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Chloroform Body Burden From Swimming In Indoor Swimming Pools

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Abstract

The use of chlorinated water in swimming pools produces elevated chloroform levels in the water and air of the pools which can cause chloroform body burden of swimming individuals. Present study confirmed the chloroform body burdens from a 40-min swimming and evaluated the decay of chloroform breath concentration after the cessation of a 60-min swimming. Air and water concentrations were measured in the pools. The water and air chloroform concentrations ranged from 18.1 to 25.3 μg/l and from 30.9 to 60.7 μg/m3 for the confirmation study, respectively. The breath level after 40-min swimming was about 64 to 266 folds higher than the corresponding background breath. The breath concentration after the 40-min swimming ranged from 10.5 to 21.3 μg/m3, while that prior to the corresponding swimming ranged from 0.07 to 0.19 μg/m3. In addition, the post-exposure breath level varied with the subjects who swam in the pool on the same visiting day. Breath concentration increased gradually during 60-min swimming, then decreased rapidly within 5 minutes after the cessation of exposure, after that, decreased slowly, and finally approached to a background breath level at 1-2 hr after exposure.

Key words : Swimming, pools, body burden, chloroform, exposure

1. INTRODUCTION

The presence of trihalomethanes(THMs) in the water of indoor swimming pools continues to be the subject of active research because of their elevated levels as compared to drinking water(Weisel and Shepard, 1994; Aggazzotti and Predieri, 1986; Aggazzotti *et al.*, 1990; Beech *et al.*, 1980; Chambon *et al.*, 1983; Lahl *et al.*, 1981; Norin and Renberg, 1980) and their potential chronic toxicity(Fry and Hathway, 1972; Bethesda, 1976; International Agency for Research on Cancer, 1979; Roe, *et al.*, 1979; Jorgenson, *et al.*, 1985). The application of chlorine or other chlorine-containing disinfectants to swimming pools has been indicated to produce a spectrum of volatile halogenated compounds including THMs in the water of the swimming pools (Aggazzotti and Predieri, 1986; Lahl *et al.*, 1981). THMs are produced in-situ by the reaction of the chlorine and organic matter of human contaminants such as urine, sweat, and human grease or from cosmetics, such as suntan oil(Chambon *et al.*, 1983; Lahl *et al.*, 1981).

Chloroform was found to be present at the highest concentration among THMs in the water of swimming pools treated with sodium hypochlorite(NaOCl) (Aggazzotti and Predieri, 1986; Chambon *et al.*, 1983; Lahl *et al.*, 1981;

Trussel and Umphres, 1978). The previous researches abroad(Aggazzotti and Predieri, 1986; Aggazzotti *et al.*, 1990; Beech *et al.*, 1980; Chambon *et al.*, 1983; Lahl *et al.*, 1981; Norin and Renberg, 1980; Weisel and Shepard, 1994) reported that the typical chloroform concentrations in the water of swimming pools disinfected with sodium hypochlorite only exceeded 100 μg/l. On the other hand, Jo and Hwang(1994) obtained the mean water chloroform concentration of 21.7 μg/l from two Korean swimming pools using both ozone and sodium hypochlorite for water disinfection. They concluded that combination of the two disinfectants would result in the lower water levels in Korea as compared to the previous studies abroad.

Chloroform in chlorinated water is partially released into the air and is present at elevated levels in the indoor air such as air of indoor swimming pool and shower room (Aggazzotti *et al.*, 1990; Jo *et al.*, 1990; Jo and Hwang, 1994; Lahl *et al.*, 1981; Wallace *et al.*, 1984; Wallace *et al.*, 1985; Wallace *et al.*, 1987; Weisel and Shepard, 1994). The previous studies abroad (Aggazzotti *et al.*, 1990; Lahl *et al.*, 1981) reported the air chloroform concentrations ranged from 66.1 to 665 $\mu g/m^3$ directly above the water surface of swimming pools using sodium hypochlorite only for water disinfection. On the other hand, Jo and Hwang(1994) reported that the mean chloroform air concentration was 30.8 $\mu g/m^3$ in two Korean indoor pools using both ozone and sodium hypochlorite, while in outdoor air near the pools the mean chloroform concentration was 0.37 $\mu g/m^3$. Jo *et al.*(1994) concluded that the lower air concentration in Korean pools would result from the lower water concentration.

It is suspected that the elevated chloroform in the water and air of swimming pools can penetrate into human body and cause body burden of swimming individuals. It is further suspected that chloroform levels in human body will decrease after the chloroform exposure because the respiratory system of swimming individuals will be cleaned up by inhaling relatively clean air as the individuals leave the chloroform-high source. The mechanism of chloroform penetration into and decay from human body is an essential tool for pharmacokinetic study. This study was designed to confirm chloroform exposure from swimming in an indoor swimming pool using both ozone and sodium hypochlorite by examining chloroform body burden after swimming and to understand the mechanism of chloroform penetration into and decay from swimming individuals.

2. METHODOLOGY

To confirm the chloroform penetration into individuals while swimming, seven volunteers took normally ten 40-min swims in the pool. The body burden was examined by measuring chloroform levels in exhaled breath of swimming individuals, prior to and after swimming. The water and air chloroform concentrations of the pool were measured to explain the chloroform body burden.

For this study, an indoor swimming pool of Taegu disinfected with both sodium hypochlorite and ozone was selected, whose location can not be specifically described since the pool manager did not allow permit to do it. The pool used a feed water treatment/control system(Dulcometer, Prominent Co., Germany) which includes hydro filter, activated carbon and sand bed, and ozone, chlorine and pH controller. Breath samples were

collected prior to and about 2 to 3 min after swimming, from seven volunteers who took ten 40-min swims in the pool. Two air samples were collected, one within the initial 20 minute and another within next 20 minutes, at 15 to 20 cm in height above the water surface at the edge of the pool. Water samples were collected prior to and right after each swim.

To understand the mechanism of chloroform penetration into and decay from human body, an individual took a 60-min swim in the student indoor swimming pools of Rutgers University in New Jersey. Breath samples were collected in time-series during and after swimming. A water and an air samples were collected during swimming.

2.1. Sampling

2.1.1. 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.

2.1.2. 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 shipping 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). Flowrate for pool air samples was set between 10 and 12.5 ml/min for about 3 minute, which was determined by considering the sensitivity of the analytical system and the breakthrough volumes of chloroform. 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 swimming.

2.2. 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 flowrate between 20 and 35 ml/min and at room temperature(13 to 19 °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 flowrate 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.

The analytical systems used in New Jersey of the United States consist of a purge and trap system, a purge and trap system, a thermal desorbing system(Perkin Elmer Model ATD 400) and a gas chromatograph(GC, Hewlett Packard 5890 II) with an mass selective detector(MSD, Hewlett Packard). The 1/4 in. O.D.-3.5 in. length Tenax-filled stainless steel(SS) tubes were connected to the 25 mL-purge device (Supelco). Water samples were purged for 15 minutes at room temperature(17 to 23 ℃). The GC column used was a 25 meter fused silica open tubular 0.2 mm I.D. capillary column, coated with 0.33 micrometer crosslinked layer of 5% phenyl-methyl-silicone(Hewlett Packard). The flowrate of the carrier gas(helium, 99.999% purity) was adjusted to 1.2 cc/min. The GC oven temperature was programmed from 45 ℃ to 200 ℃ at a rate of 8 ℃/min. The column injection temperature was 200 ℃. The temperature of the desorbing system was fixed to 250 ℃.

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.

2.3. 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 concentrations were below the detection limits. The response of an external standard was compared to the value calculated from a calibration equation. If the response differed by more than 20%, a new calibration equation was determined.

3. RESULTS AND DISCUSSION

As shown in Table 1, the breath concentration after the swimming ranged from 10.5 to 21.3 $\mu g/m^3$ with a mean value and standard deviation of 15.1 ± 3.3 $\mu g/m^3$, while that prior to the corresponding swimming ranged from 0.07 to 0.19 $\mu g/m^3$ with a mean value and standard deviation of 0.12 ± 0.05 $\mu g/m^3$. The breath level after 40-min swimming was about 64 to 266 folds higher than the corresponding background breath(breath prior to swimming). This indicates that chloroform enters into the human body during swimming in ozone- and sodium hypochlorite- used pool, confirming the chloroform exposure while swimming in the pool. The chloroform entrance can be caused by the multiple exposure routes. The possible exposure route include the inhalation, dermal and ingestion. Weisel *et al.*(1994) confirmed the presence of inhalation exposure during 30-min swimming in the U.S. indoor swimming pool, by finding the elevated chloroform concentration in the breath of a subject who remained 3 meters from the pool's edge, not in the water, as compared to the background breath concentration of the subject. They also found that there was the trace for the presence of dermal absorption during swimming. Datta(1979) estimated that children ages 5 to 9 years who swim for three hours daily, will take in and squirt out of their mouths 15.8 liters of pool water and ingest one percent of this amount. Then, the water amount ingested during swimming is estimated to be about 0.035 liter for a 40-min swimming.

Table 1. Visiting days, subject identification number(ID) and sex, and chloroform levels in water, air, and breath for swimming in the pool which was disinfected with sodium hypochlorite and ozone

Visiting Day	Subject ID & Sexa	Indoor Air Conc.(μg/m3)b	Water Conc.(μg/l)		Breath Conc.(μg/m^3)	
			Prior to[c]	After[d]	Prior to[c]	After[d]
1	1,F	53.6	18.7	18.1	0.09	13.7
	2,M	60.7			0.08	21.3
	3,M				0.07	12.1
	4,F				0.07	15.2
2	5,F	50.8	21.9	25.3	0.19	12.2
	6,F	42.7			0.12	15.7
	7,M				0.10	16.3
	1,F				0.16	10.5
	4,F				0.18	19.3
3	1,F	30.9	23.2	22.3	0.17	14.7

[a] F and M mean female and male, respectively.
[b] The second air concentration in each visiting day means duplicate air concentration.
[c] "Prior to" means prior to swimming.
[d] "After" means after swimming.

Applying the absorption efficiency of 50%(Fry and Hathway, 1972; Lahl *et al.*, 1981) and the mean water chloroform concentration(21.6 μg/l) of the present study, the oral dose only while 40-min swimming is estimated to be 0.4 μg which will also cause the elevated breath concentrations of swimming individuals. Hence, it is described that the elevated chloroform body burden from a 40-min swimming would result from the multiple routes of chloroform exposure.

The water and air levels of the present study were lower than those reported by the previous studies abroad, which was consistent with Jo *et al.*(1994). As shown in Table 1, the water concentration ranged from 18.1 to 25.3 μg/l. The air concentration ranged from 30.9 to 60.7 μg/m^3. On the other hand, the previous studies reported the chloroform levels to exceed 100 μg/l in the water and to be a few 100 μg/m^3 in the air of the swimming pools using sodium hypochlorite only (Aggazzotti and Predieri, 1986; Beech *et al.*, 1980; Chambon *et al.*, 1983; Lahl *et al.*, 1981; Norin and Renberg, 1980; Weisel and Shepard, 1994). Jo *et al.*(1994) indicated that the concentration difference between the two types of swimming pools would result from the different amount of residual chlorine in the pools.

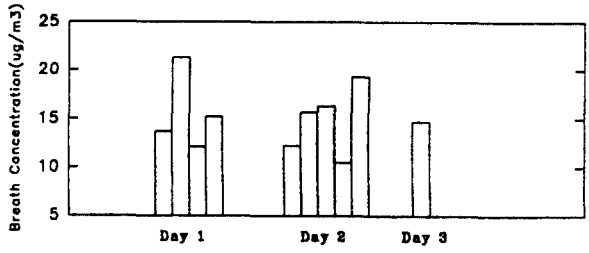

Fig. 1. Chloroform breath concentration after swimming : the number of subjects is 4, 5, and 1 for visiting day 1, 2, and 3, respectively.

Figure 1 shows the chloroform breath levels obtained from seven subjects for three visiting days, and the mean water and air levels of each visiting day. The water level was ordered downward by visiting day 2, 3, and 1, while the air level by visiting day 1, 2, and 3. Since single value only in all media was available on

visiting day 3, the single value is considered as a mean value of each media. For visiting day 1, the breath concentration ranged from 12.1 to 21.3 μg/m^3. The chloroform breath level on visiting day 1 appears not to be significantly different from that of visiting days 2 and 3. On the visiting day 1, the water concentration was lowest, with the highest air concentration. The water level was rather higher on the visiting day 2 than on the visiting day 1. It is implied that the water and air concentrations crossly acted to result in the similar breath levels for the visiting days. Hence, it is expected that the inhalation exposure would be higher on the visiting day 1 as compared to the visiting day 2, while the reverse is for the dermal exposure. However, it must be noted that in addition to water and air concentration, there are several other confounding factors which can influence the breath levels of swimming individuals on each visiting day. The confounding factor mainly include swimming environments such as water and air temperature, water and air concentration, crowd, etc., and the physiological difference, swimming activity, and swimming skill of swimming individuals.

As shown in Figure 1, the chloroform breath levels were different from each subject who visited on the same day. Since the subjects who visited to the pool on the same day swam under the same swimming conditions, the swimming environment should not be included to explain the difference. Three explanations are suggested to understand the difference. The first is the physiological difference of the 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. The second is the swimming activity difference of the subjects, since even for the same subject the physiological characteristics varies with the extent of activity. The last one is the different swimming skill of the subjects, since the water amount ingested and the respiration rate and other physiological characteristics varies with the swimming skill.

Table 2. Chloroform levels in breath prior to, during and after swimming in the pools which was disinfected with sodium hypochlorite only.

Time[a]	Breath Concentration(μg/m^3)
20 min(P)	ND
10 min(D)	45.3
20 min(D)	50.4
25 min(D)	54.8
35 min(D)	65.7
55 min(D)	72.3
5 min(A)	7.7
30 min(A)	3.8
60 min(A)	2.9
90 min(A)	ND
120 min(A)	ND
Water Concentration: 112 μg/l	
Air Concentration: 84.3 μg/m^3	

[a] Parentheses P, D, and A mean prior to, during and after swimming, respectively.

Table 2 shows chloroform breath levels for swimming which were conducted in New Jersey pool to understand the mechanism of chloroform entrance into and decay from human body while swimming. The background breath level was not detected. The breath level 5 minutes after swimming(7.7 μg/m^3) taken in New Jersey was lower than those after 2 to 3 minutes after swimming(15.1 μg/m^3) taken in Taegu. This difference is explained using two parameters: the chloroform concentrations in two media (water and air) and the time measured after swimming. The water(112 μg/l) and air(84.3 μ

g/m^3) concentrations were higher in New Jersey study as compared to those in Taegu study. On the other hand, the time measured after swimming in New Jersey was 5 minutes while that after swimming in Taegu was 2 to 3 minutes. Chloroform concentration in breath decreases rapidly within 5 minutes(first half-life) following the cessation of exposure as the body purged itself of chloroform by expiration and metabolism (Weisel and Shepard, 1994). Hence, the measuring time within 5 minutes after exposure is a critical factor which influences the breath concentration and its effects on postexposure concentration might be greater than that by chloroform concentration in two media.

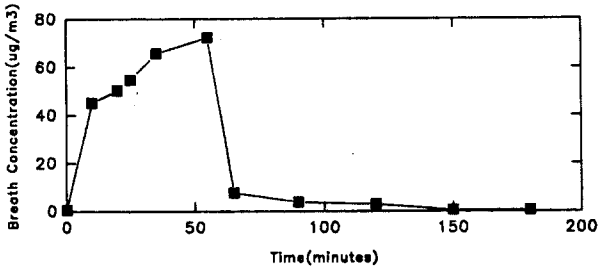

Fig. 2. Chloroform breath concentrations during and after swimming.

As shown in Figure 2, breath concentration increased gradually during swimming, then decreased rapidly within 5 minutes after the cessation of exposure, after that, decreased slowly, and finally approached to a background breath level at 1-2 hr after exposure. The two phases(early-rapid and second-slow decay phases) indicate breath that the decay mechanism after swimming fits to two- compartment model, rather one-compartment model. Hence, two-compartment model is recommended for the pharmacokinetic studies of chloroform decay after swimming.

5. CONCLUSIONS

Chloroform exposure from swimming in the pool was confirmed by comparing chloroform concentrations in exhaled breath collected prior to and after swimming. Swimming in the pool resulted in the elevated chloroform body burden which would be caused through the multiple exposure routes of ingestion, dermal, and inhalation. As a result, the health risk from chloroform exposure will be higher for regular swimming individuals as compared to the non-swimming individuals. The breath chloroform levels were different between subjects who swam in the same swimming condition of the same visiting day. This could be explained by the difference of the physiology, swimming activity, and swimming skill between subjects. Breath concentration increased gradually during swimming, and the decay mechanism better fit to two-compartment model than one-compartment model.

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실내 수영장에서 수영시 야기되는 클로로포름 인체부담

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수영장에서 염소를 이용한 살균시, 수영장의 물과 공기에서 클로로포름 농도가 증가하고, 수영자는 이로 인해 클로로포름에 대한 인체 부담을 받을 수 있다. 본 연구는 40 분 수영으로 인해 야기되는 클로로포름에 대한 인체 부담을 확인하고, 60 분 수영 후에 시간에 따라 수영자의 호흡내 클로로포름의 농도가 변화하는 것을 평가하였다. 이 실험을 위해서 수영장의 물과 공기의 클로로포름 농도도 측정되었다. 인체 부담 확인을 위한 연구에서, 수영장 물과 공기내의 클로로포름 농도 범위는 각각 18.1 에서 25.3 μg/l 및 30.9 에서 60.7 μg/m^3 이었다. 40분간의 수영으로 인한 호기내의 클로로포름 농도는 수영 전의 호기 농도에 비해 64 에서 266 배 가량 높게 나타났다. 수영 전의 호기 농도 범위가 0.07 에서 0.19 μg/m^3 인 반면에, 40분간의 수영 후 호기 농도 범위는 10.5 to 21.3 μg/m^3 로 나타났다. 또한, 수영 후의 호기 농도가 동일한 날에 방문한 피실험자들간에 서로 다르게 나타났다. 60 분간의 수영 중에 수영자의 호흡내 클로로포름 농도는 점진적으로 증가하였고, 수영 후 5 분 동안은 급격히 감소하다가 그 이후로는 천천히 감소하여 마침내 수영 후 1-2 시간에는 배경 농도에 접근하였다.