HEALTH EFFECTS
REVIEW

Risks and Benefits of Drinking Water Disinfection

Introduction

Drinking water safety continues to be a major public health concern throughout the world. While the impact of waterborne infectious disease is more devastating in third world nations, outbreaks still occur in developed countries. Between 1971 and 1998, 691 waterborne disease outbreaks were reported in the United States [1]. In 1993, a major outbreak of Cryptosporidiosis occurred in Milwaukee, resulting in over 400,000 illnesses and 100 deaths from the contaminated water.

In order to maintain a safe drinking water supply, multiple steps are taken during the treatment process. Protecting the quality of source water is important, but nature makes pristine surface waters impossible. Physical removal (i.e., filtration, coagulation, etc.) is used in most water supplies to remove a large portion of the organic matter, and chemicals like chlorine or ozone are added for microbial disinfection.

In recent years, the public health concern over drinking water has shifted. Although infectious disease will never cease to be an important issue, the attention of agencies such as the U.S. Environmental Protection Agency (EPA) and Health Canada is now focused on health risks of drinking water disinfection by-products (DBPs). This article will discuss the risks and benefits of drinking water disinfection on public health.

Microbial Risks

Waterborne illnesses are caused by microorganisms such as viruses, bacteria, and protozoa. While water is not the only mode of transmission, it has the potential for causing widespread infection. Viruses of interest are primarily found in the Picornaviridae, Adenoviridae, and Caliciviridae families. Common disease-causing bacteria include Campylobacter, Shigella, E.coli, and Salmonella.

Currently, the greatest health risk for water supplies is from Protozoa, organisms with chlorine-resistant spore or cyst forms. Cryptosporidium parvum and Giardia lambia are the most common identifiable agents of recognized waterborne disease out-breaks in the U.S. New pathogens of public health concern continue to emerge, including Mycobacterium avium complex, Microsporidium, and Cyclospora.

Infection by these pathogens most commonly results in diarrhea, nausea, and cramping, with severity often depending on the causal agent. Sensitive populations, however, especially the elderly, infants, and those with weakened immune systems, are more highly susceptible to serious infection, which may lead to death. In order to ensure the safety of the public, the EPA's Surface Water Treatment Rule (SWTR) requires a 99.9% (three-log) reduction of Giardia and a 99.99% (four-log) reduction of viruses. The Interim Enhanced Surface Water Treatment Rule (IESWTR) recently proposed by EPA requires that a 99% (2-log) reduction of Cryptosporidium be achieved [2].

Disinfection By-products

Chemical treatment of public water supplies is designed to kill pathogens that may exist in the drinking water. Disinfection by-products (DBPs) are formed when chemical disinfectants react with organic matter or bromide ions, which naturally occur in water. Chlorine has long been the chemical of choice for primary disinfection, but concerns over by-products have led to the use of other chemicals. Unfortunately, these alternative chemical disinfectants have their own set of by-products.

Chlorine, usually in the form of chlorine gas or liquid bleach (NaOCl), is most effective at lower pH levels and higher temperatures. Chlorination of water (Cl_2+H_2O) results in the formation of hypochlorous acid (HOCl), which readily passes through cell membranes and destroys most pathogens. Two exceptions are Giardia lambia and Cryptosporidium parvum, which are resistant to chlorine because of their cyst forms. Hypochlorous acid also oxidizes bromide ions, producing hypo-bromous acid (HOBr). Both hypochlorous and hypobromous acids react with organic matter like plant materials to form a variety of chlorinated disinfection by-products. The most common DBPs are trihalomethanes (THMs: chloroform, bromodichloromethane, bromoform, dibromochloromethane), haloacetic acids (HAA5: monochloroacetic acid, dichloroacetic acid, trichloro-acetic acid, monobromoacetic acid, and dibromoacetic acid), and halo-acetonitriles (HANs: dichloroaceto-nitrile, dibromoacetonitrile, trichloro-acetonitrile, and other chlorinated/ brominated species).

Ozone is used as an alternative to chlorine for primary disinfection. While effective against Giardia lambia and Cryptosporidium parvum, ozone does not offer residual disinfection. As a result, a secondary disinfection method is required. Ozone reacts with naturally occurring bromide in source water to form brominated by-products including the bromate ion. If natural organic matter is also present, ozonation can lead to the formation of brominated organohalogen compounds like bromoform.

Health Effects of By-products

Based on laboratory animal studies, the U.S. EPA has classified bromate and the three trihalomethane chlorine by-products, chloroform, bromoform and bromodichloromethane, as probable human carcinogens. The fourth, dibromo-chloromethane, is classified as a possible human carcinogen. Due to the uncertainty involved in using the results of high dose animal toxico-logical studies to estimate the risk to humans from chronic exposure to low doses of these by-products, a large number of epidemiological studies have been conducted to assess public health risks from the disinfection of drinking water.

A meta-analysis was conducted in 1992 to pool the relative risks of ten cancer epidemiological studies that investigated exposure to chlorination by-products [4]. Morris et al. found a positive association between consumption of chlorination by-products in drinking water and cancer. The study calculated that as many as 10,000 rectal and bladder cancer cases per year in the U.S. are associated with exposure to drinking water by-products. In sharp contrast, cancer risk estimates calculated from animal toxicology data attributed less than one cancer case per year to the exposure of chlorination by-products [5]. A report reanalyzed the ten studies included in the Moore et al. paper as well as four more recent studies and found that the data were too heterogeneous to pool together [6]. In addition, the aggregate estimates calculated by Moore et al. were sensitive to the addition or deletion of studies, and the selection of the studies included in the analysis was believed to be biased.

Since then, a number of epidemiological studies have been published that the EPA believes were better designed than the earlier studies included in the meta-analysis [7-12]. After evaluating the studies, EPA determined that there was a stronger association with bladder cancer than with colon, rectal, and all other cancers, but that the studies were insufficient for establishing a causal relationship between DBPs and cancer [2]. However, EPA feels that despite the lack of a causal relationship, these studies provide invaluable data that contributes to the weight of evidence for public health effects and warrants stricter regulations of disinfection by-products.

Similar reviews of studies investigating possible associations between drinking water disinfection by-products and reproductive and developmental effects have also been conducted. Reif et al. summarized much of the current literature on reproductive and developmental effects in a report prepared for Health Canada [13]. The links between DBP exposure and birth outcomes were evaluated for sixteen studies, with outcomes being grouped into three categories: fetal growth (birth weight, preterm delivery, and in vetro growth retardation), fetal viability (spontaneous abortion and stillbirth), and risk for fetal malformations (all malformations, cardiac defects, neural tube defects, and chromo-somal abnormalities). According to Reif et al., the data showed mixed epidemiological evidence for an association with DBPs and effects on both fetal growth and fetal viability. Furthermore, the small number of cases for fetal malformations provided inconsistent results for an association. Reif et al. were unable to find a dose-response pattern of increasing risk with increasing concentration, but this is more than likely an artifact of the various exposure assessment methods. Despite the lack of any strong associations, the weight of evidence from the epidemiological studies suggests that an association between drinking water by-products and reproductive and developmental birth outcomes is cause for public health concern. The authors concluded by recommending that further studies be conducted in order to resolve this issue.

Graves et al. conducted their own analysis of the same epidemiological studies to determine the weight of evidence for associations with specific birth outcomes [14]. Rather than having only three groups, outcomes were divided into the following categories: low birth weight, preterm delivery, growth retardation, other reproductive effects, congenital anomalies/birth defects, spontaneous abortion/mis-carriage, stillbirth/fetal death, and neonatal death. The analysis was suggestive of positive associations for growth retardation and urinary tract defects. While the evidence for an association with low birth weight was negative, this is probably due to the inclusion of low birth weights from premature babies. Other measures of growth retardation, however, such as small gestational age and in utero growth retardation show positive associations. As for urinary tract defects, no weight of evidence conclusions should be drawn because the outcome included only two studies. Similar to Reif et al., the authors from this review conclude that further studies were necessary in order to fully investigate the many possible reproductive and develop-mental outcomes possibly associated with DBPs.

Regardless of the outcome in question, any epidemiological study is hindered by the degree of difficulty inherent in assessing exposure to drinking water disinfection by-products. Measures of exposure were different for many of the studies, making comparisons complicated and a meta-analysis inappropriate. Cutoffs for exposure levels for total trihalomethanes varied with each study, and levels were based on monitoring of municipal water supplies matched to maternal residences. In order to detect associations at levels much lower than those used in animal toxicology studies, the concentration and quantity of water consumed must be taken into account.

Conclusions

While everyone agrees that drinking water disinfection is vital for maintaining public health, there is mounting evidence that DBPs have adverse health effects. Methods using disability adjusted life-years have been used to compare these positive and negative health effects [15]. The health benefits of preventing gastroenteritis and possible death in patients with weakened immune systems were found to outweigh the health impact of renal cell cancer by a factor of ten. However, like with any risk assessment, there is a large degree of uncertainty in the estimated health effects.

The ideal solution would be to eliminate the risk of waterborne disease without adding further health risks. While ozonation produces fewer by-products than chlorine, bromate is nonetheless a carcinogen. An alternative on the horizon of new technology is ultraviolet radiation [16]. A number of studies have been recently published that investigate the ability of UV radiation to inactivate Crytosporidium and Giardia cysts [17-20]. At high enough doses, a 99.9% (3-log) reduction of these parasites could be achieved. Despite the excitement over UV, there are concerns with the amount of maintenance required for this new technology [21]. The lamps contain mercury, which, if damaged, have the potential to contaminate drinking water. As technology continues to develop improved alternatives, environmental health agencies like Health Canada and the U.S. EPA continue to make strides towards reduced limits for drinking water disinfection by-products. Given the substantial numbers of people that could be potentially exposed to chemicals or microbial infection from disinfections, it is imperative that we ensure the safety of our drinking water.

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