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Illness associated with Contamination of Drinking Water Supplies with Phenol

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An accidental spill of phenol (100%) into the Nakdong river with subsequent contamination of the tap water for about two million consumers in Teagu city of Korea occurred in March 1991. A historical cohort study of 6,913 individuals was undertaken to determine association with illness. Population subjects were divided into two groups of exposed and unexposed. Exposed subjects were reported to have significantly more phenol associated symptoms than those in a nearby unexposed area (39.6% vs. 9.4%, $p<0.01$). Especially, in the related symptoms, highly significant differences were noted in the number of subjects reporting gastrointestinal illness such as nausea, vomiting, diarrhea, or abdominal pain. During the accident, study subjects who experienced peculiar taste or odor in the tap water were significantly more in the exposed areas (92% vs. 34.3%).

Key Words : *Phenol, Chlorphenol, Historical cohort study, Water contamination.*

INTRODUCTION

Human illness resulting from tap water contamination has not been very common. However, several large epidemics of illness have been traced to chemicals in water. These have included methyl mercury poisoning from ingestion of fish caught in the sea contaminated by industrial sewage in Minamata Bay, Japan, from 1953 to 1959, and "Itai-Itai" disease caused by cadmium contamination in Toyama prefecture, Japan. On the other hand, lead, arsenic, and pesticide poisoning have also been caused by drinking water contaminated.

This report describes an outbreak of human illness caused by accidental leakage of phenol (100%) into the Nakdong river in March 16th 1991 in Korea, which is a large source of drinking water supply for Taegu city.

Taegu city has three sources of water supply, one is the Nakdong river which was contaminated by phenol from this accident and the others are the Kachang and Kongsan lakes.

The river was contaminated with about 30 tons of 100% phenol solution effused from a manufacturing company of electronic boards at the Kumi industrial zone located 50 km away upstream from Taegu city. Subsequent chlorination of the central water supply converted much of the phenol to various kinds of chlorophenol such as monochlorophenols, dichlorophenols, and trichlorophenols, which imparted a strong foul taste to the drinking water.

The water authorities were not aware that their supply had been badly contaminated until after the phenol contaminated water had reached consumers. People who had been exposed to contaminated water came to complain of and report foul

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odor and gastrointestinal symptoms as time went by, especially pregnant women worried about abnormal outcomes of pregnancy.

This study was undertaken to assess whether there was an actual increase in the incidence of illness from this accidental spill of phenol among the exposed people in Taegu city, and if any, whether this increase was related to consumption of contaminated water.

MATERIALS AND METHODS

A historical cohort study of 6,913 individuals was undertaken to determine whether consumption of contaminated water was associated with illness. The population subjects were divided into two groups, the exposed and unexposed group based on distribution of water supply. The exposed group consisted of 1,352 households receiving water from the Nakdong river contaminated by phenol and the unexposed was composed of 907 households receiving water from the Kachang and Kongsan lakes which are located in the adjacent greenbelt area of Taegu.

Study subjects were students and their family members of one class by each grade of elementary, junior and high schools randomly selected through the department of Taegu Educational Agency. Six of the schools are located in the contaminated area, four in unexposed area.

Study subjects were subdivided into four groups depending on awareness of water supply area. 'The true exposed group' denotes people who actually live in the exposed area, and also who believe that they were exposed to contaminated water, 'The false exposed group' denotes people who believe that they were exposed to contaminated water but who do not live in the exposed area, 'the true unexposed group' denotes people who believe that they were not exposed to contaminated water and actually live in the unexposed area and 'the false unexposed group' denotes people who believe that they were not exposed to contaminated water but live in the exposed area (Table 1).

Self-administered questionnaires were distributed through students on 24th and 25th of May 1991, and returned after three days.

The questionnaire included 14 sorts of symptoms experienced after these days with nine related and five unrelated. Besides, demographic characteristics, medical care received because of related symptoms, preexisting illnesses and the underlying disease and knowledge on the sources of drinking water were also analyzed.

Unrelated symptoms were included to permit detection of exposed individuals whose symptoms were psychogenic in origin.

Results were analyzed statistically by the standard X^2 test or by estimating two tailed p values.

RESULTS

The water authorities (department of central water supply in Taegu city) started to test for the phenol in the central water supply from March 16th 1991 and continued to March 19th 1991.

Phenol concentration was revealed as 0.05 ppm at two water reservoirs(Nakdong and Dasa) pumping from the Nakdong river. The reservoirs were about five kilometers distant from each other.

The initial concentration of chlorophenol in the tap water measured by the water authorities revealed 0.0084 ppm which slightly exceeded the 0.005 ppm limit of the Korea Environmental Protection Agency for phenol in drinking water (Table 2).

Among 2,259 households, 1,888 (82%) answered the questionnaire. The replying residents were 6,913 from 1,673 households that excluded 205 households given inadequate information.

A broadly similar sex distribution was revealed in

Table 1. Distribution of respondents of study population

Study population group	Frequency	
	No.	%
The true exposed group	3,089	44.7
The false exposed group	506	7.3
The false unexposed group	450	6.5
The true unexposed	1,444	20.9
Inadequate information	1,424	20.6
Total	6,913	100.0

Table 2. Estimated phenol concentration in two reservoirs

Date	Nakdong	Dasa	Remarks
13 March			accidental leakage of phenol(100%, 30tons)
16 March	0.05 mg/L	0.05 mg/L	
17 March	0.05	0.05	
18 March	<0.01	<0.01	
19 March	0.0085		chlorophenol concentration in tap water

Table 3. Number(%) of people who experienced peculiar taste or odor in the tap water during accident

		Exposed				Unexposed			
		Before-accident		After-accident		Before-accident		After-accident	
Odors	Tastes	No.	%	No.	%	No.	%	No.	%
(−)	(−)	1,002	32.8	244	8.0	1,009	71.6	923	65.7
(+)	(−)	926	30.3	531	17.4	230	16.3	191	13.6
(−)	(+)	232	7.6	114	3.7	51	3.6	44	3.1
(+)	(+)	896	29.3	2,163	70.9	119	8.4	247	17.6
Total		3,056	100.0	3,052	100.0	1,409	100.0	1,405	100.0

both areas. The exposed was 40.0% (1,235 men out of 3,089) and the unexposed was 40.1% (578 men out of 1,444), and the mean age was 27.8 years old in the exposed area and 25.4 in the unexposed. The distribution of illness by age was fairly uniform (Fig. 1).

Table 3 shows that 92% of study subjects in the exposed area experienced peculiar taste or odor from the tap water compared to 34.3% in the unexposed areas during the accident($p<0.01$)

Respondents were questioned about whether they had experienced any one of nine related symptoms or five unrelated symptoms during the accident. The related symptoms asked were limited to those aroused with exposure to low concentration of phenol or chlorophenol. Dummy symptoms that were unrelated to phenol exposure were also asked to exclude any psychogenic effect. People who have had other illness during the time of the accident were excluded from the analysis. A significant increase in proportions of the related and unrelated symptoms was noted in the true exposed group than the true unexposed (Table 4).

In the related symptoms, highly significant differences are also noted in the subjects reporting gastrointestinal illness defined as nausea, vomiting, diarrhea, or abdominal pain as well as those reporting any related symptom except malaise. There were no significant differences in the unrelated symptoms except fever between both groups. The proportion of study subjects having at least one or more related symptoms are 39.9% in the exposed but 9.4%

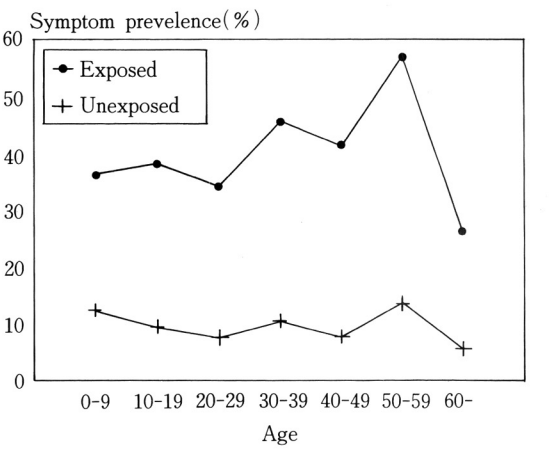

Fig. 1. Proportions of illness in exposed and unexposed areas by age

in the unexposed. When proportions of symptoms in the exposed area are compared to those in the unexposed area, the proportion of nausea in the exposed group is greater than that of the unexposed 4.0 times, diarrhea 4.5 times, skin rash 4.0 times, nausea 4.0 times, abnormal pain 5.3 times, burning sensation of the oral cavity and pharynx 3.0 times, dark urine 3.3 times and malaise 2.3 times. All symptoms except malaise are significantly higher than that of the unexposed areas ($p<0.01$). When five unrelated symptoms, i.e., tremors in the extremities, fever, back pain, dyspnea, cyanosis are com-

Table 4. Percentage(%) of people reporting symptoms during the accident(March 16th-23th 1991)

Symptom	Study group		Exposed/unexposed	X^2
	Exposed (N=1,824)	Unexposed (N=1,064)		
Related symptoms				
Nausea	15.8	3.9	4.0	p<0.01
Vomiting	4.3	1.2	3.6	p<0.01
Diarrhea	14.9	3.3	4.5	p<0.01
Abdominal pain	10.0	1.9	5.3	p<0.01
Headache	11.4	1.9	6.0	p<0.01
Sore throat	5.8	1.9	3.0	p<0.01
Dark urine	3.6	1.1	3.3	p<0.01
Skin rash	4.0	1.0	4.0	p<0.01
Malaise	1.6	0.7	2.3	N S
one and more	39.9	9.4	4.3	p<0.01
Unrelated symptoms				
Tremor	0.9	0.3	3.0	N S
Fever	3.8	0.8	4.8	p<0.01
Backache	3.1	1.7	1.8	N S
Dyspnea	2.1	1.0	2.1	N S
Cyanosis	1.3	0.4	3.2	N S

Table 5. Percentage(%) of people reporting symptoms by exposure level

Symptom	Exposed		Unexposed	X^2
	High (N=1149)	Low (N=648)	(N=1064)	
Related symptoms				
Nausea	17.1	13.7	3.9	p<0.01
Vomiting	5.1	2.8	1.2	p<0.01
Diarrhea	17.4	10.3	3.3	p<0.01
Abdominal pain	11.7	7.1	1.9	p<0.01
Headache	12.8	8.8	1.9	p<0.01
Sore throat	6.6	4.0	1.9	p<0.01
Dark urine	4.2	2.5	1.1	p<0.01
Skin rash	4.4	3.4	1.0	p<0.01
Malaise	2.1	0.8	0.7	p<0.01
Unrelated symptoms				
Tremor	1.2	0.5	0.3	p<0.01
Fever	4.3	2.8	0.8	p<0.01
Backache	3.3	2.6	1.7	N S
Dyspnea	2.0	1.9	1.0	N S
Cyanosis	1.2	1.4	0.4	N S

Exposed high : People who live in exposed areas and drink tap water only.
low : People who live in exposed areas, and drink tap water and water from other sources.
Unexposed : People who live in unexposed areas.

pared, back pain is most prevalent (3.1%). However unrelated symptoms of the exposed are compared to those of the unexposed, fever only is most prevalent (4.8 times).

Study subjects were divided into three groups, such as high, low and no exposure group according to level of exposure. Table 5 shows does-response relationships in the related symptoms, however it is not noted in the unrelated symptoms except tremor of the extremities and fever.

During the time of the accident, it was remarkable the increase in families who seek other water

source than tap water. The proportion of families who used tap water was remarkably decreased in exposed areas after the accident from 65.4% to 32.2%, and the proportion of families who have not used tap water was increased from 6.5% to 29.6%.

DISCUSSION

Accidental spill of phenol into drinking water, especially a central water supply, is not very common in the world.

In January 1984 the river Dee in North Wales was contaminated with phenol, with subsequent contamination of the tap water received by about two million consumers. A retrospective study performed by Jarvis et al. (1985) revealed that the proportion of gastrointestinal symptoms was significantly higher in the exposed area (32.6% vs. 8.7%), as well as reporting a higher incidence of other symptoms (43.6% vs. 18.4%). They reported that chlorophenol produced during the treatment of water may have aggravated the symptoms.

In April 1974, 37,900L of 100% phenol were spilled in a train accident and contaminated wells in a rural area of southern Wisconsin in the U.S.A. (Baker et al., 1978). This accident of contamination of ground water in Wisconsin induced sub-acute poisoning characterized by nausea, vomiting, diarrhea, burning sensation and sores in the mouth, together with dark urine which were shown to occur at concentrations of phenol above 0.1 mg/L in the drinking ground water. And this finding was subsequently reinforced by an episode of minor gastrointestinal illness in Georgia after contamination of drinking water with a mixture of phenols from the lining of a solar water tank at concentrations of 0.35 mg/L in July 1980(Trincher and Rissing, 1983).

Phenol, first recognized as a disinfectant by Lister (1827-1912) in England has been used to disinfect skin. At the end of the 19th century one episode of chronic poisoning of phenol was reported and at the beginning of the 20th century phenol has been used for suicidal purposes. So it has been recently substituted for cresol known to be less poisonous. One gram of phenol administered by oral route can be lethal (Tada, 1970; Deichamann and Keplinger, 1981). Vapor pressure of phenol is 3.24 ppm and concentrations of 0.047 ppm can be detected by smell.

There were two accidental phenol spillage into the river Nakdong, the first was March 16-18th, 1991, and the second was April 23th.

In the first, 30 tons of phenol was spilled over three days until the residents of Taegu city were suffering from various symptoms. But the concentration was found to be 0.05 ppm in the source of water prior to pumping up to that time and after treatment its concentration was reduced to 0.004 ppm, however the time when the level of concentration was measured was presumed to have already passed the peak point with maximal concentration. Even the level of peak concentration measured is not enough to cause detectable odor (threshold level 1 ppm) and abnormal taste (threshold level 0.1 ppm). Bad odor and related symptoms may be aggravated by chlorophenol after massive chlorination to reduce the bad odor.

In general chlorophenol obtained after treatment with chloride water which was contaminated by phenol includes 2-monochlorophenol, 4-monochlorophenol, 2,4-dichlorophenol and 2,4,6-trichlorophenol. Threshold levels detecting odor and taste of 2-and 4-monochlorophenol and 2,4-dichlorophenol are 0.001 ppm, respectively (WHO, 1989). They are 1,000 times stronger than phenol in odor and 100 times stronger in taste. Carcinogenecity in animal study has been proved in 2,4,6-trichlorophenol (Boutwell and Bosch, 1956 ; Blackburn et al., 1986 ; Rodwell et al., 1989).

The level of phenol concentration of contaminated drinking water by accidental spillage in Taegu city was one half that in North Wales reported (Jarvis et al., 1985) as 0.1 ppm in a water reservoir and 0.01 ppm of tap water. The level of chlorophenol was 0.03 ppm in the accident of North Wales, however it has not been measured in this Taegu accident. In the experiment of generating chlorophenol by chlorokalki treatment of drinking water, which 10 ppm of phenol solution, O-chlorophenol (2-monochlorophenol) was formed with less than a concentration of 10 ppm of chloride. O-chlorophenol and 2,6- and 2,4--dichlorophenol was formed with 20-100 ppm of chloride, and 2,6- and 2,4-dichlorophenol was generated with more than concentration of 200 ppm (Chung and Kwon, 1978 ; Ahlborg and Thunberg, 1980 ; WHO, 1984). From the above mentioned information we supposed that mono-, and or dichlorophenol were formed in the accidental spillage in Taegu city. In the formation of tetrachlorophenol, high temperature is required, and the activity of catalysts, i.e., $AlCl_2$, $FeCl_2$, $AtCl_2$ are necessary to form pentachlorophenol. People may be exposed to

tetrachlorophenol or pentachlorophenol when contaminated water is heated or those catalysts contaminate drinking water.

Chung (1978) has also reported the cytotoxicologic effect of chlorophenol in an experimental study using mice. He observed as follows : -weight loss, hepatomegaly, reduction of hemoglobin and hematocrit, reduction of albumin/globulin ratio, diminution following a rise in the level of alkaline phosphatase, lactic dehydrogenase, glutamin oxaloacetic transaminase, reduction of respiratory mitochondrial activity of hepatocyte and microsomal cytochrome p-450, expansion of rough endoplasmic reticulum, an increase of free ribosome, edematous and degenerative change of mitochondria, atrophy of nucleous membrane, and abnormal chromatid exchange.

The incidence rate of abnormal odor and taste detected in the accidental spillage of phenol in Taegu Korea was two times greater than that before the accident. A proportion showing at least one or more related symptoms in the exposed area is 4.2 times higher than that of the unexposed area. This result (39.9% vs. 9.4%) is similar to the accidental spillage of phenol in North Wales which showed 2.4 times difference (43.6% vs. 18.4%). In this exposed area, the related symptoms included nausea (15.8%), diarrhea (14.9%), headache (11.4%), abdominal pain (10.0%), burning sensation of oral cavity and pharynx (5.8%), vomiting (4.3%), dark urine (3.6%), skin rash (4.0%) and malaise (1.6%). Eight related symptoms of the above except malaise show 3-6 times higher in prevalence was very attentive. Dyspnea and cyanosis which are unrelated symptoms are revealed as acute symptoms from high exposure, but these symptoms are excluded from the related symptom in this study.

Dose-response relationships were shown frequency of symptoms between among three group : -use of the contaminated tap water only, of the mixed with tape water and natural or other uncontaminated water, and of the uncontaminated.

Study subjects were subdivided into four groups, but results were analyzed by comparison of two groups as 'true' exposed and unexposed for rule out psychogenic effects.

Psychogenic effects were the most potential bias in this study. Especially, psychologic influence from this accident made people who lives in the false exposed area also complained symptoms, however great deal of them also provably exposed to contaminated water in their workplace. Because, the overall response to the questionnaire was 82%, and there was little difference in response between the exposed and the unexposed areas. Men in the unexposed area complained higher frequency of symptoms than women, and men even who live in unexposed area are tent to drink contaminated water in their workplace and complained higher frequency of symptoms than women. Residents in boundary of the unexposed area were probably affected by contaminated tap water, because the pipe lines of central water supply system from three sources anastomose under ground in each other.

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