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Original Paper

Estimating the Amounts of Toluene Inhaled by Workers Wearing Protective Masks by Measuring Determinants Derived from Toluene in Biological Specimens

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Abstract

Personal air samplers were attached to workers wearing protective masks during work to determine the levels of toluene vapors in the breathing zone.

Also, concentrations of toluene in exhaled air, blood and urine, and concentrations of hippuric acid and o-cresol in urine were determined.

Subsequently, concentrations of toluene vapors in the inhaled air of workers, with and without gas masks, were estimated using regression equations between concentrations of toluene in the air and biological exposure indicators of toluene. In the present study, wearing masks decreased exposure by 35 ~ 45 %. The exposure that remained was due to leakage of toluene through the interstice between the facepiece of masks and worker's faces and direct inhalation of toluene when removing masks. Workers must be taught proper procedures for using masks while an effort is made to lower toluene vapors in the workshop. Suitable methods are discussed, including the correction factor for estimating the amount of toluene inhaled using the biological exposure indicators of toluene.

Introduction

Gas masks have been widely used for protection against exposure to organic solvents in workshops.

Workers continue to suffer exposure, even when wearing masks, for the following reasons. First, adsorption of solvents by activated charcoal is not complete and some solvents pass through the charcoal and are in-

haled by workers. Second, there is leakage of toluene through the interstice between the facepiece of gas masks and the worker' faces[1,2]. Third, when workers remove their masks in the workplace, solvents in the air are inhaled directly. The actual exposure, including inhalation and dermal absorption, can only be estimated by determining the amounts of exposure indicators in biological specimens. However, there has been a report by Kira[3] which describes the actual efficiency of masks used by workers in the workplace.

The present paper describes toluene exposure for workers wearing masks, as determined by the levels of exposure indicators of toluene in their biological specimens.

Materials and Methods

Materials

Workers surveyed averaged forty one years in age. Eight workers were engaged in mixing pigments into toluene and were exposed to toluene in a plant that manufactured cathode ray tubes. They did not wear masks on the first day and wore masks on the second day. Another eight workers in the same shop did not wear masks. Their samples were assayed for supplementary confirmation of the regression equations between toluene concentrations in the air and concentrations of biological exposure indicators in biological specimens. The masks used in this study were chemical cartridge respirators (Kouken Co. Type R8A).

Methods

The methods used for collecting and assaying the biological specimens of workers, with and without masks, were described in a previous paper[4].

Statistical analyses were carried out with Lotus 1-2-3 software.

Results

In this section, toluene in the exhaled air, blood and the urine and hippuric acid and o-cresol in the urine are abbreviated as Tol-EH, Tol-Bl, Tol-U, HA-U and CRS-U, respectively.

1. Regression equations

Regression equations, with correlation coefficients, between the concentrations of toluene in the breathing air of workers without masks and biological exposure indicators in their urine.

Three kinds of data were used. The first set was data from the eight workers that wore gas masks on the second day. The second was from the sixteen workers in the same workshop, including the eight workers described above and the third was data from the literature[5~8].

Regression equations are listed in Table 1. Close correlations were obtained in each of the three sets of data between the concentrations of toluene in the breathing air of workers and the concentrations of biological exposure indicators of toluene. Therefore, these three regression equations were used to calculate the efficiency of masks in removing toluene from the breathing zone air (tol-BTHZ) and also to calcuate the amounts of toluene inhaled (tol-INHL) from the amounts of biological exposure indicators (BEITs).

2. Effectiveness of wearing gas masks.

The amounts of toluene inhaled by workers (tol-INHL), with and without gas masks, were calculated from the three regression equations described above.

1) The method of calculation

Method for calculating the reduced amounts of toluene vapors inhaled by workers wearing masks from concentrations of biological exposure indicators.

The factors in the equation are abbreviated

Table 1 Factors for the regression equations between concentrations of toluene in the breathing zone and concentrations of biological exposure indicators (BEIT) for toluene for sixteen workers without masks on the first day, eight workers wearing masks on the second day and data from other previous papers.

Period	BEIT	Unit	a	b	r	Test
lst day	Tol-EX	ppm	0.315	0.182	0.83	$p<0.01$
(N=16)	Tol-BL	μg/L	11.0	16.7	0.67	$p<0.01$
without	Tol-U(AC)	μg/L	14.5	0.871	0.64	$p<0.01$
masks	HA-U(CR)	g/g. cre.	0.28	0.023	0.76	$p<0.01$
	OCRS-U(CR)	g/g. cre.	194.0	6.40	0.58	$p<0.05$
lst day	Tol-EX	ppm	0.0042	0.211	0.883	$p<0.01$
(N=8)	Tol-BL	μg/L	47.0	19.74	0.796	$p<0.05$
without	Tol-U(AC)	μg/L	16.26	0.948	0.723	$p<0.05$
masks	HA-U(CR)	g/g. cre.	0.34	0.002	0.763	$p<0.05$
Origin	BEIT	Unit	a	b	r	(Ref)
Other	Tol-BL	μg/L	28.8	19.0	0.92	Campbell et al (5)
papers	Tol-U(AC)	μg/L	−1.4	2.26	0.87	Ghittori et al (6)
	HA-U(CR)	g/g. cre.	0.36	0.021	0.85	Ogata et al (7)
	OCRS-U(CR)	g/g. cre.	162	8.14	0.71	Inoue et al (8)

y=a+bx, y=concentrations of toluene (ppm), x=concentrations of biological exposure indicators for toluene, r=correlation coefficient, cre.=creatinine, Tol-U(AC)=actual concentration of Tol-U, HA-U(CR)=hippurid acid concentration corrected with creatinine and OCRS-U(CR)=o-cresol concentration corrected with creatinine.

as follows: toluene concentrations inhaled by a worker before and while wearing masks are abbreviated as (tol-INHL without mask) and (tol-INHL with mask), respectively. Toluene concentrations in the breathing zone of workers before and while wearing masks are abbreviated to (tol-BTHZ without mask) and (tol-BTHZ with mask), respectively. Three kinds of ratios were used for estimating the effect of masks on the amounts of toluene inhaled.

(1) The direct method.

This method (DR) involved the ratio of (tol-INHL with mask), as determined from the exposure indicators of toluene, to (tol-BTHZ with mask). That is, the equation for the ratio by the direct method (DR) is: DR = (tol-INHL with mask)/ (tol-BTHZ with mask).

(2) The indirect uncorrected method.

In this method, the non-corrected ratio (NCR) was calculated to be as follows: NCR = (tol-BTHZ with mask)/ (tol-BTHZ without mask). When (tol-INHL with mask) and (tol-INHL without mask) are the same, this equation is useful. However, when they are different, the indirect corrected ratio should be used.

(3) The indirect corrected method.

The corrected ratio (CR) for amounts of toluene inhaled, without and with masks, is the following: [(tol-INHL with mask)/(tol-INHL without mask)] × [(tol-BRZ without mask)/(tol-BRZ with mask)].

The CR can also be expressed as follows: [(tol-INHL with mask)/(tol-BRZ with mask)] ÷ [(tol-INHL without mask)/(tol-BRZ without mask)]. That is, the corrected ratio can be expressed by the equation (tol-

INHL with mask per exposed concen. with mask)/(tol-INHL without mask per exposed concen. without mask). Data are listed in Tables 2, 3 and 4.

2) Calculation made from the regression equations from the sixteen workers for each from five indicators as a typical example.

The results from the sixteen workers not wearing masks, including the eight workers who wore masks on the second day, are shown in Table 2.

(1) Reduced amount of toluene inhaled by using masks as determined from toluene in exhaled air.

a. Toluene inhaled by workers wearing masks using the indirect method.

a) The indirect uncorrected method.

The average concentrations of tol-INHL by workers wearing gas masks was 10.9 ppm (x) as calculated using the 2.3 ppm (y) of tol-ETHA with the regression equation from the sixteen workers without masks (Table 1). The regression equation is $y = 0.315 + 0.182x$, where y is concentration in exhaled air and x is concentration in inhaled air.

Table 2 Exposure levels of toluene vapors by personal air samplers, concentrations of toluene in biological specimens, urinary o-cresol, and urinary hippuric acid and estimated removing efficiencies by the use of protective masks using regression equations from sixteen workers without masks, including eight workers who wore masks on the second day.

Exposure ind. of toluene	Unit	The 1st day without mask (Exp. 19.9 ppm)		The 2nd day with mask (Exp. 18.9 ppm)		Efficiencies			
		Mea. conc	Inh. conc est.	Mea. conc	Inh. conc est.	Remained (%) Act. (Direct)	Corr.	Removed (%) Act. (Direct)	Corr.
Toluene		ppm		ppm					
In exh. air	ppm	4.2	21.3	2.30	10.9	51.2 (57.7)	54.0	48.8 (42.3)	46.0
In blood *	μg/L	438.7	25.6	210.7	12.0	46.9 (63.5)	49.4	53.1 (36.5)	50.6
In urine (n. c.)	μg/L	35.1	23.7	26.1	13.3	56.1 (70.4)	59.1	43.9 (29.6)	40.9
Hippuric acid In urine	g/gcr.	0.77	21.3	0.63	15.2	71.4 (80.4)	75.2	28.6 (19.6)	24.8
o-Cresol In urine	μg/gcr.	341.5	23.0	245.8	8.1	35.2 (42.8)	37.1	64.8 (57.2)	62.9
m ±SD						52.2 ±13.2 (63.0 ± 14.1)	55.0 ±14.0	47.8 ±13.2 (37.0 ± 14.1)	45.0 ±14.0

Exposure concentrations of toluene without mask were 19.9 ppm and with masks were 18.9 ppm. Remained corrected concent. = remained actual concent. x (19.9/18.9). (Direct) in the column for remained (%) is the direct noncorrected ratio (estimated concentration inhaled in the 2nd day)/(exposed conentration in 2nd day). ind. = indicators, Exp. = concentration of exposure, Mea. = measured, Inh. = inhaled, conc = concentrations, est. = estimated, * = samples are taken only at the end of the first 4 hours of exposure. (n. c) = without correction, gcr. = g creatinine and corr. = corrected.

Similarly, the average concentration of tol-IHL by workers without masks was calculated to be 21.3 ppm (x) as calculated from the 4.2 ppm (y) of tol-EH. Therefore, the ratio of (tol-INHL with masks) to (tol-INHL without masks) was 10.9 / 21.3 = 0.512 (51.2 %).

b) The indirect corrected method

On the other hand, (tol-BRZ without mask) and (tol-BRZ with mask) were 19.9 ppm and 18.9 ppm, respectively.The corrected ratio of toluene remaining is (10.9 / 21.3) × (19.9 / 18.9) = 0.54 (54.0 %) and the corrected ratio removed is 0.46 (46.0 %).

b. Direct method

Ratio of toluene inhaled by workers wearing masks measured directly without correction (DR).

Inhaled concentration was estimated to be 10.9 ppm and the exposed concentration to workers with masks was 18.9 ppm. The amount inhaled was 10.9 / 18.9 = 0.577 (57.7 %) and the amount removed was 42.3 %.

(2) Amounts of toluene inhaled by workers (tol-IHL) wearing masks as calculated from toluene in the blood.

a. Indirect method.

a) The indirect uncorrected values of toluene inhaled by workers was 12.0 / 25.6 = 0.469 (46.9 %).

b) The indirect corrected values of toluene remaining in workers. The corrected value was (12.0 / 25.6) × (19.9 / 18.9) = 0.494 (49.4 %).

Therefore, the corrected amount removed was 50.6 %.

b. Direct method.

The direct uncorrected values of toluene inhaled by workers was 12.0 / 18.9 = 0.635 (63.5 %).

(3) The effect of wearing mask on tol-INHL as calculated from toluene in the urine.

a. Indirect method.

The corrected value of toluene inhaled by workers.

The corrected value was (13.3 / 23.7) × (19.9 / 18.9) = 0.591 (59.1 %).

Thus, the corrected amount removed was 40.9 %.

b. Direct method.

The uncorrected value of toluene inhaled by workers was 13.3 / 18.9 = 0.704 (70.4 %).

(4) Reduction in inhalation of toluene by wearing masks as determined by hippuric acid in the urine.

a. Indirect methods.

The corrected value of toluene inhaled by workers was (15.2 / 21.3) × (19.9 / 18.9) = 0.752 (75.2 %).

The corrected amount removed was 24.8 %.

b. Direct method.

The non-corrected value of toluene inhaled by workers was 15.2 / 18.9 = 0.804 (80.4 %).

(5) Reducion in inhalation of toluene by wearing masks as calculated from urinary o-cresol corrected with creatinine (CRS-UCCR).

a. Indirect method.

The corrected value of toluene inhaled by workers was calculated to be (8.1 / 23.0) × (19.9 / 18.9) = 0.371 (37.1 %).

The corrected amount removed was 62.9 %.

b. Direct method.

The uncorrected value of toluene inhaled by workers was 8.1 / 18.9 = 0.428 (42.8 %).

3) The average amount of toluene inhaled (Tol-INHL/TOL-BTHZ) as estimated from concentrations of the biological exposure indicators of toluene.

(1) Calculation from regression equations using the data of sixteen workers (Table 2).

a. Indirect method.

The indirect corrected values for toluene inhaled by workers.

Using five biological exposure indicators, the average ratio of (tol-INHL with masks/tol-INHL without masks), an indicator of the amount of toluene passing through the masks, was calculated to be 52.2 ± 13.2 % (mean ± standard deviation). After correcting for the exposure concentration ratio of 19.9 ppm/18.9 ppm, the remaining ratio was 55.0 ± 14.0 % and the ratio removed, which indicates the removal efficiency of masks, was 45.0 ± 14.0 %.

b. Direct method.

The direct uncorrected ratios of toluene inhaled by workers.

The average of the ratio (Tol-IHL/tol-BTHZ) was 63.0 ± 14.1 %, which was higher than the ratio obtained for the corrected value inhaled by the workers, 55.0 ± 14.0 %. The amount removed was 37.0 ± 14.1 %.

(2) Calculation from regression equations using the data from eight workers who did not wear gas masks on the first day. The results are shown in Table 3.

a. Indirect method.

The indirect corrected ratios of toluene removed from workers.

The indirect corrected ratios of toluene removed from workers by wearing masks were as follows: The corrected values calcu-

Table 3 Exposure levels of toluene vapors by personal air samplers, concentrations of toluene in biologal specimens, urinary o-cresol, and hippuric acid and estimated removing efficiencies by the use of protective masks using regression equations from eight workers wearing masks on the second day.

Exposure ind. of toluene	Unit	The 1st day without mask		The 2nd day with mask		Efficiencies			
		Mea. conc	inhal. conc est.	Mea. conc	inhal. conc est.	Remained (%) Act.	Corr. (Direct)	Removed (%) Act.	Corr. (Direct)
Toluene									
In exh. air	ppm	4.2	19.8	2.30	10.9	55.1	58.1	44.9	41.9
						(57.7)		(42.3)	
In blood *	μg/L	438.7	19.9	210.7	8.3	41.7	43.9	58.3	56.1
						(43.9)		(56.1)	
In urine (n. c.)	μg/L	35.1	19.9	26.1	10.4	52.3	55.1	47.7	44.9
						(55.0)		(45.0)	
Hippuric acid In urine (c. cr)	g/gcr.	0.77	19.9	0.63	13.4	67.3	70.9	32.7	29.1
						(70.9)		(29.1)	
m			19.9		10.8	54.1	57.0	45.9	43.0
±SD			± 0.1		± 2.1	±10.5	±11.1	±10.5	±11.1
						(56.9 ± 11.1)		(43.1 ± 11.1)	

note: contents are described in Table 2.

lated from concentrations of toluene in the exhaled air, toluene in the blood, toluene in the urine, and hippuric acid in the urine were 41.9 %, 56.1 %, 44.9 % and 29.1 %, respectively. The average corrected ratio removed as calculated from the four biological exposure indicators of toluene was 43.0 ± 11.1 %.

b. Direct method.

The direct uncorrected ratios of toluene removed from workers.

The uncorrected ratios of toluene removed from workers by the use of masks were as follows: The uncorrected average values calculated from concentrations of toluene in the exhaled air, toluene in the blood, toluene in the urine and hippuric acid in the urine were 42.3 %, 56.1 %, 45.0 % and 29.1 %, respectively. The average for these four biological exposure indicators of toluene was 43.1 ± 11.1 %. The average indirect corrected ratios and direct uncorrected ratios are similar.

(3) Calculation from regression equations determined from the data reported by other scientists[5~8].

The results are shown in Table 4.

a. Indirect method.

The indirect corrected ratios of toluene removed from workers.

The corrected ratios of toluene removed from workers by wearing masks were as follows: The corrected values calculated from concentrations of toluene in the exhaled air, toluene in the blood, toluene in the urine and hippuric acid in the urine were calculated to be 53.3 %, 20.2 %, 30.3 % and 36.2 %, respectively. The average corrected ratio obtained for these four biological exposure indicators of toluene was 35.0 ± 13.9 %.

b. Direct Method.

The direct uncorrected ratios of toluene removed from workers.

The uncorrected ratios of toluene removed

Table 4 Exposure levels of toluene vapors by personal air samplers, concentrations of toluene in biological specimens, those of urinary o-cresol, those of hippuric acid and estimated removing efficiencies by taking protective masks using regression equations from previous reports including those of the authors.

Exposure Ind. of toluene	Unit	The first day without mask		The second day with mask		Efficiencies			
		Mea. conc.	Inh. conc. est.	Mea. conc	Inh. conc est.	Remained (%) Act.	Corr. (Direct)	Removed (%) Act.	Corr. (Direct)
Toluene			(ppm)		(ppm)				
In blood *	μg/L	438.7	21.6	210.7	9.6	44.4	46.7	55.5	53.3
						(50.8)		(49.2)	
In urine (n. c.)	μg/L	35.1	16.1	26.1	12.2	75.8	79.8	24.2	20.2
						(64.6)		(35.4)	
Hippuric acid	g/gcr.	0.77	19.5	0.63	12.9	66.2	69.7	33.8	30.3
In urine (c. cr)						(68.3)		(31.7)	
o-Cresol	μg/gcr.	341.6	22.1	270.9	13.4	60.6	63.8	39.3	36.2
In urine (c. cr)						(70.9)		(29.1)	
m			19.6		12.0	61.8	65.0	38.2	35.0
±SD			± 2.7		± 1.7	±13.1	±13.9	±13.1	±13.9
						(63.6 ± 8.9)		(36.4 ± 8.9)	

from workers by wearing masks were as follows: The corrected values calculated from concentrations of toluene in the exhaled air, toluene in the blood, toluene in the urine and hippuric acid in the urine were 49.2 %, 35.4 %, 31.7 % and 29.1 %, respectively. The average for these four biological exposure indicators of toluene is 36.4 ± 8.9 %.

Discussion

For calculating the reduced amount of toluene inhaled by workers using masks, direct and indirect methods were used in the present study.

The direct method is convenient because the estimated values can be calculated from the concentrations of biological indicators of toluene and concentrations of toluene in the breathing zone of workers wearing masks. However, the regression lines generally used by scientists and the actual regression lines for individual workers used for calculation are not the same because of individual differences.

In the indirect method, the regression equation used for calculating the reduced amount of inhalation by using masks was determined using the same workers, thus reducing the effect of individual variation. However, the exposure concentrations in the breathing zone of workers, with and without masks, were different. Therefore, a correction factor was incorporated into the equation to account for this difference.

When workers use masks in the workplace to reduce the amount of toluene inhaled, the present study indicates that three factors must be taken into consideration.

First, the adsorbing ability of the activated charcoal in masks should be maximized. In the present study, workers changed the activated charcoal cartridges in their masks every day. The fact that toluene vapors were not completely removed by the activated charcoal was not taken into account.

Second, there is leakage of toluene vapors through the interstice between the face piece of the gas mask and the worker's face. The leakage rate was reported to be 10 percent, less for skilled workers, and leakage rates during exercise were higher than when at rest[1,2]. Third, while workers only took off their gas masks in places where or at a time when the concentrations of toluene were thought to be low, they were still inhaling toluene directly. In the present survey, three kinds of regression equations were used to determine that masks removed 35 ~ 45 % of the toluene by the indirect corrected rate. The amounts of toluene leaking through the interstice between the mask and the worker's face was estimated to be 10 % of exposure. Therefore, using masks should have remove 90 % of the toluene to which workers were exposed if used continuously. Therefore, the problem of direct inhalation while removing gas masks in lower concentrations should be given serious consideration.

This study shows that there is a need to educate workers about the proper use of masks, in addition to a greater effort to lower toluene vapors in the workplace.

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