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Original Paper

Relationship between the Ambient Concentration of Toluene in the Air of Workplaces and the Concentration of Toluene or Its Metabolites in the Urine of Workers

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Abstract

According to regulations issued by the Japanese Ministry of Labor, all workplaces that use major solvents must be monitored in two ways. The vapor concentrations in the workplace must be measured and urine of exposed workers must be analyzed for the metabolites of the solvents being used. To investigate the relationship between the concentration of toluene vapor in the workplace and the concentration of toluene or its metabolite in the workers' urine, three sets of air samples were taken. A first set of samples (1) was taken at many points equally distributed in the workplace to get an average value, a second set (2) was obtained from places near the position of the workers and a third set (3) was secured from the breathing zone of workers. Close correlations were found between the concentration for each air sampling, i.e. there was a straight line relationship when comparing sets (1)-(2), (2)-(3) and (1)-(3). There was also a close relationship between the concentration of toluene in the air samples and the concentration of toluene or its metabolites in the urine of the workers. The results suggest that the concentration of solvent vapors near the workers is a useful indicator of exposure suffered by workers who remained in the same place for most of their working time.

Introduction

Protecting workers against the health risk of exposure to solvents may be achieved by three types of monitoring, i.e., ambient monitoring, biological monitoring and health surveillance. Ambient monitoring may involve both work station monitoring (stationary monitoring) and personal monitoring, depending on the sampling systems[1).

In Japan, stationary monitoring has been conducted according to the requirements of the Working Environment Measurement Law since 1975[2], and biological monitoring of urine for major solvents has been done since 1989[3]. In the present investigation, the relationships among stationary monitoring, personal monitoring and biological monitoring in the workplace were studied.

Materials and Methods

Sampling points of toluene vapors:

Control levels have been generally established by a combination of the results of A and B samplings[1].

A sampling is set for overlooking emission condition of toxic chemicals for determining the average concentration of chemicals in the air of unit workplaces. B sampling is for measuring the concentration at a particular place and time at which the worker's exposure is considered to be at a maximum.

In the present study, ① A sampling was done at not less than five proper sampling points in accordance with the regulations of the Ministry of Labor. Sampling positions were located about 1.5 meter from the floor. ② Samplings of toluene vapors in the air near the workers position were carried out by placing samplers 1.5 m from the floor and 1.5 m from the breathing zone of the workers. The sampling points were selected out of the positions of A sampling. ③ The sampling points for B sampling are also described in the Working Environment Measurement Law. The law describes that samples be taken at points at which and at a time when the manufacturing process and working conditions indicate that the workers are being subjected to the greatest exposure.

In the present study, B samplings were omitted and only the A sampling was used, because workers worked at places having the highest concentration of toluene for periods of less than 15 min during their working times. Therefore B sampling was not feasible under these conditions.

Sampling methods for toluene vapors:

Solvents in the ambient air were adsorbed by activated charcoal in a passive sampling tube (Shibata Chemical Co, Tokyo), desorbed by 2-hydroxypyridine[4] and applied to a headspace-gas chromatograph.

Headspace-gas chromatography:

Concentrations of solvent gases were determined by headspace-gas chromatography. The analytical procedure was described in a previous report[4].

High performance liquid chromatography:

Concentrations of hippuric acid were determined by high performance liquid chromatography in the following manner: Urine was diluted 1:20 with mobile phase or deionized water and filtered through membrane filters with 0.45 μm of pore size. Then the filtrate was applied to a high performance liquid chromatograph (Integra. 4000, Perkin Elmer. Co, USA).

A column (4 mm$\phi \times$50 mm) packed with octadecyl-silanized silica gel (Tsk gel ODS-80 , 5 μm, Tosoh Co, Japan), and a UV detector at 230 nm wavelength were used throughout this investigation. A mixed solution of deionized water/methanol/acetic acid (800/250/3; by volume) was the most favorable mobile phase for the separation of hippuric acid.

Results

Relationships among the average concentrations of toluene in the workplaces, concentrations near the work station and concentrations in the breathing zones of workers:

The concentrations of toluene vapors in the workplaces and of toluene and hippuric acid in the urine of the workers are shown in Table 1. It shows that workers were exposed to low toluene vapor concentrations ranging

Table 1 Concentrations of toluene in the air and concentrations of toluene and hippuric acids in the urine of workers

Work shops	Workers	Concent. of toluene in breathing zone	Concent. of toluene in urine	Concent. of HA in urine	Concent. of toluene in air by A sampling	Concent. of toluene in air near work station
		ppm	μg/L	g/gcr.	ppm	ppm
I	A.	15.3	47.4	0.99	13.4	19.1
	D.	15.5	34.6	0.80	13.4	19.1
	B.	11.2	32.8	0.69	13.4	11.7
	E.	15.0	39.9	0.71	13.4	13.5
II	F.	3.4	9.1	0.21	4.2	2.9
	G.	5.9	13.3	0.64	4.2	5.9
	J.	9.2	25.2	0.75	4.2	9.2
III	M.	21.5	31.4	0.70	28.5	28.8
	L.	29.5	58.0	1.92	28.5	32.0
	O.	34.3	43.2	0.98	28.5	32.0

Concent.; concentrations HA; hippuric acid

from 3.4 to 34.3 ppm in their breathing zones. A typical example of sampling positions in the workplace is shown in Fig. 1. The geometric mean concentration and standard deviation of toluene in the workshop (I) were 13.4 and 1.4 ppm, respectively. The correlation coefficient and regression equations are shown in Table 2. The toluene vapors in three workplaces were collected by the A sampling method in which the concentrations of toluene near the breathing zone of the workers were determined.

The correlation coefficient between the toluene concentrations by the A sampling method (toluene concentrations by A sampling in short) and the concentrations of toluene in the breathing zones (toluene concentrations in breathing zone in short) of 10 workers was 0.93. This value was the lowest among the coefficients for air samplings but the correlation was significant ($p<0.01$).

The correlation coefficient between the concentrations of toluene in the ambient air near the breathing zone of workers (toluene concentrations near workers in short) and the breathing zone concentrations was 0.96 ($p<0.01$).

The significant close correlation ($p<0.01$) was obtained between toluene concentrations by A sampling and toluene concentrations near workers with a correlation coefficient of 0.96.

Relationship between ambient concentrations of toluene in the air and the urinary concentrations of toluene:

The correlation coefficient between toluene concentrations in breathing zone and those in the urine of the workers (urinary toluene concentrations in short) was 0.79, and the correlation was significant ($p<0.01$).

The correlation coefficient between toluene concentrations near workers and urinary toluene concentrations was 0.78, and a significant close correlation ($p<0.01$) was recognized.

Furthermore, the regression equations related to the two correlations above were similar to each other.

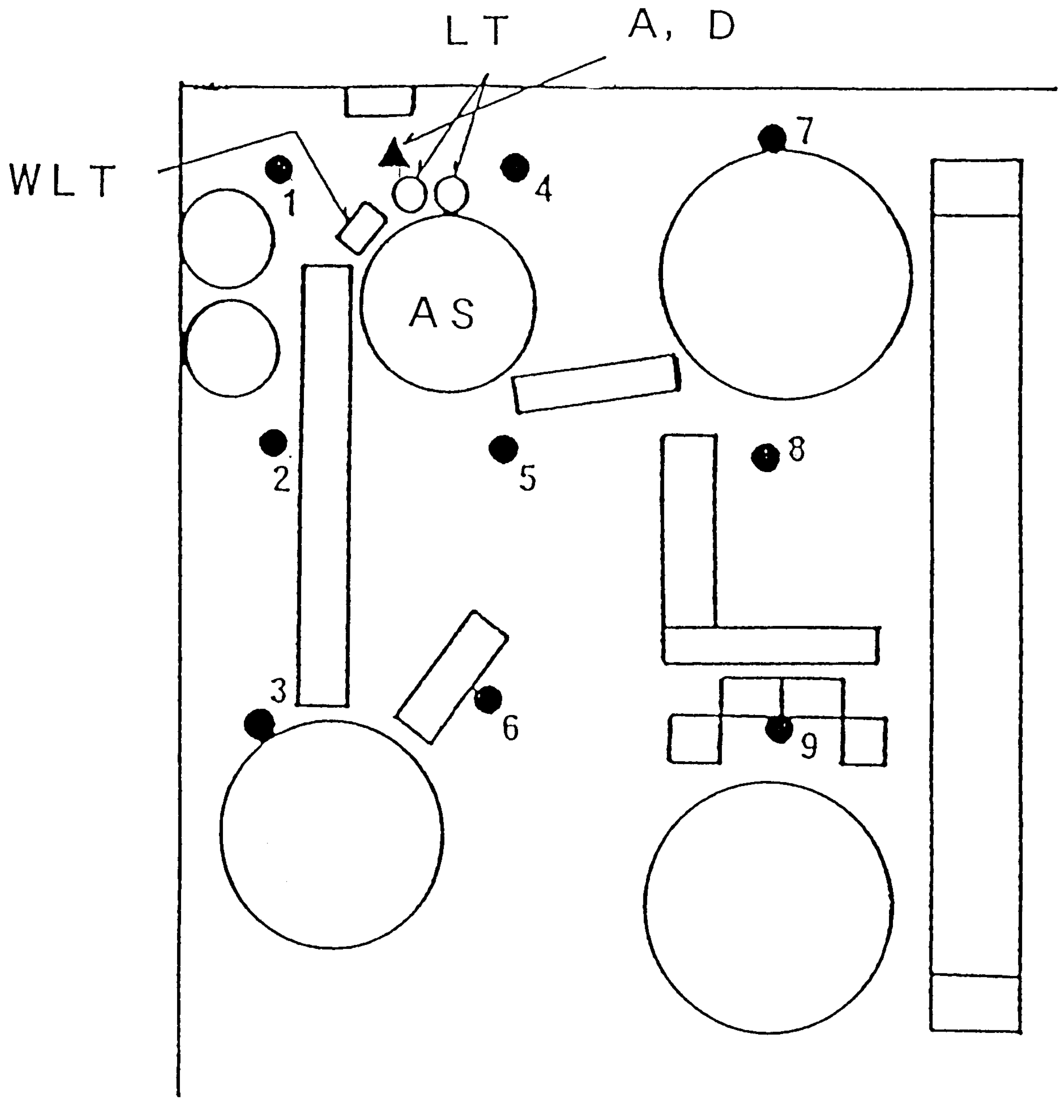

Fig. 1 A typical example of a workplace for showing the relationships among the three kinds of ambient monitoring.
Numbers 1 to 9 indicate sampling points using the A sampling method. The interval between 1 and 2 is 3 m. Symbols A and D indicate the working positions of workers A and D. AS; A sealed automatic spray machine. LT; Lacquer tanks with lids. WLT: Waste lacquer tanks with lids. Workers also put lacquer solution in the LT every two hours and take out waste lacquer from the AS and poured it into a bottle in the WLT every two hours. The average concentration of toluene in a workplace was the mean value of ambient concentrations collected from sampling points 1 to 9, at 1.5 m from the floor. The concentrations of toluene vapors sampled at a place near the positions of the workers were the average concentrations of toluene vapors sampled at the position 1 and 4. The toluene concentrations of breathing zones were concentrations determined by a personal sampler attached to the collars of the working clothes of workers A and B. The concentration of toluene in each station having symbol of 1, 2, 3, 4, 5, 6, 7, 8, and 9, was 27.7, 17.2, 10.5, 10.4, 13.5, 9.1, 13.4, 13.9 and 11.5 ppm, respectively. The geometric average and standard deviation of the stations were 13.4 and 1.40 ppm which was determined as required by the Working Environment Measuring Law[2].

The correlation coefficient between toluene concentrations by A sampling and those in urine was 0.72. This correlation coefficient was the lowest among the coefficients tested in this group but was still significant ($p<0.05$).

Table 2 Relationships among airborne concentrations in workplaces, concentrations in breathing zones and urinary concentrations of solvents or metabolites

airborne toluene(x)-urinary excretions(y)	regress. equat. $\alpha \pm \beta x$	cor. coef. r	t-test
mean airborne-breath zone.	2.13±0.92x	0.93	**
near airborne-breath zone	0.52±0.89x	0.96	**
mean airborne-Near airborn	1.90±1.02x	0.96	**
mean airborne-urinary tol.	17.2±1.07x	0.72	*
near airborne-urinary tol.	14.1±1.11x	0.78	**
breath zone-urinary tol.	14.3±1.20x	0.79	**
mean airborne-urinary HA	0.42±0.027x	0.63	*
near airborne-urinary HA	0.33±0.029x	0.71	*
breath zone-urinary HA	0.33±0.032x	0.72	*
urinary tol.-urinary HA	0.01±0.006x	0.85	**

regress. equat.=regression equation; cor. coef.=correlation coefficient; mean airborne=average toluene concentrations in the workplaces by A sampling; breath zone=toluene concentrations in the breathing zones of workers; near airborne=toluene concentrations near the breathing zone of workers; tol.=toluene; HA hippuric acid. * $=P<0.05$; ** $=P<0.01$

Relationship between ambient concentrations of toluene in the air and the urinary concentration of hippuric acid:

The correlation coefficient between toluene concentrations in breathing zone and the concentrations of hippuric acid in the urine of the workers (urinary hippuric acid concentrations) was 0.72, and the correlation was significant ($p<0.05$).

The correlation coefficient between the toluene concentrations near workers and urinary hippuric acid concentrations was 0.71, and a close correlation ($p<0.05$) was recognized. Furthermore, the regression equations related to the two correlations above are similar.

The correlation coefficient between toluene concentrations by A sampling and urinary hippuric acid concentrations was 0.63. This correlation coefficient was the lowest among the coefficients tested in this group but was still significant ($p<0.05$).

The concentration of hippuric acid and toluene in the urine of unexposed persons:

In the urine of 31 persons who have not been exposed to toluene, the concentration of toluene was less than 5 μg/L, which was the detectable concentration (n=31), and the average hippuric acid concentration and standard deviation were 0.193 and 0.163 g/g creatinine (n=31), respectively.

Making Comparison of urinary concentrations between toluene and hippuric acid:

The correlation coefficient between toluene concentrations in the breathing zone and toluene concentrations in the urine of the exposed workers was 0.79, while the correlation coefficient between toluene concentrations in the breathing zones and hippuric acid concentrations in the urine was 0.72. The former is higher than the latter, due to the fact that background concentrations of urinary toluene were relatively low, while those of urinary hippuric acid were relatively high. In addition, the level of urinary hippuric acid was affected by the amounts of benzoic acids contained in the workers' food. Therefore, correlation coefficients using urinary toluene as a factor were higher than those using urinary hippuric acids in workers exposed to low concentrations of toluene. The correlation coefficient between the urinary toluene concentrations and urinary hippuric acid concentrations was 0.85, and a significant close correlation ($p<0.01$) was found.

As first proposed by Ogata and Taguchi[5], metabolite concentrations in the urine samples from non-exposed persons and those taken at the end of a shift were used to obtain the discriminant solvent concentration in air (DC) was considered to discriminate exposure from non-exposure at a 5 % level of error. The value of DC was 35 ppm of toluene in the regression line between concentrations of toluene in the air and of toluene in the urine of workers exposed to toluene. The value of DC was 45 ppm of toluene in the regression line between the concentration of toluene in the air and that of hippuric acid in the urine of the workers. The lower value for urinary toluene shows that it is a better indicator than urinary hippuric acid.

Discussion

The regression equation between the concentration of toluene in the air (x ppm) and the concentration of toluene (y μL) in the urine as described by Monster et al.[6] was $y = 17.9+1.40x$ — (1), and the regression equation used in the present study was $y = 14.3+1.20x$ — (2) as shown in Table 2. The concentration of y corresponding to $x = 0$ is 17.9 μL from the equation (1) and 14.3 μL from equation (2). The concentration of toluene in the urine of unexposed person was less than 5 μL. The discrepancy above will be studied in the future.

The regression equation between the concentration of toluene in the air (x ppm) and the concentration of hippuric acid (y g/g creatinine) in the urine which was described in a previous paper[5] was $y = 0.36+0.021x$ — (3) and the regression equation in the present study as described in Table 2 was $y = 0.33+0.032x$ — (4). The concentration of y corresponding to $x = 0$ is 0.36 g/g creatinine from the equation (3) and 0.33 g/g creatinine from the equation (4). The concentration of hippuric acid in the urine of unexposed person is 0.193 g/g creatinine which is less than the values calculated by equations (3) and (4).

The measurement of solvent vapors in workplaces and of the urinary metabolites of major solvents is mandatory in Japan. However, the relationship between the two measurement has not been studied.

The concentrations of solvent vapors in the workers' breathing zones are related to the concentrations of solvents in the urine of workers and also to the concentrations of solvent vapors in the workplace.

To investigate the relationship between the results by work station monitoring and those by urinary biological monitoring, there is a need to study the relationship between results by stationary monitoring and those by personal monitoring and between results by personal monitoring and those by urinary biological monitoring.

The results of the present study showed when workers mostly remained in a fixed workplace and concentrations of solvents were relatively stable during their working time, the toluene concentrations near the positions of the workers were similar to those in the breathing zones of the workers. The results also indicated that the former is a good indicator for the latter.

Therefore, a close correlation was found between the concentrations of toluene vapors near the working positions of workers and those of urinary toluene and hippuric acid.

In Japan, urinary biological monitoring should be used to measure the amount of exposure to workers. The concentrations of hippuric acid and/or o-cresols in the urine of workers exposed to toluene should be compared with biological exposure indices (BEI). When the concentrations of urinary determinants exceed BEI, an effort should be made to decrease the amount of personal exposure by utilizing the results of both stationary and biological monitorings.

In addition, comparisons of the concentrations of solvents in workers' breathing zones and urinary solvents or metabolites would be useful for the improvement of working conditions. When the former is found to be higher than the latter, the workers should be recommended to wear a protective mask for the absorption of solvents. Conversely, when the opposite is true, the presence of dermal absorption should be considered. In most workplaces in Japan, data on the concentrations of solvents in breathing zones were lacking because such measurements were not required by the Working Environment Measurement Law. The present report suggests that the concentrations of solvent vapors in air located near the positions of workers obtained by the A sampling method are useful indicators of the concentrations of solvents in the breathing zones of workers.

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