韓國環境科學會誌 第4卷(第3號), 277~284, 1995
J. of the Korean Environmental Sciences Society

CHLOROFORM BODY BURDEN FROM BATHING

Wan-Kuen Jo* and Young-Mee Hwang

*Dept. of Environmental Engineering, Kyungpook National University, Taegu, 709-701, Korea
Dept. of Environmental Health, Hyosung Women's University, Kyungsan, Kyungpook, 713-702, Korea
(Manuscript received 25 October 1994)

Abstract

There has been an increased awareness of the need to confirm the chloroform exposure associated with using chlorinated household water. Ten of a 30-minute tub bath were normally taken by two volunteers in a bathroom of an apartment. Chloroform concentrations were measured in bathing water and bathroom air, and exhaled breath of the subjects prior to and after bathing. Bathing using chlorinated tap water resulted in a chloroform exposure and caused a body burden. Based on the difference of chloroform concentrations between breath samples collected prior to and after bathing, the chloroform body burden from a 30-minute bath was estimated to be about 8 to 26 folds higher than that prior to the bath. The mean water and bathroom air chloroform concentrations measured to evaluate the body burden were 9.4 μg/l and 14.9 $\mu g/m^3$, respectively. The chloroform level of the bathroom air was 34 to 130 times higher than that of the living-room air. The relationship between the bathroom air and the corresponding breath chloroform concentrations were significant with $p=0.03$ and $R^2=0.47$.

Key Words : Chloroform exposure, body burden.

INTRODUCTION

Regulation of chemical contaminants in public water supplies has been based on the assumption that a daily ingestion of two liters represents the principal source of exposure. Recently, several research groups have characterized or modeled other exposure routes from domestic water for several volatile organic compounds(VOC)(Weisel *et al.*,1992; Jo *et al.*, 1990a; Jo *et al.* 1990b; McKone and Knezovich, 1991; McKone, 1987; Andelman *et al.* 1986; Andelman, 1985a; Andelman, 1985b). They indicated that exposure to VOC from routes other than direct ingestion may be as large as or larger than exposure from ingestion alone. The routes include inhalation of VOC after transference to the air and/or dermal absorption of VOC from domestic water uses, such as bath, shower, dish and cloth washing, and cooking.

Because of that individuals are exposed to elevated concentrations of VOC in the air within the confined space of the shower, and whose entire body is exposed to any contaminants present in the water while showering, significant studies have been conducted on showering. Previous studies(Andelman, 1985a; Andelman *et al.*, 1986; McKone and Knezovich, 1991) found that the air in the vicinity of the shower water increased in Trichlororoethylene

(TCE) concentration with time. Nicholas *et al.*(1992) reported that the inhalation exposures to TCE from a 6-min shower in these homes were estimated to be as much as two times higher than those from direct ingestion of 1-liter of the contaminated water. Jo *et al.*(1990a) concluded that the chloroform dose from inhalation and dermal exposure were about equal during showering.

Similar to showering, a bathing individual can be exposed to VOC present in chlorinated water and in the air released from the bathtub water. Using a mathematical model, Foster and Chrostowski(1986) estimated the inhalation exposure to VOC to be higher than the dermal exposure to VOC while bathing. Murphy(1987) and Brown *et al.*(1984,1989) indicated that dermal absorption of VOC can occur while bathing. These imply that VOC can enter into the individual's body through the routes of dermal and inhalation exposures while bathing, and can be at elevated levels in the exhaled breath of the individuals. The confirmation of this implication can be made by measuring the contaminants in the human body (breath, urine, or blood) of a bathing individual. The breath analysis technique can be successfully used to monitor occupational or nonoccupational exposure to toxic volatile compounds with a number of advantages over other biological monitoring techniques (Weisel *et al.*, 1992; Wallace *et al.*, 1991; Zweidinger *et al.*, 1982). The basic principle underlying exhaled breath monitoring is that VOCs in exhaled breath are indicative of the body burden of these chemicals. This is based upon the gaseous equilibrium that exists between alveolar air and pulmonary capillary blood(Berlin *et al.*, 1980).

The present study was designed to examine chloroform body burden from a bathing, which can be caused by the inhalation and/or dermal exposures. Each tub bath was normally taken for 30 minutes. The body burden was estimated by measuring chloroform levels in exhaled breath of bathing individuals collected prior to and right after bathing. The water and bathroom air samples were collected to explain the chloroform body burden. Another air samples were collected in the living room to determine background indoor air levels for chloroform.

METHODOLOGY

Two females whose health status were considered as healthy based on their statement volunteered for the chloroform body burden study from bathing using the chlorinated tap water. The subjects took ten normal tub baths with Ivory soap in an bathroom of an apartment located in Kyungsan, Korea. The normal bathing means that baths were taken without controlling the bathing parameters. The breath samples were collected from the subjects prior to and 2 to 3 minute after a 30-minute bathing. At similar time to the breath sampling, water samples were collected from the bathtub. Air samples were collected during the tub baths. Living-room air samples were collected at the similar time period to the air sampling of bathroom, as background air samples.

Construction of Breath Sampler

A breath sampling system was constructed to examine chloroform body burden from a normal 30-minute bathing. It consisted of a non-rebreathing two-way valve(Laerdal Medical Co.) attached to a one-inch(in.) outside

diameter(O.D.) - 16 feet(ft) long plastic tube at inhaling side and a 1/2 in.O.D.-25 ft long teflon tube at sampling side. Two NIOSH- and MSHA-approved organic vapor cartridges(Cole-Parmer Co.) were attached to the air entrance end of the inhaling tube.

Sampling

Water

The water samples were collected using clean 40 mL vials with a PTFE-faced rubber septum and capped immediately. Prior to sampling, the vials received 10 mg of sodium thiosulfate to quench residual chlorine reactions. EPA method 502.1(USEPA, 1981) was applied to collect the water samples.

Air and Breath

Tenax traps were used to collect chloroform and cleaned by Soxhlet extraction with methanol(Spectra grade) and then, with n-pentane (Spectra grade). The cleaned Tenax was packed in Pyrex sampling cartridges and conditioned 220 °C for 8 hours in a dry oven with supplying clean nitrogen into the cartridges. The conditioned traps were placed in clean sipping containers and transported to field.

Air and breath samples were collected by drawing air or exhaled breath through 0.6 mm outside diameter(O.D.) by 11 cm long Pyrex tubes with Tenax-GC adsorbent(0.1 g), using personal air samplers(AMTEK MG-4). Flow rate for bathroom air samples was set between 10 and 12.5 ml/min for about 30 minutes, which was determined by considering the sensitivity of the analytical system and the breakthrough volumes of chloroform. Air samples of the livingroom were collected for about same time period as that of the bathroom air sampling, at the flow rate between 35 and 40 cc/minute. Breath samples were collected at the flowrate set between 230 and 250 ml/min for 1 minute for the breath samples collected prior to and for 30 second for the breath samples collected after dermal exposure.

Analysis

The water analytical system includes a purge and trap system, a thermal desorption unit(Supelco Model 890), and a gas chromatograph(GC, Hewlett Packard 5890 II) with an electron capture detector(ECD) for chloroform. EPA method 502.1, which is based on the two-film mass-transfer theory (USEPA, 1981; Bellar and Lichtenberg, 1974), was used for the water analysis. The 0.6 mm O.D. and 11 cm length Tenax-filled pyrex tubes were connected to the 25 mL-purge device(Supelco). Water samples were purged for 15 minutes at the flow rate between 20 and 35 ml/min and at room temperature(18 to 25 °C). The GC column used was a fused silica capillary with 30 m long x 0.53 mm inside diameter(I.D.) and 3.0 μm film(Supelco, VOCOL). The flow rate of the carrier gas(nitrogen, 99.999% purity) was typically adjusted to 60 cc/min. The GC oven temperature was programmed from 35 to 70 °C at a rate of 16 °C/min. The column injection temperature was 200 °C. The desorbing temperature was fixed to 200 °C at the thermal desorption unit.

For air and breath chloroform measurements, the same analytical system and procedure as used for water analysis were applied. One exception is that the purge and trap system and the procedure which were used for water analysis were not included for the air analysis.

Table 1. Chloroform concentrations in the air of bathroom and living room, the water of bathtub, and the exhaled breath of bathing individuals

Number of	Air Conc.(μg/m^3)		Water Conc.(μg/l)		Breath Conc.(μg/m^3)	
Experiment	Bathroom	Living room	Prior to[a]	After[b]	Prior to[a]	After[b]
1	12.3	0.24	8.2	10.1	0.3	2.4
2	9.8	0.08	8.5	8.7	0.1	1.4
3	21.2	0.31	10.8	10.7	0.2	5.2
4	15.7	0.19	10.4	9.3	0.3	3.3
5	13.5	0.20	8.5	9.1	0.2	3.5
6	20.7	0.34	8.7	8.4	0.2	3.1
7	14.1	0.16	9.1	8.9	0.4	3.7
8	7.8	0.06	10.1	9.8	0.2	2.2
9	19.6	0.58	9.7	9.6	0.3	3.1
10	15.2	0.29	10.1	9.8	0.3	2.2

[a] indicates chloroform concentrations obtained from samples collected "prior to bathing".
[b] indicates chloroform concentrations obtained fromsamples collected "after bathing".

Instrument Performance

The performance of the entire analytical system was checked daily by analyzing a blank and an external standard. At the beginning of the day, a trap blank and a water blank were analyzed to check whether the blanks and the analytical system were contaminated. If no problems were found, an external standard was analyzed to check the quantitative response. Typically, the blank chloroform concentrations were trace, whose corresponding peak areas were less than one-hundredth of those of background breath chloroform concentrations. The response of an external standard was compared to the value calculated from a calibration equation. The response differed by less than 20%.

Statistical Analyses

Statistical analyses were conducted using the SAS programs(Version 6.03). Using analysis of variance(ANOVA), comparisons were made for the chloroform concentrations obtained from the water, air, and breath samples. A regression analysis was conducted on the bathroom air and the corresponding breath chloroform concentrations.

RESULTS

Ten tub baths were taken by two volunteers, using chlorinated tap water. Table 1 summarizes the chloroform concentrations obtained from the exhaled breath of the two subjects and those obtained from corresponding water and air samples. The mean and standard deviation of the livingroom air chloroform concentration were 0.25 and 0.15 μg/m^3, respectively. Elevated chloroform levels were measured in the bathroom air while bathing using chlorinated tap water, with the mean and standard deviation of 14.9 and 4.5 μg/m^3, respectively. The chloroform concentration difference between the livingroom and bathroom air was statistically supported

with p=0.0001. The chloroform level of the bathroom air was 34 to 130 times higher than that of the livingroom air. The chloroform water concentrations were not significantly different between samples collected prior to and right after bathing, the all water concentrations were used to average the water chloroform concentration. The mean and standard deviation of water chloroform concentration were 9.4 and 0.8 μg/l, respectively. The chloroform breath level after bathing whose mean and standard deviation were 3.1 and 0.9 $\mu g/m^3$ were significantly different(p=0.0001) from that prior to bathing whose mean and standard deviation were 0.25 and 0.08 $\mu g/m^3$, respectively. The chloroform breath level after a 30-minute bathing was about 8 to 26 folds higher than that prior to bathing.

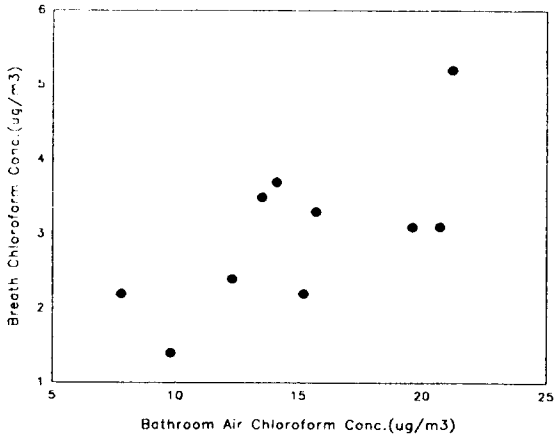

Fig. 1. Variation of breath chloroform concentration with the change of bathroom air chloroform concentration.

Figure 1 shows the relationships between the bathroom air and the corresponding breath chloroform concentrations. A regression analysis was conducted based on the data which were shown in the Table 1. The analysis indicated significant correlations between chloroform concentrations of the two media, with p=0.03 and R^2=0.47. Since the variation of water chloroform concentration was small, the correlations between water and air, and water and breath chloroform concentrations were not tested.

DISCUSSION

Bathing using chlorinated tap water resulted in a chloroform exposure and caused body burden. It was considered that during bathing, the chloroform levels in the water of bathtub(9.4±0.8 μg/l) and elevated chloroform levels of the bathroom air(14.9±4.5 $\mu g/m^3$) as compared to those of the livingroom air(0.25±0.15 $\mu g/m^3$) caused the dermal exposure and the inhalation exposure, respectively. Based on the difference of chloroform concentrations between breath samples collected prior to and after bathing as shown in Table 1, chloroform body burden from a 30-minute bathing was estimated to be about 8 to 26 folds higher than that prior to the bathing. The resulting body burden confirms that chloroform enters into the human body while bathing with chlorinated tap water. Jo *et al.*(1990a, 1990b) reported that the chloroform dose from inhalation and dermal exposures would be about equal during showering, based on their experimental results. This implies that the chloroform body burden from bathing can be caused by both the inhalation exposure and dermal absorption. The presence of the dermal absorption during bathing is supported by Brown et al.'s report(1984, 1989) of that VOC in diluted water enter into the body through the skin absorption.

On the other hand, Weisel *et al.*(1992) and Wallace *et al.*(1991)'s indication support that the inhalation exposure can cause chloroform body burden during bathing. They indicated that VOC in air enter into the human body through lung and caused elevated levels of VOC in exhaled breath. In addition, the present study showed that the chloroform concentration of bathroom air was significantly related with the corresponding breath concentrations, supporting that the inhalation exposure is a route for the corresponding body burden. Hence, it is indicated that both the dermal and inhalation exposures are two expected routes for the chloroform body burden from bathing, suggesting the need of further study to separately confirm the presence of dermal absorption while bathing.

Figure 1 shows the relationship between the bathroom air and corresponding breath concentration following swimming. Even though the relationship of chloroform concentrations was significant with $p=0.03$ and $R^2=0.47$ between the bathroom air and the corresponding body burden, the correlation intensity was not strong. Three explanations are suggested to understand the weak correlation intensity. The first is that the sample size can affect the coefficient and its significance. The second is the physiological difference of two subjects on chloroform body burden. Since the respiration rate, and other parameters such as cardiac output, volume of tissue groups, and blood volume are different between the subjects, some variations can be expected in breath concentrations for similar exposure situations. Last one is that bathing parameters such as the bathroom ventilation and the activity of bathing individuals were not controlled, which could influence on the bathroom air concentration and then, water concentrations.

Based on the resulting chloroform body burden from bathing observed in this study, it is indicated that people who drink the purified commercial water, instead of chlorinated tap water, not to be exposed to carcinogenic chloroform should not take bathing using chloroform-contaminated tap water to minimize the carcinogen exposure. However, because of high expenses it is not reasonable to take bathing with the purified commercial water. Then, we may have two choices to minimize VOC exposures from bathing with chlorinated tap water. First, the tap water should be treated in municipal water treatment plant to contain minimal chloroform, prior to supplying the tap water. The other one may be to control the bathing conditions, such as bathroom ventilation and bathing duration.

CONCLUSIONS

Bathing with chlorinated tap water results in chloroform body burden which would be caused through the possible exposure routes of dermal and inhalation. The presence of the inhalation exposure during bathing was supported by the significant relationship between the bathroom air and corresponding post-exposure breath concentration. The further study is recommended to confirm the presence of dermal exposure by measuring chloroform in the human body(breath, urine, or blood) of a bathing individual. With the help of the previous studies reported that showering using chlorinated tap water also causes VOC body burden, it is noted that dermal and inhalation exposures from bathing and other household water uses in addition to ingestion should be included when regulation of chemical contaminants in public

water supplies is considered.

ACKNOWLEDGEMENTS

The authors wish to thank the reviewers for their thoughtful comments of this manuscript. We also would like to thank Miss Eun M. Hwang and Miss Eun Y. Sung who volunteered and patiently completed the demanding protocol.

REFERENCES

Andelman, J. B., 1985a, Inhalation exposure in the home to volatile organic contaminants of drinking water, Sci. Total Environ. 47, 443-460.

Andelman, J. B., 1985b, Human exposures to volatile halogenated organic chemicals in indoor and outdoor air, Env. Health Persp. 62, 313-318.

Andelman, J. B., S. M. Meyers, and L. C. Wilder, 1986, Chemicals in the environment, 323-330.

Bellar, T. A. and J. J. Lichtenberg, 1974, Determining volatile organics at microgram-per litre levels by gas chromatography, Amer. Water Assoc. 66, 739-744.

Berlin, M, J. C. Gage, B. Gullberg, S. Holm, P. Knutsson, and A. Tunek, 1980, Breath concentration as an index of the health risk from benzene, Scand. J. Work Environ. Health, 6:104-111.

Brown, H. S., and D. Hattis, 1989, The role of skin absorption as a route of exposure to volatile organic compounds(VOCs) in household tap water: A simulated kinetic approach, J. Am. Coll. Tox. 8:839-851.

Brown, H. S., D. R. Bishop, and C. A. Rowan, 1984, The role of skin absorption as a route of exposure for volatile organic compounds(VOCs) in drinking water, Amer. J. of Public Health, 74:5:479-483.

Foster S. A. and P. C. Chrostowski, 1986, Integrated household exposure model for use of tap water contaminated with volatile organic chemicals, the 79th Annual Meeting of the Air Pollution Control Association.

Jo, W. K., C. P. Weisel, and P. J. Lioy, 1990a, Chloroform exposure and the health risk and body burden from showering with chlorinated tap water, Risk Analysis, 10, 581-585.

Jo, W. K., C. P. Weisel, and P. J. Lioy, 1990b, Routes of chloroform exposure and body burden from showering with chlorinated tap water, Risk Analysis, 10, 575-580.

McKone, T. W., 1987, Human exposure to volatile organic compounds in household tap water, Sci. Total Environ. 47, 443-460.

McKone T. E. and J. P. Knezovich, 1991, The transfer Trichloroethylene(TCE) from a shower to indoor air: Experimental measurements and their implications, J. Air Waste Manage. Assoc. 40:282-286.

Murphy B. L., 1987, Total exposure from contaminated tap water, the 80th Annual Meeting of the Air Pollution Control Association.

Nicholas, J. Giardino, E. Gumerman, N. A. Esmen, and J.B. Andelman, 1992, Shower volatilization exposures in homes using tap water contaminated with trichloro-ethylene, J. Exposure Analysis and Environ. Epid. Suppl. 1, 147-158.

U.S. Environmental Protection Agency, 1981, The determination of halogenated chemi-

cals in water by the purge and trap method, Method 502.1, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

Wallace, L., W. Nelson, R. Ziegenfus, E. Pellizzari, L. Michael, R. Whitmore, H Zelon, T. Hartwell, and R. Perritt, 1991, The Los Angeles TEAM Study: Personal Exposures, Indoor-Outdoor Air Concentrations, and Breath Concentrations of 25 Volatile Organic Compounds, J. of Exposure Analysis and Environmental Epidemiology, Vol.1, No.2.

Weisel, C. P. and T. A. Shepard, 1994, Chloroform exposure and the resulting body burden associated with swimming in chlorinated pools. In: Water Contamination and Health. Marcel Dekker, Inc. New York, NY. pp. 135-148.

Zweidinger, R, M. Erickson and S. Cooper, 1982, Direct Measurement of volatile organic compounds in breathing-zone air drinking water, breath, blood, and urine, United States Environmental Protection Agency. NTIS No. PB-82-186-545.

목욕으로 인한 클로로포름의 인체부담

조 완 근* · 황 영 미

*경북대학교 공과대학 환경공학과, 효성여자대학교 자연대학 환경보건학과

(1994년 10월 25일 접수)

일반 가정의 염소 처리된 수도수 사용과 관련된 클로로포름 노출을 확인 할 필요성에 대한 관심이 증가하고 있다. 삼십분 동안의 정상적인 목욕이 아파트의 한 욕실에서 두명의 자원자에 의해서 10차례 행해졌다. 클로로포름 농도가 물과 욕실 공기 및 목욕 전후에 피실험자의 호기로부터 측정되었다. 염소처리 수도수를 사용하여 목욕을 했을 때 클로로포름에 대한 노출이 일어났고, 인체 부담도 야기되었다. 목욕 전후에 채취된 호기 시료의 농도차에 기초하여, 한번의 30분 목욕으로 부터 야기되는 클로로포름에 대한 인체부담은 목욕전에 비하여 8배 내지 26배가 되는 것으로 산정 되었다. 이와같은 인체부담을 설명하기 위해서 측정된 물과 욕실 공기내의 클로로포름 농도는 각각 9.4 μg/l 및 14.9 μg/m^3 이었다. 이러한 욕실 공기내의 클로로포름 농도는 거실공기 보다 34배 내지 130배 가량 높게 나타났다. 욕실공기와 해당 호기에서의 클로로포름의 농도 관계는 $p=0.03$ 와 $R^2=0.47$의 조건에서 유의성이 있는 것으로 나타났다.