EXPOSURE TO VOLATILE ORGANIC COMPOUNDS RESULTING FROM SHOWERING WITH CHLORINATED WATER

Clifford P. Weisel
Paul J. Lioy
Joint Graduate Teaching
Program in Human Exposure
Rutgers: The State University and
UMDNJ - Robert Wood Johnson
Medical School and
The Environmental and Occupational
Health Sciences Institute
Piscataway, NJ

Wan K. Jo
InJae University
Dept. of Environmental Science
A-Bang Dong, KimHae
Seoul, Korea

Showering is the single, largest use of water in the home. Volatile organic compounds present in the water are released to the air and contact the skin. This study measured the concentration of chloroform in exhaled breath and determined that these two exposures routes increase the body burden of chloroform. Water concentration, water temperature, and shower duration were determined to have a significant influence on the chloroform body burden. The chloroform concentration measured in breath after normal showers ranged from 3.8 to 13.0 µG/cu-m while the pre-exposure concentrations were below the minimum detection limit of 0.9 µG/cu-m. Approximately half of the measured body burden resulted form inhalation exposure and half from dermal exposure. Estimates of the chloroform dose and risk from showers were found to be comparable to that from ingestion.

Introduction

Exposure to indoor volatile organic pollutants have been shown to exceed those from the ambient environment when indoor sources are suspected (1-2). One source of volatile organic compounds (VOC) is municiple water. Chlorinated water contains µG/L quantities of trihalomethanes (THM), which are formed as by-products of the chlorination process (3). Recently, several studies (4-7) 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 volatile compounds after transference to the air and/or dermal absorption of volatile compounds from water uses, such as showers, baths, toilets, dish and clothes washing, and cooking.

Showering with chlorinated water exposes individuals to elevated concentrations of THMs in the air within the shower, and in the water impacting on the skin. Estimates of inhalation exposure to volatile organic compounds (VOC) in shower air have been made using unoccupied shower laboratory chambers (4,6,7). However, no estimates have been made of dermal exposure while showering. Dermal exposure occurs since the entire body is exposed to the contaminants in the water while showering, thus, absorption through the skin could significantly increase their body burden. The present study evaluated the parameters that affect exposure to chloroform and quantified the relative chloroform dose due to dermal and inhalation exposure from chlorinated tap water while individuals took showers under typical conditions.

Methods

Sampling

Breath samples were collected from the subjects by having them breathe through a non-rebreathing two-way valve until a sampling bag was filled. The subjects breathed purified, humidified air through the valve from an inhalation bag and the exhaled breath was collected in a sampling bag. Breath from this bag was then drawn through a Tenax packed trap which adsorbed chloroform. Shower water samples were collected from the tap in the experimental bathroom using clean 50 mL vials. The procedure for shower water sampling is given in the EPA Method 502.1 (8). Shower air samples were collected from the breathing zone of the shower using Tenax traps for 10 minutes at a air flow rate between 750 and 1250 cc/min.

Analysis

Breath and air analyses were performed by thermal desorbtion followed by packed column gas chromatograph with an electrolytic conductivity detector in the halogen-specific system mode. The water was analyzed by purge and trap-gas chromatography following EPA method 502 (6-7).

Quality Assurance

The analytical system was checked daily by analyzing a blank and an external standard. Typically, the blank concentrations were below the detection limit, thus any response indicated contamination in the system. The response of an external standard was compared to that predicted by a calibration equation. If it differed by more than $\pm 20\%$ a new calibration equation was determined. The precision and minimum detection limit (MDL) of the breath and air analytical systems for chloroform were $12.7 \pm 2.5\%$ and 12.9 ± 2.6 nG, respectively. The precision and MDL of water analytical system were $10.1 \pm 2.0\%$ and 0.65 ± 0.13 uG/L, respectively.

Experiment I - Evaluation of Parameters

A model shower was used to evaluate the effect of water temperature and duration of exposure on breath concentration. Water was sprayed inside the chamber using a standard shower head at two temperatures, 34°C and 41°C, and the air within the chamber was inhaled for 5, 10 or 15 minutes duration. A standard, full size shower was use to evaluate the relationship between the chloroform air concentration within the chamber and the water concentration, with and without a subject present. A shower duration of 10 minutes and a water temperature of 40°C was used for this and all subsequent studies. Additionally, the following parameters were fixed for all experiments: a water flowrate of 8.7 L/min, the shower head setting, the ventilation system was turned off and a post exposure delay of 5 minutes prior to collection of a breath sample. The chloroform water concentration was measured on samples collected immediately after a breath or air sample.

Experiment II - Chloroform Exposure from Normal Showers

To estimate total chloroform exposure from a shower, thirteen showers were taken by six subjects (5 males and 1 female) using a defined set of shower parameters. Breath samples were collected from each subject prior to and after each shower. Water samples were collected from the tap in the bathroom after each shower. All showering conditions were set as indicated in Experiment I.

Experiment III - Chloroform Exposure from Inhalation Only six subjects (4 males and 2 females) participated in thirteen inhalation only exposure experiments using the same full-size shower, shower parameters and protocols as in Experiment I. Each subject was exposed to chloroform vaporized from shower water while standing within the shower stall. The subject wore rubber clothes and boots during the experiment to avoid dermal contact with the shower water. A breath sample was collected from the subject prior to each inhalation only exposure. Chloroform exposures from inhalation only were determined by measuring chloroform concentration in water samples and breath samples taken from subjects after inhalation only exposures. The data obtained from Experiment II and Experiment III were used to compare the chloroform body burden resulting from a normal shower with that from an inhalation only exposure. The comparison was conducted using a covariance analysis.

Results and Discussion

The chloroform concentration in air was measured as a function of water concentration, water temperature, duration and the presence of a showering individual. The air concentration was found to be positively correlated with water temperature, shower duration and water concentration. No significant difference was found for the presence or absence of a subject.

The shower air concentration generally increased with water concentration (12.9 to 40.0 uG/L). The mean and standard deviation of chloroform air concentrations without a showering individual were 157 uG/m^3 and 75.5 uG/m^3, respectively. The mean and standard deviation of air chloroform concentrations while an individual was showering were 186 uG/m^3 and 76.0 uG/m^3, respectively. Chloroform was not detected in any of the air samples collected prior to the shower being turned on. The relationship between the air and water concentration is described by the linear model:

$$C_{air} = 8.11 * C_{water} - 39.2 \quad \text{for } C_{water} > 4.8\ \mu G/L$$

$$\text{with an } R^2 = 0.87 \text{ at a } P = 0.001$$

Breath samples were collected prior to and after a shower, which resulted in both inhalation and dermal exposure. The pre-exposure breath chloroform concentration was less than the detection limit of 0.86 uG/m^3 in all samples. As shown in Figure 1, the breath concentrations tended to increase with the chloroform concentration in water for the range 5.3 to 36 uG/L. The mean and standard deviation of the breath concentrations after a normal shower were 13 uG/m^3 and 3.9 uG/m^3, respectively. Minimum and maximum breath concentrations after normal showers were 6.0 and 21 uG/m^3, respectively.

Breath samples were collected prior to and after inhalation only exposure. Chloroform was not detected in any of the breath samples collected prior to each inhalation only exposure experiment. As shown in Figure 1, the breath concentrations after inhalation only exposures tended to increase with increasing water concentration for the range 10 to 37 uG/L. The mean and standard deviation of breath concentrations measured after inhalation only exposure were 7.1 uG/m^3 and 2.5 uG/m^3, respectively. Minimum and maximum breath concentrations after inhalation only exposures were 2.4 and 10 uG/m^3, respectively.

The quantitative difference of chloroform body burdens resulting from normal showers and i8nhalation only exposures was estimated using a least mean squares (LSM) of chloroform breath concentration controlled for variations in the water concentration. The LSM of the breath concentrations after normal showers, which is a sum of inhalation and dermal exposures, was 13 μG/m^3, while the LSM of the breath concentrations after inhalation exposures only was 6.8 μG/m^3. The difference of 6.2 μG/m^3 is attributed to dermal exposure. Based on the above difference, the ratio of chloroform body burden increase from dermal exposure to that from inhalation exposure is 0.95. Hence, both inhalation and dermal absorption contributed equally to the internal chloroform dose.

The total chloroform dose from a shower was estimated from the sum of the inhalation exposure and dermal exposure. The chloroform dose from inhalation exposure was calculated using the following equations:

$$Di = Er \times Ca \times R \times T/Wt$$

Di = chloroform dose from an inhalation only exposure (uG/inhalation exposure-kG)
Er = absorption efficiency of chloroform via respiratory system (.77)
Ca = shower air concentration (mean from data 157 uG/m^3)
R = breathing rate (0.014 m^3/min)
T = Shower duration (10 min)
Wt = body weight of a reference person (70 kG)

The resulting dose for inhalation is 0.24 μG/kG-day.

The chloroform dose from dermal exposure was estimated from the above ratio as follows:

$$Dd = Di \times F$$

Dd = chloroform dose from a dermal exposure(uG/dermal exposure-kG)
F = ratio of the body burden from dermal exposure to that from inhalation exposure (0.93)

The resulting dose from dermal exposure is 0.23 μG/kG-day and the total from a shower is 0.47 μG/kG-day.

Estimates of Chloroform Exposure from Water Ingestion

The chloroform dose from water ingestion was estimated using the following equation:

$$Dig = Ei \times Cw \times Aw/wt$$

Dig = Dose from water ingestion
Ei = absorption efficiency via the gastrointestinal tract (100%)
Cw = tap water concentration (mean for study 25 μG/L)
Aw = water amount ingested per day (0.15 to 2 L/day)

The resulting dose are given in Table 1.

Estimates of Cancer Risk from a Shower and Water Ingestion

The chloroform risk associated with a shower and water ingestion for a reference person was calculated from the estimated doses. A linearized model was used to estimate the cancer potency of the chloroform exposure (9). The model extrapolates animal data at high experimental doses to low environmental exposure levels in order to estimate cancer risk for humans. The cancer risk from a shower was estimated by extending the model developed for ingestion exposure to inhalation and dermal routes of exposure. The model is:

$$Pd = q \times D \times 10^{-3}$$

Pd = lifetime risk,
q = cancer risk potency slope (0.26 mG/kG-day)$^{-1}$
D = chloroform dose (uG/kG-day)

The risks calculated per million are given in Table 1.

Conclusions

An increase in the chloroform body burden resulting from inhalation exposure and dermal exposure during a normal shower was observed in the present study. The breath concentration after showering was approximately twice as high as that after inhalation only exposure, indicating that the contribution to the internal dose by dermal absorption was equivalent to inhalation adsorption.

Individuals are exposed to chloroform from daily showers when using chlorine-treated municipal tap water. The chloroform body burden from a shower was estimated to be 14 to 49 times the background chloroform body burden, depending on the shower tap water concentration.

Chloroform dose and cancer risk from a single, ten minute shower was equal to or greater than that from daily water ingestion. Hence, in situations where individuals are told not to drink water because it has been contaminated with VOC they should also be told not to shower or bath with the water. Furthermore, the chloroform dose received from showers and from other uses of chlorinated tap water must be considered when agencies and health officials evaluate the quality of a chlorinated water supply.

Acknowledgements

The research was funded by the New Jersey Department of Environmental Protection, Division of Science and Research. Dr. Wan received Fellowship support from the Environmental and Occupational Health Sciences Institute.

References

1. Wallace, L.A.; Pellizzari, E.; Hartwell, T.; Rosenzweig, M.; Erickson, M.; Sparacino, C.; and Zelon, H. (1984) Personal Exposure to Volatile Organic Compounds. Env. Research, 35:293-319.
2. Wallace, L.A.; Pellizzari, E.D.; Hartwell, T.D.; Sparacino, C.; Whitmore, R.; Sheldon, L.; Zelon, H.; and Perritt, R. (1987) The TEAM Study: Personal exposures to toxic substances in air, drinking water, and breath of 400 residents of New Jersey, North Carolina, and North Dakota. **Environ. Res., 43:290-307.**
3. Krasner, S.W.; McGuire, M.J.; Jacangelo, J.G.; Patania, N.L.; Reagan, K.M.; and Aieta, E. M. (1989) The Occurrence of Disinfection By-Products in US Drinking Water. Journal American Water Works Assoc., p. 41-53.
4. Cothern, C.R.; Coniglio, W.A.; Marcus, W.L. (1985) Techniques for the assessment of carcinogenic risk to the U.S. population due to exposure from selected volatile organic compounds from drinking water via the ingestion, inhalation, and dermal routes. U.S. Environmental Protection Agency, Office of Drinking Water, EPA 570/9-85-001.
5. Andelman, J.B. (1985) Inhalation exposure in the home to volatile organic contaminants of drinking water, Sci. Total Environ. 47:443-460.
6. Andelman, J.B. (1985) Human exposures to volatile halogenated organic chemicals in indoor and outdoor air. Env. Health Persp. 62:313-318.
7. Weiss, C.F. (1985) Volatilization of Organic Groundwater Contaminants in a Shower Environment. Undergraduate Independent Work, Department of Chemical Engineering, Princeton University.
8. (April 1981) The determination of halogenated chemicals in water by the purge and trap method, Method 502.1; U.S. Environmental Protection Agency. Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268.
9. Marty, M.A. (June 1989) A Health Risk Assessment for Airborne Chloroform, Presentated at the the 82nd Annual Meeting of APCA. Anaheim, CA.

Table 1 - Chloroform dose and the corresponding risk estimates for the chloroform water concentration of 24.5 uG/L

Exposure Type	Dose* (uG/kG-day)	Risk (per million)
Normal Shower		
Inhalation Exposure	0.24	62
Dermal Exposure	0.23	60
Total	0.47	122
Water Ingestion		
2-L Ingestion	0.7	180
0.15-L Ingestion	0.05	13

*** the dose was estimated based on one shower per day**