Risks Associated with Chlorination

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Abstract:

This paper examines the risks of using and not using chlorine chemicals in the water disinfection process. Water disinfection has been termed by some as the most significant public health measure of this century. When the consideration of eliminating chlorine completely surfaces, one must take a step back and try to understand more completely the risks of such a decision. This paper presents the risks associated with chlorination and its by-products. This paper also discusses with the results of not chlorinating and presents several actual consequences experienced by several countries.

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PURPOSE

This paper examines the risks of using and not using chlorine chemicals in the water disinfection process. Water disinfection has been termed by some as the most significant public health measure of this century. When the consideration of eliminating chlorine completely surfaces, one must take a step back and try to understand more completely the risks of such a decision. This paper presents the risks associated with chlorination and its by-products. This paper also discusses with the results of not chlorinating and presents several actual consequences experienced by several countries.

INTRODUCTION

Since chlorination was started in the early 1900's, many waterborne diseases such as typhoid and cholera have been virtually eliminated. These dramatic reductions of cholera and typhoid were achieved in the first half of this century well before antibiotics and immunizations were even invented (United States Environmental Protection Agency. "Fact Sheet on Water Chlorination", 1992).

As early as 1893 chlorination was used to treat sewage effluent in Brewster, NY, to protect New York City drinking water. In 1897, chlorination was used to disinfect a **water main in Maidstone, Kent, UK, after an outbreak of typhoid. This lead the way for the rest of** the **world to develop continuous methods for water disinfection.** Chicago stopped **the** spread of **typhoid** by **treating the contaminated water of stock yards (Farland, W.H., Gibb, H.J.,** 1993). **These disinfection processes generally centered around** chlorination, due **to its** large range of **effectiveness and low cost. In effect, chlorination was applied throughout** the United **States and produced dramatic reductions in morbidity and mortality** associated with waterborne disease such as typhoid, cholera, amoebic dysentery, bacterial gastroenteritis, and giardiasis. **"The introduction** of **drinking water disinfection** in the United States in the early 1900's is credited with reducing the incidence of cholera by 90%, typhoid and leptospirosis by 80% and amoebic dysentery by 50%" (Cruan, G.F., 1993).

Several methods of disinfection **and** filtration are currently being used in the United States. Table 1 lists the percentages of current disinfection methods and as you can see chlorine is used 95% of the time when serving populations of less than 10,000 people and 70% of the time when serving population of over **10,000 people.**

Table 1.

Methods of Disinfection	
Drinking water systems serving a population > 10,000	
• **Chlorination**	**70%**
• **Chloramination**	**25%**
• **Chlorine Dioxide**	**5%**
• **Ozonation**	**<1%**
Drinking water systems serving a population < 10,000	
• **Chlorination**	**>95%**

Cruan, G.F. **Safety of Water Disinfection: Balancing Chemical & Microbial Risks.** *International Life Sciences Institute.* (1993).

CHLORINATION BY-PRODUCTS

Over the past decade many concerns have been raised about the formation of toxic and carcinogenic by-products of chlorination. It was discovered, in 1974, that the combination of chlorine with organic compounds in drinking water produced trihalomethanes as well as other by-products, in particular, chloroform (EPA, "Fact Sheet on Water Chlorination[11], 1992).

In 1975, the EPA began the highly publicized National Organics Reconnaissance Survey. This survey revealed the presence of halogenated organic compounds resulting from chlorination in the municipal drinking **water** supplies **of 80** cities. Because of the recognition that the chlorination process caused the formation of THM's (trihalomethanes) and other by-products, intense interest in the possible health effects of such compounds prompted numerous animal and epidemiologic studies. In the 80's several epidemiological studies reported an increased risk of bladder, colon **and** rectal cancer in individuals drinking chlorinated drinking water, however studies evaluating the carcinogenicity of chlorine in animals are negative (EPA, "Fact Sheet on Water Chlorination[11], 1992). The International Agency for Research on Cancer reported in 1991 that there was sufficient evidence that several by-products of chlorination had caused cancer in animals. This resulted in the EPA establishing a regulation in 1979 that limited the amount of THMs to 0.1 mg/L for water supplies serving 10,000 or more people (United States Environmental Protection Agency. "Ambient Water Quality Criteria for Chlorine - 1984.").

Chlorine disinfection by-products include under scrutiny acetaldehyde, chloroform, 2,4-dichlorophenol, formaldehyde, 2,4,6-trichlorophenol, and pentachlorophenol. Three of these compounds, 2,4-dichlorophenol, formaldehyde, and 2,4, 6-trichlorophenol, were reported to have limited evidence of carcinogenicity. Only one of the compounds, formaldehyde, is probably carcinogenic to humans, albeit primarily via inhalation. The overall evaluation of the evidence for the rest of the compounds were considered possibly carcinogenic and is presented in Table 2 (Cruan, G.F., 1993).

Table 2.

International Agency for Research on Cancer (IARC) Evaluations of Chlorination By-Products

		Degree of evidence		
Compound	**Year**	**Human**	**Animal**	**Evaluation**
Acetaldehyde	1987	I	**S**	**2B**
Chloroform	1987	I	**S**	**2B**
2,4-Dichlorophenol	1986	L	**-**	**2B**
Formaldehyde	1987	L	**S**	2A
2,4,6-Trichlorophenol	1987	L	**S**	**2B**
Pentachlorophenol	1990	I	**S**	2B

I = inadequate, S = sufficient, L = limited, 2A **= probably carcinogenic, and 2B = possibly** carcinogenic.

Cruan, G.F. **Safety of Water Disinfection: Balancing Chemical & Microbial Risks.** *International Life Sciences Institute.* (1993).

Halogenated by-products have also been identified in chlorinated finished drinking water. In 1983, haloacetic acids (HAAs) were first identified by Miller, Uden, and Christman. Trihalomethanes were identified as the most prevalent class of halogenated organic compounds in finished drinking water. Halogenated acids have since been found to be the second most prevalent class of halogenated organic compounds in finished drinking water (Reckhow, D.A., Singer, P.C., 1990).

The major halogenated disinfection by products identified with regular frequency in finished drinking water are the haloacetonitriles, halopicrins, cyanogen halides, haloketones, haloaldehydes, halophenols, and chloral hydrate.

There are also a number of non-halogenated oxidation by-products that have been reported to result from water chlorination. Formaldehyde, acetaldehyde, and a number of aldo- and ketoacids are the most common.

Chlorinated furanone MX deserves specific mention. Although its concentration in finished drinking water has been found only on the order of tens of nanograms/liter compared to the tens of micrograms/liter concentrations for more common disinfection by-products, MX has been reported responsible for 40-60% of the overall mutagenicity of chlorinated drinking water. MX's significance from a public health standpoint is questionable, however, due to its detoxification in mammalian systems (Kronberg, L., Holmbom, B., Reunanen, M., Tikkanen, L., 1988).

Researchers have only been able to account for about 50% of the resultant halogenated organic material. This percentage was found by using a measurable parameter total organic halide (TOX) as a collective parameter for all halogenated organic by-products. Reckhow and Singer showed in 1990 that on a chlorine-equivalent basis, chloroform constituted an average of 22%, trichloroacetic acid 17%, dichloroacetic acid 7%, dichloroacetonitrile 0.3%, and trichloroacetone 0.4% of the TOX measured following the chlorination of several raw drinking water at pH 7.0 and 20°C, with a holding period of 3 days (Reckhow, D.A., Singer, P.C., 1990).

It has been established that disinfection by-products formation is "strongly influenced by the following parameters: pH, temperature, type and concentration of precursors, chlorine concentration, bromide ion concentration, and organic nitrogen concentration" (Cruan, G.F.). This means that the formation of THMs and Halogenated by-products can vary greatly depending upon what time of the year it is.

It has also been established that "humic substances are the principal precursors of trihalomethanes and other halogenated disinfection by-products."(Cruan, G.F.) Humic substances (humic and fiilvic acids) make up a major part of dissolved organic carbon in most natural waters and also pollution from industry above the flow of ones water supply. Numerous laboratory studies have demonstrated that chlorination of these materials yield the same disinfection by-products as are observed in finished drinking water. The activated aromatic structures within humic substances are believed to be especially reactive with chlorine and produce the majority of the by-products identified to date. Reckhow and Singer showed, based on data from alkalimetric titration and ^CNMR analysis, that chlorine consumption was strongly related to the activated aromatic content of aquatic humic material and, correspondingly, that disinfection by-products formation was related to the activated aromatic content. This basically means that the more pollution and debris in the water results in more chlorine being used and additional disinfection by-products increasing.

RISK OF USING CHLORINATION

Since the public health impact of contaminated drinking water has become nearly non-existent, more emphasis has been placed on smaller once tolerated risks of other diseases such as cancer. The carcinogenic risk of consuming chlorinated drinking water has to be compared with the benefits of chlorination. This comparison is difficult for many reasons. Carcinogenic risk and microbial risk utilize different assumptions and contain different uncertainties, the theoretical carcinogenic risk is likely minuscule compared to the demonstrated decrease in microbial risks from drinking water. Furthermore, it is difficult to compare the costs of diseases such as typhoid of cholera with the costs of cancer. Similarly, it is difficult to compare the cost of any of these diseases with economic cost of chlorination or some other form of disinfection.

TOXICOLOGICAL STUDY

In 1989, bromodichloromethane was administered to Wistar rats in a lifetime study of the compound. The specimens in this study developed liver and kidney cancer (Tumasonis, C.F., McMartin, D.N., Bush, B., 1989). In another study the carcinogenic potential of chlorinated water and several THM by-products was tested on male and female mice and rats. Neoplasms of the kidney, colon, and rectum are rare in untreated animals and occur at an incidence of less than 1%. The doses given, were well above the maximum permissible contaminant level for total trihalomethanes, 100 fig/L, in drinking water. Chloroform, chlorodibromomethane, bromodichloromethane, bromoform, chlorine, and chloramine was tested. The treatment with trihalomethanes caused liver, kidney, colon and rectal neoplasms. Most of the treatment related neoplasms were observed in animals at the end of the 2-year dosing period. Kidney tumors had an incidence of 24-30%. Large-intestine neoplasms had an incidence of 25-90%. The decreased survival in come on the high-dose groups may have been related to treatment, although the cause of death in individual animals couldn't be definitely determined (Dunnick, J.K., Melnick, R.L., 1993).

No neoplasms or toxic effects were observed in the chlorine or chloramine study done by Dunnick and Melnick (1993). Several other studies which only lasted 13 weeks also found no toxic effects in the liver, kidney, or intestine in rats (Daniel, F.B., Condie, L.W., Robinson M., 1990).

Figure 1 shows a dose response relationship for the formation of liver neoplasms. As you can see the relationship follows a curve with the effects leveling out as the dose become larger. Also notice that the chlorodibromomethane centers around about 38% liver tumor incidence at its highest dose while chloroform was closer to 95% liver tumor incidence at its highest dose. These doses were however "well above the EPA-regulated permissible levels for trihalomethanes" (Dunnick, J.K., Melnick, R.L., 1993).

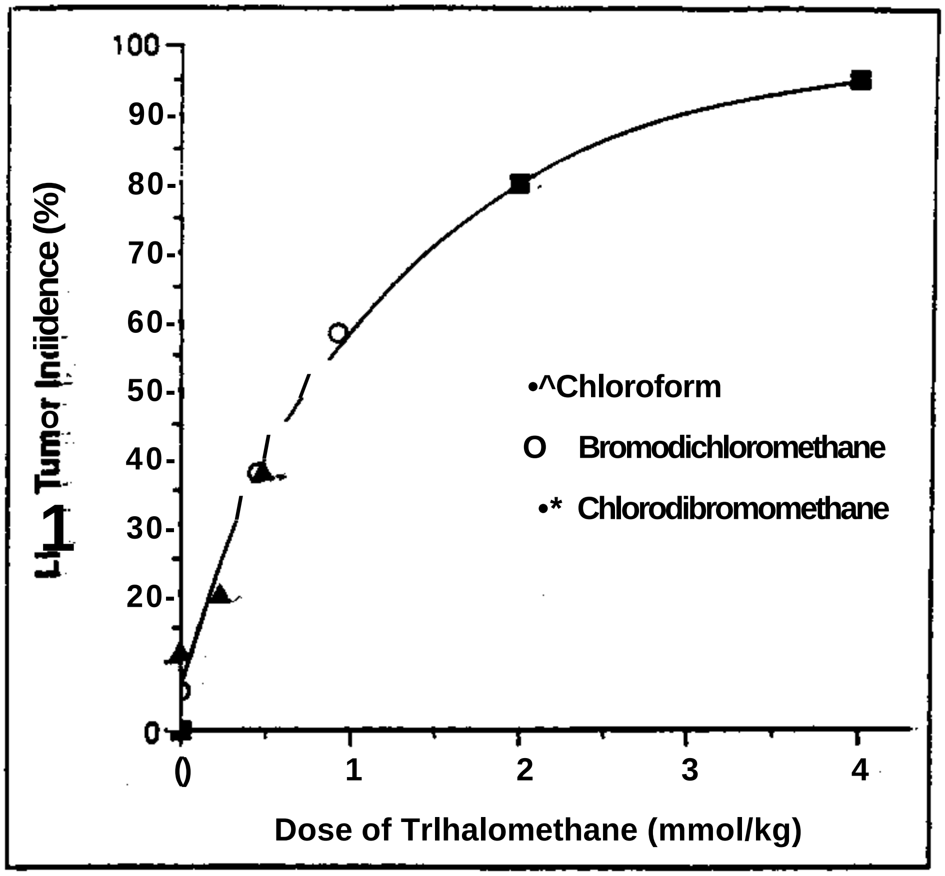

Figure 1.
Dunnick, J.K., Melnick, R.L. "Assessment of the Carcinogenic Potential of Chlorinated Water: Experimental Studies of Chlorine, Chloramine, and Trihalomethanes". ***Journal of National Cancer Institute.*** **85(1Q), p. 817-822, (1993).**

EPIDEMIOLOGICAL STUDIES

Although numerous epidemiologic and animal studies have been conducted on the carcinogenicity of chlorination by-products, the estimated relative risks of cancer from such studies are still considered quite small. With the large background of cancer in the general population, it is difficult to determine whether such small risks can actually be associated with the consumption of chlorinated drinking water. Exposures are difficult to determine, particularly over the long periods of the lives of those being studied and with respect to the amount of tap water consumed. Furthermore, chlorination by-products differ according to local conditions, practices of chlorination and time of year, thus making it difficult to get a good measure of exposure. Lifestyle, such as dietary practices and smoking, may differ between populations served by chlorinated and unchlorinated water supplies and could affect the incidence of certain types of cancer, thus confounding the apparent risk.

Occupations also may differ. Although some studies addressed some of these issues, none of the studies has addressed all of the issues simultaneously.

It has been shown in one study that the way that one collects and dissimulates the data effects the outcome of the risk assessment. Four methods were presented in this paper and **the results** differed **depending upon the way the data was broken down.**

POSSIBLE MISCALCULATIONS IN EPIDEMIOLOGICAL STUDIES

354 bladder cancer cases and 752 population controls were personally interviewed for a national bladder cancer study. The questions asked included detailed histories concerning sociodemographic factors, artificial sweetener use, coffee, tea, and other fluid consumption, occupation, tobacco and hair dye use, personal illnesses and medical treatments, family **health, and lifetime residential mobility including primary source of drinking water at each residence. Bladder cancer cases where identified through a statewide cancer reporting system. The controls where selected at random from the Iowa population. Detailed information about the existing water system used by these people was collected** (Lynch, C.F., **Woolson, R.F., O'Gorman, T., Cantor, K.P., 1989).**

In order to show how miscalculations could occur, four different methods were used to quantify chlorination exposure. **Method 1** used only the last place of residence from a participant's lifetime residential history and assumed that the person had lived their entire life at that residence and used only the residential water supply. This method assumed that the person consumed chlorinated water for as long as the system was chlorinated. Method 2 was the same as method 1 with the exception that a participant was only assigned to the town drinking water only if they indicated it as their primary source. Method 3 used the potential years that the person was exposed to chlorinated drinking water during the participants time interval at their last residence. Method 4 included the participants entire lifetime of potential exposure to chlorinated drinking water.

Twenty-eight other potential risk factors for bladder cancer were also evaluated. These included age, sex, years of education, religious affiliation, marital status, coffee consumption, hot tea consumption, iced tea consumption, daily tap water consumption (includes coffee, tea, tap water and reconstituted concentrated juices), daily chlorinated tap water consumption, daily non-tap water consumption (includes soft drinks, fruit juices, milk, wine, beer, and spirits), hazardous occupational materials, fanning occupation, pack-years of cigarette smoking, cigar smoking, pipe smoking, use of chewing tobacco, use of snuff, irradiation of the pelvic area as a medical treatment, use of artificial sweeteners, use of hair coloring products, family history of urinary tract cancer, history of diabetes mellitus, history of bladder infection, history of bladder stones, history of kidney infection, history of kidney stones, and urban density (Lynch, C.R, Wooison, R.F., O'Gorman, T., Cantor, K.P., 1989). In other words many factors were considered. Risk of many hazardous occupational materials were also measured.

After a breakdown of person-years verses primary drinking water source was done, it was observed that bladder cancer cases more frequently used chlorinated water supplies while controls more frequently used nonchlorinated drinking water. There is nothing statistically significant about this result, however it does indicate a possible trend.

When analyzed, method one had the lowest odds of chlorinated water being a significant factor. The odds increased as the remaining three methods were examined. All of the methods showed increasing odds ratio with relation to longer duration of exposure. However, none of the ratios were significant when using method 1 while they were when using method 4. Method 4 ratios for 26-50 and 50+ years of chlorination exposure were significant with a Chi-squared p value of $< .01$. Method 4 used the most information about the participants mobile histories and drinking water sources. Therefore depending on how a person breaks down the data can determine whether the results are significant or not. "Bladder cancer risk in this study increased with duration of exposure to chlorinated drinking water sources. The estimates of risk were quite sensitive to the method used to estimate exposure duration (Lynch, C.F., Wooison, R.F., O'Gorman, T., Cantor, K.P., 1989).

ACTUAL STUDIES

One study done in Norway due to the excellent nationwide cancer registration in a stable, genetically and socioeconomicaily uniform population included many of the criteria mentioned above plus information such as total organic carbon and color in the water which is thought to reduce the consumption of water. The Norwegian population was also rather stationary. In 1960, 60% of the population received chlorinated water from the same municipality where they were born. Total yearly migration (4-5% of the total population) between municipalities was very stable from the years 1961-1982. This means that the data contained fewer questionable chlorinated drinking water histories (Flaten, T.P., 1992).

In this study colon and rectal cancer rates were 20-30% higher in the chlorinated than in the nonchlorinating municipalities. The study used regression analysis which is shown in Figure 2. At 75% chlorination the rates are 44% (men) and 24% (women) higher than those at zero chlorination (Flaten, T.P.). Bladder cancer rates were 6% (men)

and 18% (women) higher in the chlorinated than in nonchlorinated water supplies. These percentages however were not significantly higher (Flaten, T.P., 1992).

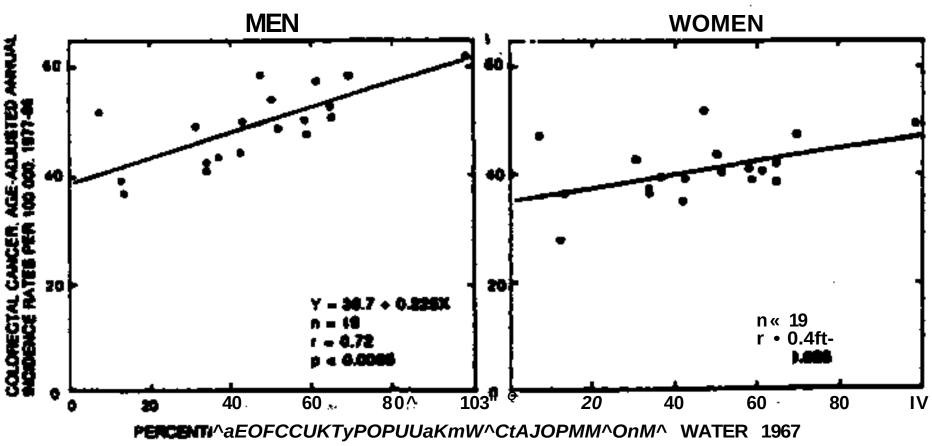

Figure 2.
Flaten, T.P. "Chlorination of Drinking Water and Cancer Incidence in Norway." ***International Journal of Epidemiology.*** **21(1), 7-15, (1992).**

Figure 3 shows the trend towards more colorectal cancer.

- **(1, filled circles) Age-adjusted incidence rates from colorectal cancer in seven consecutive time period for Norway.**
- **(2, open circles) 2 nonchlorinating municipalities.**
- **(3, filled squares) 6 municipalities starting chlorination in 1952-1956.**
- **(4, open squares) 7 municipalities starting chlorination in 1958-1964.**

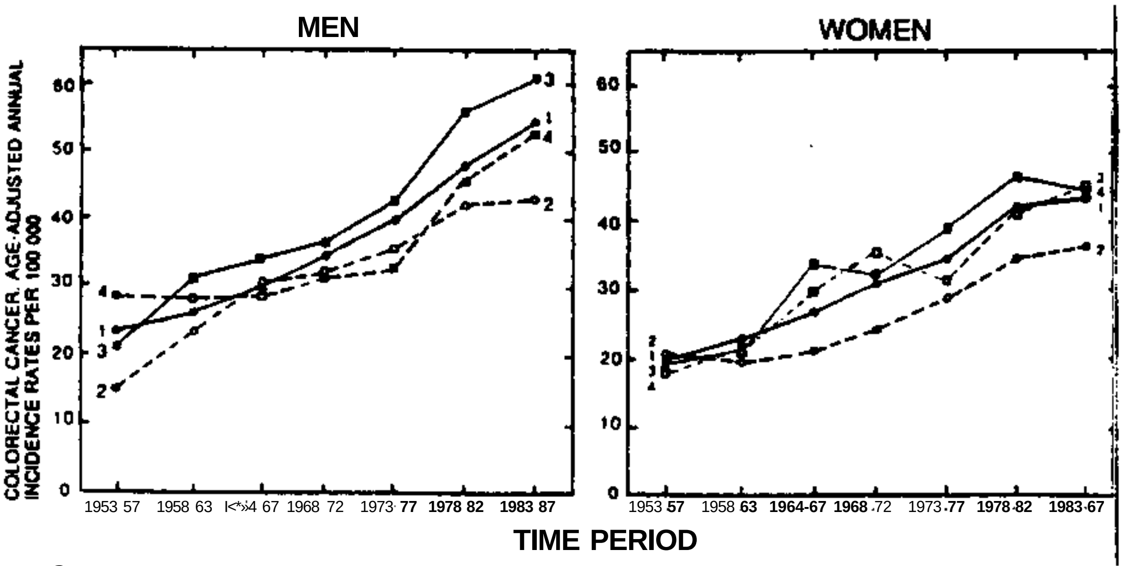

Figure 3.
Flaten, T.P. "Chlorination of Drinking Water and Cancer Incidence in Norway." *International Journal of Epidemiology.* 21 (I), 7-15,(1992).

If you combine all of the different cancers together, strong correlation's were found and the rates were higher in chlorinating than in the nonchlorinated water supplies. More than half of these differences were attributed to colorectal cancer. It is also interesting to note that the death rates were higher for men in nonchlorinated water supplies and similar for women (Flaten, T.P., 1992).

This study done in Norway gives some support to indications from U.S. epidemiological studies that drinking chlorinated water may be associated with colorectal cancer, but the associations are weak and don't provide substantial evidence of a causal relationship.

A meta analysis of 10 epidemiologic studies demonstrated an association that followed a dose-response relationship between consumption of chlorination byproducts in drinking water and the development of urinary bladder and rectal cancers in humans. The relative risk for urinary cancer was 1.2 (95% confidence interval = 1.09-1.34), and the relative risk for rectal cancer was 1.38 (95% confidence interval = 1.01-1.87). The increase in cancer risk was estimated to account for 9% of urinary bladder cancers (4200 cases) and 18% of rectal cancers (6500 cases) per year in the United States. But the findings were qualified by the following: (1) "Individual epidemiological investigations into the association between chlorination by-products in drinking water and cancer have been suggestive but inconclusive." (2) "The most important potential confounder not adjusted for in these studies is diet." (3) "Precise cause and effect cannot be determined." (Morris, R.D., Audet, A.M., Angelillo, I.F., 1992).

The International Agency for Research on Cancer concluded that there was inadequate information from epidemiologic studies and experiments in animals to assess the risk for development of cancer in humans from chlorinated drinking water alone and that chlorination of drinking water remains essential in prevention of disease (Dunnick, J.K., Melnick, R.L., 1993).

RISK OF NOT CHLORINATING WATER SUPPLIES

Not chlorinating the water is more dangerous than the risk of cancer. "The World Health Organization estimates that 25,000 people die each day of diseases from water that has not been properly disinfected (Smith, K., 1994). That adds up to 9.1 million deaths per year. "We must take care so that our current attention to such risks doesn't overshadow the strides made in the traditional public health considerations" (Cruan, G.F., 1993). In 1991 a Cholera epidemic swept Peru and has since spread to several other countries of the American Continents. A very rapid and overwhelming dissemination of the disease occurred within cities and neighboring towns. Within a few weeks, the epidemic has spread from the coastal area, inland to the mountains, and to the Amazon watershed (Salazar-Lindo, E., Alegre, M., Rodriguez, M., Carrión, P., Razzeto, N., 1993). The Peruvian officials decided not to chlorinate much of the country's drinking water based on studies by the US Environmental Protection Agency showing that the chlorine may create a slight cancer risk. More than 300,000 cases of cholera were reported. Pan American Health Organization (PAHO) officials believe that the bacteria first arrived with a Chinese freighter, which released its apparently contaminated bilge water into the harbor at Lima, Peru (Anderson, C, 1991). Although eating raw fish and raw sea food were initially suspected as the vehicle of transmission of cholera in this epidemic, the explosive nature of the outbreak, particularly in the urban areas, suggested that drinking water supplies must have been contaminated. A detailed study of Trujillo in the coastal area showed that the problem lay in the poor or non-existent water disinfection methods. Trujillo public water supply consisted of 43 drilled wells and engineers in charge of the system at the time believed that no water treatment was necessary. "Ironically, water had not been disinfected in Trujillo because those in charge of the system had a disproportionately large concern over possible harmful disinfection by-products and little concern for water borne diseases like cholera" (Salazar-Lindo, E., Alegre, M., Rodriguez, M., Carrión, P., Razzeto, N.).

The first cases of cholera in the city were reported during the first week of February 1991,5 days after cholera broke out in Chimbote, a seaport 45 minutes by road south of Trujillo. Figure 4 shows the epidemic curve in Trujillo. By the end of 1991, the total number of cases reported was 14,957. However, 75% of the cases occurred within only the first 8 weeks of the epidemic. The second wave of cases started increasing in the last 2 weeks of 1991, coinciding with the return of the summer season in the area. The epidemic curve of this second wave was shorter but wider when compared to the previous year.

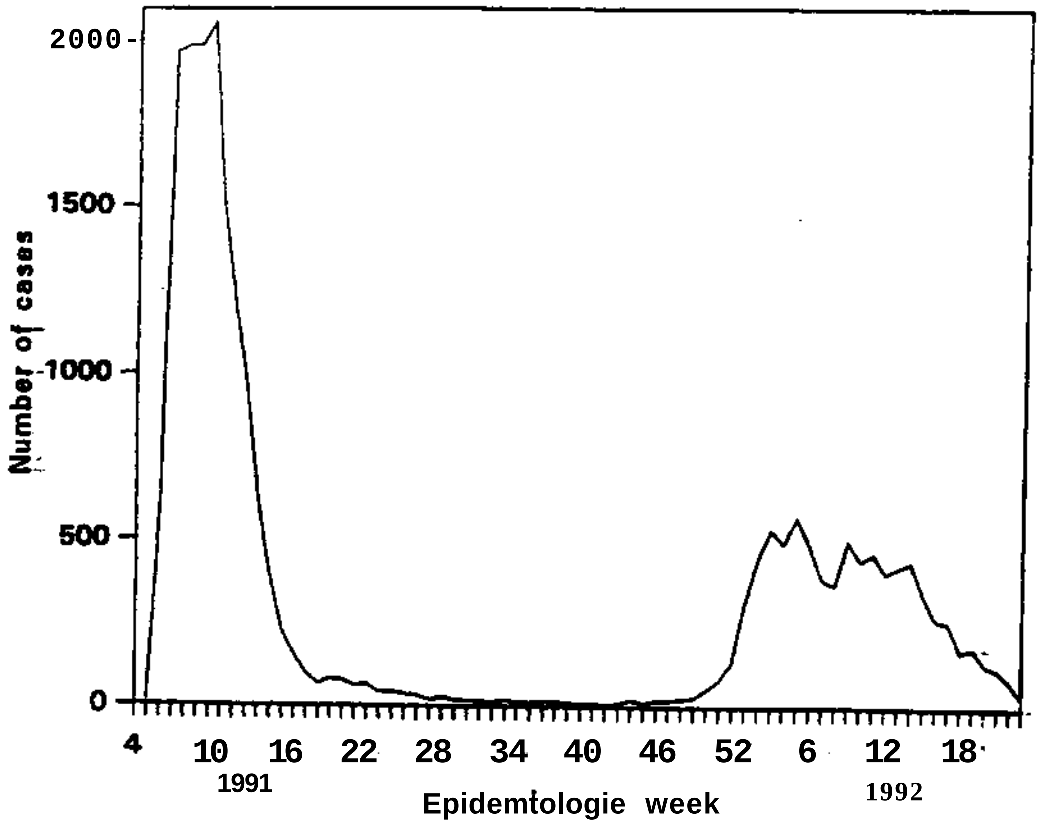

Figure 4.
Salazar-Lindo, E., Alegre, M., Rodriguez, M., Carrión, P., Razzeto, N. "The Peruvian Cholera Epidemic and the Role of Chlorination in its Control and Prevention." ***International Life Sciences Institute,*** **p. 401-413, (1993).**

It seems that the tap water was polluted with sewage flows. The high attack rate observed in sections on the city of Trujiilo connected to the water system, and the occurrence of clusters of cases in areas served by wells known to bear fecal contamination, support this assertion (Salazar-Lindo, E., Alegre, M., Rodriguez, M., Carrión, P., Razzeto, N.). Chlorine could have protected the water supply even if it were exposed to bacteria.

CONCLUDING REMARKS

The risks of using chlorine in water disinfection is miniscule. There is, however, a trend towards increasing cancer in chlorinated areas. Alternatives could be substituted in chlorine's place, but even less is known about by-products from alternatives. Further studies must be conducted before a final disicion can be made about chlorine.

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