

WATER CHLORINATION AND ITS RELEVANCE TO HUMAN HEALTH

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ABSTRACT

Climatic conditions are fundamental to life on earth and their destruction or disturbance by direct or indirect human activities is the greatest threat to human health. Human life on earth is directly associated with environmental factors such as "air" and "water." Pollution of air by toxic substances by the activities of mankind has shown to cause serious health issues, including damage to the immune, respiratory, neurological, and reproductive systems, and other health problems like cancer. Water intended for human consumption should be free from microorganisms and toxic substances. The impact and drastic effects of chlorinated water and their impact on human health are poorly studied. Chlorination is an inexpensive and effective process for disinfecting water worldwide. During the disinfection, the chlorine generates hundreds of different by-products called chlorination by-products such as trihalomethanes and halo acetic acids (HAA's) at low levels. In this article we address the action of two HAA's, tri- and di-chloroacetic acid and their impact on the progression of cancer, respiratory disorder, and neurological anomalies.

Keywords: Pollution, Chlorination, Chlorine by-products.

INTRODUCTION

Water plays an important role in the maintenance of human health; therefore, its consumption should be safe, easily accessible, adequate in quantity, and free from contamination [1]. Every cell in our body needs water, because it carries nutrients, minerals, and vitamins but also remove toxins. Therefore, maintenance of quality water and its safety is an important to avoid long-term irreversible effects on human health [2]. It is estimated that more than one billion people still depends on unsafe drinking water sources although humans have taken the control over the natural resources. Similar observations were also noticed in neighboring countries like China, Russia and Brazil [3].

Disinfection strategies of drinking water

Several methods are being used for maintaining the water quality and to inactivate pathogens and other microorganisms such as ozonation, dialysis, filtration, chlorination and UV treatment [4]. Ozonation is an effective method for disinfecting water at wide range of pH [5]. Ozonation eliminates the taste of water by reducing the concentration of inorganic elements such as iron, manganese, and sulfur [6]. Ozonation requires sophisticated techniques and operational methods and is a bit expensive [7]. Chlorination is most widely used inexpensive and effective chemical process for multiple applications, such as the deactivation of pathogens such as *Escherichia coli*, *Rotavirus*, *Salmonella*, and *Shigella*, adenoviruses and *Pseudomonas aeruginosa* species in drinking water, swimming pool water and wastewater [8]. Chlorine is a commonly used chemical for water disinfection, and the fate of chlorine in the water has been studied [9]. However only chlorination is the active technique used all over the world for disinfection in which chlorine byproducts generates trihalomethanes (THM's; mainly chloroform) and halo acetic acids (HAA's), with smaller amounts of haloaldehydes, haloacetonitriles (HAN's) and halo ketones (HK's) and these often cannot be identified and degraded. The disinfecting property of chlorine in the water is based on the oxidizing power of the free oxygen atoms and on chlorine substitution reactions [10]. Although chlorine effectively disinfect several microbes, certain pathogens like protozoan parasites *Giardia* and *Cryptosporidium*, protozoan cysts and eggs have been found to be resistant even at high concentrations of chlorine [11]. UV is one

of the photoelectric methods of disinfecting water and has shown to destroy the microbes by causing mutation in the genomes [12]. UV has shown to kill a wide range of bacteria, viruses, giardium and also yeast cryptosporidium species [13]. UV disinfection is the most effective disinfection water purification system [14]. However, if flow rate of water is high, exposure of UV radiation to microbe was found to be less effective [15].

Water purification strategies played an important role in lengthening the life-expectancy of humans by killing the numerous pathogens ranging from bacteria to viruses by breaking the chemical bonds in their molecules. Among several disinfection strategies, chlorination is only the disinfection strategy is widely being used in developing countries due to its effective oxidant and bleaching characteristics along with inexpensive and labor less procedures [16].

By-products of water chlorination

Chlorination is an inexpensive and effective process for disinfecting water worldwide. Because surface water (water from lakes and rivers) contains organic matter, chlorination found to generate hundreds of different by-products at low levels, called chlorination by-products (CBP's). Chlorine is toxic to microbial communities; therefore, biodegradation is not considered to be a relevant fate process [17]. According to the agency for toxic substances and disease registry trichloroethylene is the most frequently reported organic contaminant in groundwater and 9% and 34% of drinking water supply have been contaminated with trichloroethylene [18]. Most commonly found toxic CBP's in tap water are THM's, HAN's, HK's, chloropicrin, polychlorinated biphenyls and nonvolatile HAA's (Fig. 1) [19]. Many chlorinated CBP's have been identified and are regulated by the environmental protection agencies, but their impact on human health has been neglected [20]. In addition to CBPs, chlorination also has shown to generate several disinfection by-products (DBP's) by reacting with naturally occurring organic matter, anthropogenic contaminants, bromide and iodide during water treatment [6,21]. Although there are potentially a large number of chlorine-derived DBP's, the substances produced in the greatest quantities are the THM's of which chloroform is present prevalently in the highest concentration, and the HAA's, of which

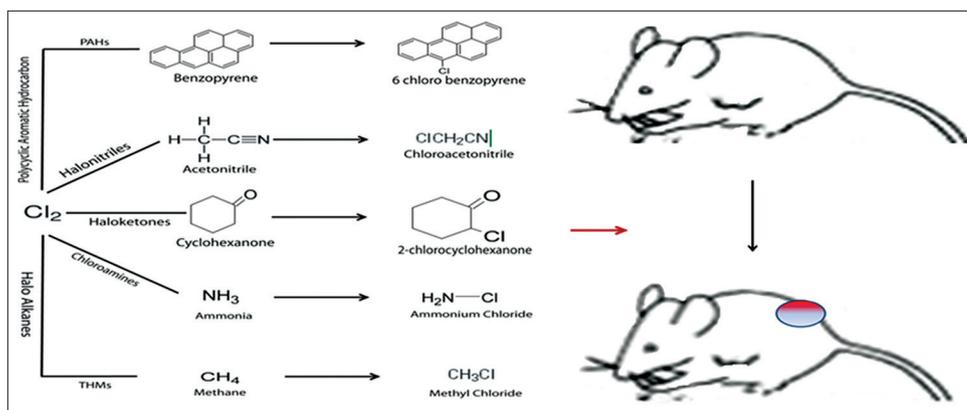


Fig. 1: Pictographic representation of chlorine by-products that are leading to tumor

di- and trichloroacetic acid (DCA and TCA) are generally present in the greatest concentrations [22]. THM's and HAA's were detected in the amniotic fluid and also in breast milk [23]. Breast milk is a major nutrient source for neonatal babies. Therefore, it is also essential to address the action of THM's on brain growth in newly born babies of low-income and geographically vulnerable populations.

Immunological perspective of CBP's

Sodium chlorite can be an inorganic by-product associated with chlorine produced over the chlorination associated with normal water. On the other hand, minor is highlighted regarding the undesirable health consequences associated with exposure to salt chlorite in drinking water. Minimal toxicological and also immunological modifications ended up observed right after exposure to chlorite simply by raising inside the percentages associated with blood reticulocytes, as well as the comparative spleen weights ended up both observed on various sodium chlorite treatment ranges and this also enhance has not been returned simply by modifications in serum Ig-M ranges. A significant enhance inside the final number associated with splenic CD8⁺ cellular material was seen in mice handled together with 30 mg/L with sodium chlorite, but not at the additional concentration. Splenic merged leukocyte result and also peritoneal macrophage activity ended up unaffected simply by sodium chlorite. Lastly, exposure to sodium chlorite did not have an impact on natural killer cellular activity, though some sort of reduction in increased natural killer cellular activity [24].

Biochemical perspective of CBP's

A report on ClO₂, ClO₂⁻ or even ClO₃⁻ demonstrated experiment with alterations within erythrocyte morphology along with osmotic fragility; on larger dosages gentle hemolytic anemia transpired. A study of blood glutathione content material along with red blood cells enzymes concerning glutathione formation demonstrated a dose-related diminution connected with glutathione within chlorine element handled animal groups. The greater oxidative capability from the chlorine materials causing the particular decrease in erythrocytic glutathione may really do the biochemical function producing the other hematological alterations furthermore inhibited DNA activity in a number of microorganisms [25].

Chlorination to genotoxicity

A research spelled out particularly DBP's and on mutagenicity (capacity to bring about permanent DNA mutations) compiled by water samples inside a couple household swimming pools; one particular disinfected together with chlorine as well as the some other together with bromine. The research incorporated short-term changes observed in the biomarkers of genotoxicity and respiratory system issues among participants with all the pool treated together with chlorine. The actual serum study confirmed, biomarkers which often increased inside quantities had been micronuclei inside bloodstream (indicator of DNA injury as well as a cancer malignancy threat predictor inside

healthy subjects) and urinary mutagenicity, a good sign of contact with genotoxic providers [26].

Chlorination to carcinogenicity

Chlorine by-products have shown to trigger the production of free radicals (a highly reactive atomic or subatomic particles lacking an electron) and oxy-sterol (formed when lipids and oxygen molecules combines) in cell and becoming highly carcinogenic [27]. Very recently it was found that the risk associated with exposure of CBP's occurring in drinking water is region specific [28]. According to US council of environment quality "cancer risks" (colon cancer, bladder cancer, hepatic cancer, rectal cancer, breast cancer) among people drinking tap water has 93% than people drinking normal water. DBP's such as trichloroethylene chloroform, chlorodibromomethane, bromodichloromethane, Dichlorophenoxy acetic acid, halogenic acetic acids, TCA and DCA has shown to induce kidney and liver tumors in mice [29]. Both DCA and TCA have been shown to work as complete carcinogens and also as tumor promoters [30]. Similar to some other hepatic carcinogens, the carcinogenicity of HAA's is thought to be due to their ability to induce peroxisome proliferation (PP) [31]. For example, exposure to HAA's has shown to increase liver weight, hepatocyte proliferation and markers of PP in mice [32]. Knock out of studies in mice with peroxisome proliferator alpha receptor (PPAR) demonstrated that, TCA and DCA failed to increase markers of PP including enzymes that catalyze β - and ω -oxidation of fatty acids [33]. Studies have suggested the carcinogenicity of TCA and DCA is due either overproduction of active oxygen species that results from excessive proliferation of peroxisomes or from PPAR-mediated cell proliferation. There are, however, certain studies that do not support the involvement of the PPAR. Most important is that concentrations of HAA's needed to activate a PPAR reporter gene was 10,000 fold greater than a synthetic PPAR agonist [34], and yet the concentrations of TCA and DCA needed to induce PPAR are only 10 times higher than Wy-14,643 in mice [35]. Indeed, several studies have failed to replicate the findings on peroxisomes observed *in vivo* in experiments on cultured cells treated with TCA and DCA. It is possible that TCA and DCA do not act directly on the PPAR. Rather, an intermediary present *in vivo* is needed for the effects of TCA and DCA. One of the closest possible mechanisms of HAA's in induction of tumors is epigenetic regulation.

CBP's such as DCA and TCA have shown to trigger carcinogenesis by up-regulating the expression of one of the proto-oncogene c-Myc. c-Myc belongs to Myc family of transcription factor, and it dimerize with basic helix loop helix transcription factor Max. Myc-Max dimeric complex translocates to the nucleus and down-regulate the expression of cell-cell adhesion molecule, E-cadherin upon binding to the consensus E-box sequence (CACGTG) (Fig. 2). Down-regulation of E-cadherin has shown to associate in epithelial mesenchymal-like transition and the acquisition of a number of phenotypic and genotypic alterations leading to increased angiogenesis, radio-resistance, genomic instability,

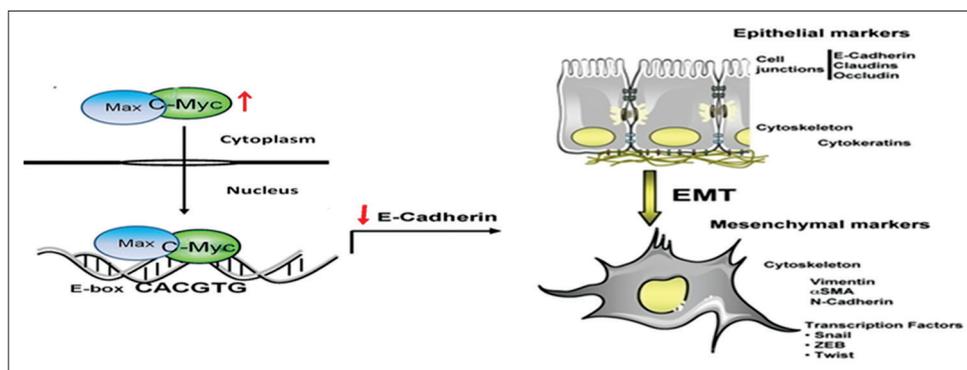


Fig. 2: Myc-Max dimeric complex translocates to the nucleus and down-regulate the expression of cell-cell adhesion molecule, E-cadherin

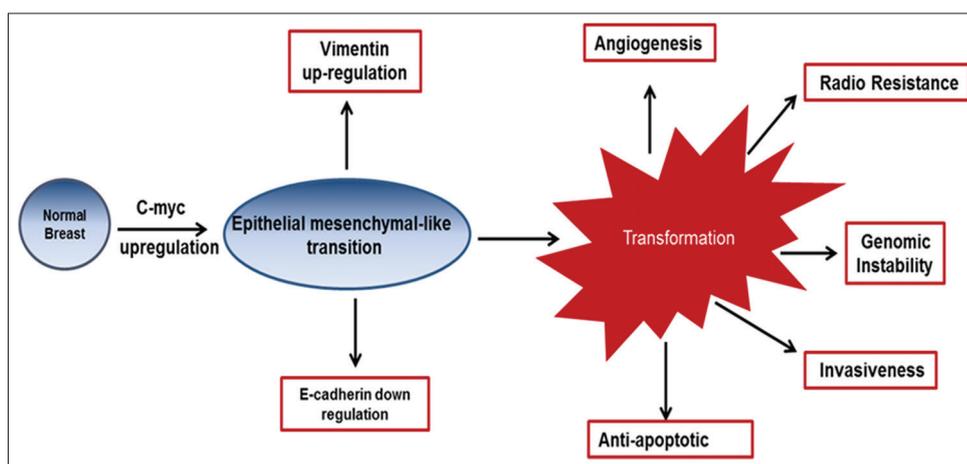


Fig. 3: Down-regulation of E-cadherin has shown to associate in epithelial mesenchymal-like transition and transformation leading to increased angiogenesis, radio-resistance, genomic instability, invasiveness and anti-apoptotic functions

invasiveness and anti-apoptotic functions (Fig. 3). Taken together, we hypothesize that CBPs trigger the neoplastic transformation of normal cells by activating the cellular proto-oncogenes.

CBPs affect respiratory disorder

CBPs have shown to impair the normal physiological function of the lungs by disrupting the airway capillaries leading to asthma [36]. Asthma is a disease affecting more number of individuals irrespective of economic status, gender and age [37]. One of the main symptoms associated with this disease is shortness of breath, wheezing chest tightness and coughing [38]. The prevalence of asthma in urban areas are more prevalent than rural areas due to large scale utilization of several cosmetics products, dyes, lack of exercise, dietary changes, occupational changes and swimming in indoor pool water [39]. Pool water with chlorine reacts with organochemical constituents in cosmetics and dyes and shown to generate several CBP's [40]. Long-term exposure of chlorinated water vapor has shown to damage the lungs by causing inflammation to the air passageways [41]. Moreover, CBP's has shown to act as allergens in where people who always encounters with chlorine treated water such as swimmers, water treatment plant workers and many sewage treatment labors [42]. High absorption or encounter of CBP's to body noticed that the abnormal increase of mast and eosinophils cells in airway mucosa [43]. Research studies conducted on 341 pool children have identified an elevated level of immunoglobulin Ig-E in serum. An Ig-E level in serum was found to be a prognostic marker and also found to associate with histamines and leukotrienes. Eventually leads to blockage of bronchi capillaries smooth muscle contraction and proceeds respiratory syndrome i.e.; Asthma. A research study conducted on 341 children [44].

Influence of CBPs on neurological and other human health problems

By-products of water chlorination (CBP) have shown be associated with birth defects and several neurological anomalies, due to small gestational growth [45]. Gestational growth has shown to associate with abnormal craniofacial anomalies and larger brain volumes are features commonly observed early in children within different types of mental retardations including Down' syndrome [46], Fragile X [47], and autism [48]. In a critical review, the authors agreed that the data supported associations between exposure to CBP and smaller gestational growth [49]. The review, however, found inconsistencies among studies that claimed associations between CBP and birth defects and neurological anomalies. In studies so far conducted, however, the effects of exposure to CBP during pregnancy have been evaluated immediately after birth rather than later when the child matures. Several mental retardations never are diagnosed immediately after birth. For example, Rett syndrome, which is due to a mutated Mecp2, a member of the family of methyl DNA binding proteins, and autism are not detected until a child is 2 years old [50].

Removal of CBP's from water

As well as carbon purification adsorbs chlorine devoid of making virtually any side effects on your water supply. Adsorption comes about whenever your water comes in contact with the particular carbon filtering. Carbon removes of chlorine, taste, odor and also natural substances to produce clean, water to be able to every store in your home. You'll find a couple key kinds of techniques in which eliminate chlorine. The first kind of system is a heavy duty carbon filtration system. This technique works with huge amounts involving filtering

media to produce the highest carrying out carbon purification. The second kind of system is a regular capacity contact to water cartridge. This kind of filter housings work with carbon filtration systems to be able to adsorb chlorine and so are encouraged with regard to regular water volume.

CONCLUSION

We would like to conclude that the levels of exposure to CBP are based on the amount of drinking water consumed and the amount of CBP discharged by the water treatment plant. The amount of CBP reaching each household, however, will not be the same; it depends on several factors including temperature, water delivery systems, and distance from the treatment plant. Moreover, these CBPs together with air pollutants such as secondhand smoke, volatile compounds like benzene can have negative health effects by deteriorating body's immune servelence thereby affect the socio-economic status of low-income and geographically vulnerable populations. Therefore, development of natural or nanoparticle mediated water purification strategies provide safe drinking water with either less or no microbial contamination and is an ongoing process.

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All the authors are equally contributed in this article.

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