that DBPs could be prioritized for future health effects studies. In addition to providing important quantitative information on these unregulated, priority DBPs, we discovered that many of the priority DBPs were formed at higher levels with alternative disinfectants than with chlorine. Also, new iodo-acid DBPs were identified for the first time—and one of these—iodoacetic acid has been shown to be more genotoxic than all of the other haloacid DBPs currently regulated. New research includes toxicological and quantitative occurrence measurements for the five iodo-acids identified. In addition, another EPA study (the Four Lab Study), which involves the chemical and toxicological evaluation of complex drinking water mixtures treated with chlorine and alternative disinfectants, will be briefly discussed, along with other important new health effects information.

1 Introduction

Drinking water disinfection by-products (DBPs) are of concern because some epidemiologic studies have shown that some DBPs are associated with cancer or adverse reproductive/developmental effects in human populations and other studies have shown that certain DBPs cause similar health effects in laboratory animals. As a result, the U.S. Environmental Protection Agency (EPA) has regulated several DBPs; however, most DBPs have not been tested for adverse health effects due to the high costs involved. In order to prioritize new DBPs for health effects testing, we initiated a U.S. Nationwide Occurrence Study to quantify 'high priority' DBPs (those predicted by toxicology experts to possibly have an adverse health effect [1]) to determine how often they occur and at what levels. The fate and transport of these DBPs in the distribution system was also studied, and new DBPs were identified [2].

2 Methods

Drinking water samples were collected across the United States from 12 plants that use chlorine, ozone, chlorine dioxide, and/or chloramines for disinfection. Locations were chosen to provide waters that contain low and high bromide levels, different pH conditions, and different natural organic matter (NOM) levels. For comparison purposes, regulated and Information Collection Rule DBPs were quantified along with the high priority DBPs. Quantitation methods developed involved various extraction, derivatization, and detection methods including solid-phase extraction, liquid-liquid extraction, solid-phase microextraction, and purge-and-trap with gas chromatography (GC)/electron capture detection or GC/mass spectrometry (MS). For identifying new DBPs, GC with low and high resolution electron ionization-MS and chemical ionization-MS were used.

3 Results

Many of the high priority DBPs were found in drinking waters across the United States. High priority DBPs identified and quantified include 3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone (MX) and brominated forms of MX (the so-called BMXs), iodo-trihalomethanes, other halomethanes, halonitromethanes, haloacids, haloacetaldehydes, haloacetonitriles, haloketones, haloacetates, haloamides, and a few non-halogenated DBPs. Important findings include levels of MX being higher (300-400 ng/L at certain locations) than in previous limited studies. In addition, while the use of alternative disinfectants minimized the formation of the four regulated trihalomethanes, certain DBPs were formed at significant concentrations. For example, iodo-trihalomethanes were highest at a plant that used chloramines only for disinfection; dihaloaldehydes were higher at plants using ozonation and/or chloramination; bromo-trihalonitromethanes were highest at a plant using pre-ozonation (followed by chloramination); and MX and BMX compounds were high at a plant using chlorine dioxide (followed by chlorination-chloramination). Another important finding was the discovery of iodo-acids. Iodo-acids have never been reported previously for any disinfectant. Five iodo-acids (iodoacetic acid, bromoiodoacetic acid, (*Z*)-3-bromo-3-iodopropenoic acid, (*E*)-3-bromo-3-

iodopropenoic acid, and (*E*)-2-iodo-3-methylbutenedioic acid) were identified in drinking water from a plant that used chloramine disinfection for high-bromide source waters (Figure 1).

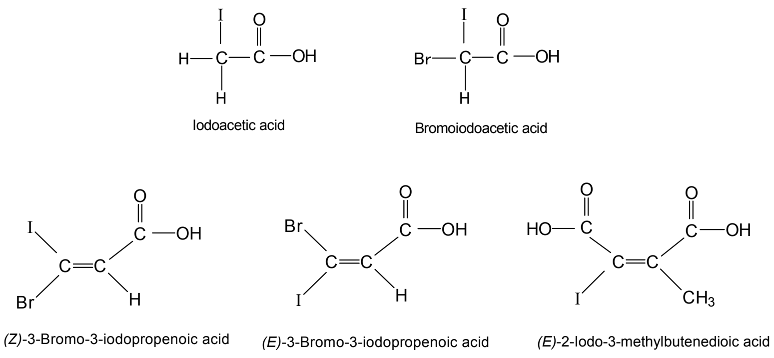

Figure 1: Structures of iodo-acids.

More recent work has shown that they are also present in other chloramination drinking water plants in the United States, and there is increasing evidence that chloramines increase their formation relative to chlorine. In the Nationwide Study, many new brominated haloacids were also identified in drinking waters from several states. Brominated DBPs are important, as current toxicology (and some recent epidemiology) studies suggest that certain brominated DBPs may be of higher health concern than the chlorinated species. Also, studies with iodoacetic acid show that it is more genotoxic to mammalian cells than brominated DBPs [3] (including bromoacetic acid) and is a developmental toxin in mouse embryos [4, 5].

Another recent effort combines comprehensive chemical DBP characterization with comprehensive toxicological characterization of complex DBP mixtures. This effort is called 'the Four Lab Study' because it involves the efforts of the four national laboratories of the U.S. EPA's Office of Research and Development (including the National Health and Environmental Effects Research Laboratory, the National Exposure Research Laboratory, the National Risk Management Research Laboratory, and the National Center for Environmental Assessment). In this effort, treated drinking water from a pilot plant and a full scale treatment plant is being concentrated using reverse osmosis, and the resulting complex DBP mixtures (including identified DBPs and nonidentified DBPs) are being tested in a battery of toxicity assays, with an emphasis on reproductive/developmental effects [6]. Comprehensive DBP characterization is being carried out using GC with low and high resolution-MS, and quantitative measurements are being conducted on a number of targeted DBPs, including regulated DBPs and unregulated 'high priority' DBPs measured in the Nationwide Occurrence Study.

Acknowledgement

Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy.

References

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