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Exposure to toluene in a photogravure printing plant

Concentration in ambient air and uptake in the body

by PER ÖVRUM, M.Sc., MAY HULTENGREN and THOMAS LINDQVIST¹

ÖVRUM, P., HULTENGREN M. and LINDQVIST, T. Exposure to toluene in a photogravure printing plant: Concentration in ambient air and uptake in the body. *Scand. j. work environ. & health* 4 (1978) 237-245. Workers in the photogravure printing industry were studied concerning exposure of toluene. The study included determination of exposure with personal air sampling and with direct reading physical instruments and determination of the concentration in alveolar air. Uptake of toluene in the body was ascertained with a direct and an indirect method. The physiological work load was determined with pulmonary ventilation measurements, and the toluene concentration in the blood was determined. The results showed that there was no appreciable difference between exposure determined with personal air sampling and with stationary direct reading physical instruments. The study also showed that alveolar air sampling during exposure can be used when the uptake of toluene is being estimated. The alveolar air concentrations after the end of exposure reflected the uptake during exposure, but the correlation to the concentration in the inspiratory air was low. The results also showed a correlation between the concentration in alveolar air and the concentration in blood. Estimations made showed that the uptake in the body was of such a magnitude that there could be a risk of central nervous disturbances. No change in the uptake of toluene, as the percentage of the given amount, could be seen, neither during a day's exposure nor from day to day during a week. The authors recommend measurements of alveolar air concentrations as a method for biologically monitoring toluene uptake.

Key words: alveolar air, blood concentration, exposure, photogravure printing industry, pulmonary ventilation, toluene, uptake.

Experimental exposure to toluene has previously been performed in our laboratory (2). The aim of the present study was to apply the laboratory methods during normal work in industry. The methods used in the present study included measurements of the toluene concentration in

inspiratory, expiratory and alveolar air, determination of percentage and total uptake of toluene with a simple method for field studies, estimation of physical work load by determinations of pulmonary ventilation, and determination of toluene concentrations in blood.

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STUDY DESIGN

The measurements were made during three weeks in a printing plant and were

Fig. 1. The printing plant room. The numbers 7, 23, 24 and 26—30 represent the different printing presses.

concentrated to workers at two presses (fig. 1). Samples were taken from the first printer and three other coworkers.

During a shift, the workers wore a personal sampler with which samples were continuously taken from the ambient air for 30 min at a time. These samplers sucked air from the respiratory zone through a copper capillary tube into a 30-ml all-glass syringe. In addition the toluene content of the air was registered continuously with direct recording instruments at two stationary sampling sites. An IR instrument (MIRAN I, Wilks Scientific Corp., U.S.A.) equipped with a gas cell and a recorder was used at site 1 (S1) and a photo ionization instrument (model PL 101, HNU Systems Inc., U.S.A.) equipped with a recorder was used at site 2 (S2) (fig. 1). Calibrations were made on site.

Every 60 min during a shift samples of the worker's alveolar air were taken for determination of the toluene concentration. Alveolar air samples were also taken after the end of work one day and before the start of work the following day.

During the last two weeks of the study the total and the percentage uptake of toluene in the body was measured with the Douglas bag technique using aluminium laminate bags. Uptake determinations included measurements of pulmonary ventilation and concentrations in inspiratory and expiratory air. These measurements were made during different work operations. The percentage uptake was also determined indirectly from alveolar air

samples and samples of ambient air. The quotient between the two values was used for the estimation of percentage uptake according to fig. 2. The correlation in the figure is actually valid each moment under exposure. It should be noted that the bag method gives a mean value for total and percentage uptake during the sampling period, whereas the alveolar air method only gives an instantaneous percentage value.

Arterialized capillary blood samples were taken before and after work for the determination of the toluene concentration. At the same time alveolar air samples were taken.

METHODS OF ANALYSIS

The toluene content of air samples from inspiratory, expiratory and alveolar air was determined with a portable gas chromatograph AID, model 511 (Analytical Instrument Development, Inc., U.S.A.) equipped with a flame ionization detector. It had a stainless steel column (1 m long with an inner diameter of 2.2 mm) and was packed with 3 % 1, 2, 3-Tris (2-cyanoethoxy)-propane on Chromosorb G, 80—100 mesh. The column temperature was 70° C, and the carrier gas (nitrogen) flow rate was 25 ml/min. Standard gas was prepared in 20-l bags made of aluminium laminate. Any solvent present was re-

moved as the air passed through an activated charcoal filter before being pumped into the bag.

The toluene content in blood was determined with the head space method. The assay was performed with a gas chromatograph (Perkin-Elmer, model F11, with a flame ionization detector). The column was made of stainless steel (2 m long with an inner diameter of 2.2 mm) and was packed with 1 % Squalane on Chromosorb G, 80–100 mesh. The column temperature was 50° C, and the carrier gas (nitrogen) flow rate was 30 ml/min.

RESULTS

The continuous registration of the stationary measurements at sites S1 and S2 disclosed that the toluene concentrations ranged from a few parts per million to 350 ppm. Examples of the findings are shown in table 1. The difference between the concentrations measured at the two presses was slight. Thus toluene vapor was relatively well mixed with the air in the room. In fig. 3 one typical example of results recorded at sampling site S1 is given. As can be seen, the toluene concen-

Fig. 2. The amount of toluene taken up as the percentage of the supplied amount in relation to the alveolar concentration as the percentage of the concentration in inspiratory air. The figure is taken from Carlsson and Lindqvist (4). Direct measurements were made both at rest and during work on a bicycle ergometer at work loads of 50, 100, 150 W. Each symbol indicates the mean percentage uptake during 30 min in relation to the mean alveolar concentration during the last 10 min of the same 30 min. The concentration in inspiratory air was constant. The equation of the regression line is $y = -0.6x + 72.9$.

Table 1. Time-weighted average values from measurements with direct recording instruments. The values are given at 25° C. (100 ppm = 375 mg/m³)

Week/day	Sampling site 1 (ppm toluene)			Sampling site 2 (ppm toluene)		
	Mean value	Lowest value	Highest value	Mean value	Lowest value	Highest value
1/1	145	65	198	202	77	301
1/2	137	80	287	160	76	268
1/3	148	65	353	162	61	248
1/4	88	43	117	95	38	137
2/1	53	23	95	47	18	145
2/2	38	20	83	42	20	150
2/3	60	20	120	72	18	160
2/4	80	43	135	59	28	154
3/1	34	7	71	25	5	53
3/2	67	14	155	42	13	94
3/3	117	56	165	82	51	108
3/4	83	29	127	59	30	77

Fig. 3. Four typical examples of a continuous exposure recording during a day. Black lines under the curves indicate when the different photogravure presses (29, 30, 26, 23 and 7) were in operation.

tration declined whenever one of the presses was shut down. Even more remotely situated presses affected the findings, although to a lesser degree.

The results of exposure measurements for different persons working in the immediate vicinity of a printing press are given in table 2. The time-weighted mean

exposure during a day was similar for the different persons. It is also apparent that exposures during the first week were higher than during the second and third weeks. There are a number of explanations for this. More presses were in operation the first week than in the last two weeks. Moreover, there was more multi-

Table 2. Time-weighted 8-h average values of exposure measurements made with personal samplers and direct recording instruments.

Press	Week/day	Personal samplers (mean toluene concentration, ppm)					Stationary instruments (mean toluene concentration, ppm)	
		1st printer	2nd printer	3rd printer	Helper	Mean value	Press 29	Press 30
29	1/1	130	164	140	150	146	145	202
29	1/2	108	133	125	127	123	137	160
29	1/3	99	122	116	138	119	148	162
29	1/4	72	81	97	84	84	88	95
30	2/1	51	52	54	49	52	53	47
30	2/2	55	50	41	37	46	38	42
30	2/3	76	82	66	78	75	60	72
30	2/4	63	97	70	134	91	80	59
29	3/1	20	20	16	26	21	34	25
29	3/2	110	64	51	87	78	67	42
29	3/3	90	86	82	95	88	117	82
29	3/4	62	60	68	70	65	83	59

color printing the first week, and therefore the amount of toluene used was greater.

It is also shown in table 2 that the mean value for the exposure of all the workers at a printing press failed to differ systematically from the concentration recorded with stationary, direct recording instruments.

The mean exposure concentrations measured with personal sampling equipment during the three weeks for all groups

amounted to 118, 66 and 63 ppm of toluene, respectively.

In fig. 4 examples of the ambient and alveolar air concentrations of one subject for four days are shown. The concentrations in inspiratory air varied greatly during the course of a work shift. The toluene content in alveolar air was about 20–50 % of the mean concentration in inspiratory air at the same time or immediately before.

Fig. 4. Mean exposure for each hour during four different days. The measurements were made by the personal sampling technique for the first printer at press 29. The printer's alveolar concentration is also noted (●).

Fig. 5. Concentration of toluene in alveolar air (25°C) after 8 h of exposure to time-weighted mean concentrations between 16 and 134 ppm. Each line represents mean values of measurements from at least two different individuals whose mean time-weighted exposure during the immediately preceding 8 h was within the same 10-ppm interval. (124, etc. = time-weighted mean exposure for the group during the day)

Fig. 6. Concentration of toluene in the alveolar air (25°C) of seven persons after 8 h of exposure during five days. The time-weighted mean exposure concentration before alveolar sampling varied between 63 and 134 ppm on the last day. (81, etc. = time-weighted mean exposure during the day)

As previously mentioned, alveolar air samples were taken both after work and during work. Thus, samples were taken 1, 6 and 16 h after the end of exposure each measurement day and 1, 6, 16, 45 and 60 h after the end of exposure during two weekends.

Fig. 5 shows the toluene concentrations of the alveolar air samples. Each curve is based on mean values for workers whose mean exposure during the preceding 8 h was within the same 10 ppm interval. The ten different curves represent exposure levels from 20 to 132 ppm. In fig. 6 the concentration in alveolar air samples from seven persons are shown. The samples were taken up to 60 h after exposure. The results indicated that it was not possible to specify the degree of exposure with sufficient accuracy on the basis of alveolar

air samples taken up to 16 h after exposure. Nor could exposure be calculated satisfactorily if sampling was extended up to 60 h after exposure.

The mean percentage value of uptake for the determinations made with the bag method was 47 % (SD = ± 3) (table 3). The corresponding value calculated with the indirect method was 51 % (SD = ± 4). Thus, the uptake of toluene amounted to about 50 % of the quantity supplied. It was on the same level on all the days studied, irrespective of the degree of exposure and time for sampling. This also applied to all the subjects.

In table 4 the pulmonary ventilation per minute is given for the subjects. The mean value for all of them was 15.9 l/min, corresponding to an oxygen uptake of about

0.7 l/min. Thus, the work, which comprised the operation and maintenance of a photogravure press, was relatively light, and the work intensity varied only slightly.

The total uptake of toluene in milligrams during a workday was calculated. The percentage uptake was set at 50,

pulmonary ventilation at 16 l/min, work duration at 8 h and the concentration in inspiratory air at 80 ppm, i.e., 300 mg/m³. When these figures are used $[(50/100) \times 16 \times 60 \times 8 \times (300/1,000)]$, the uptake amounted to about 1,150 mg during the course of a workday.

The aforementioned laboratory study (2)

Table 3. Comparison between the direct and indirect methods of determining the percentage uptake of toluene. The mean values $\pm$ the errors of the mean (SE), standard deviations and number of measurements are stated. The corresponding values for all the subjects were 46.9 ± 1.0 , SD = 2.9, N = 8 for the direct method and 51.3 ± 1.3 , SD = 3.8, N = 8 for the indirect method.

Press	Week/day	1st printer	2nd printer	3rd printer	Helper	Four workers combined
<i>Direct method (% uptake)</i>						
30	2/1—2/4					
	Mean $\pm$ SE	45.6 ± 1.7	49.1 ± 2.7	48.5 ± 2.0	49.5 ± 1.9	48.2 ± 0.9
	SD	5.7	5.7	6.7	4.6	1.8
	N	11	12	11	6	4
29	3/1—3/4					
	Mean $\pm$ SE	44.8 ± 1.8	49.7 ± 2.9	41.5 ± 0.9	46.6 ± 4.7	45.7 ± 1.7
	SD	5.2	8.2	2.7	13.2	3.4
	N	8	8	8	8	4
<i>Indirect method (% uptake)</i>						
30	2/1—2/4					
	Mean $\pm$ SE	44.1 ± 3.0	52.4 ± 1.9	52.1 ± 2.2	53.8 ± 2.8	50.6 ± 2.2
	SD	14.5	9.8	11.6	11.0	4.4
	N	23	26	25	16	4
29	3/1—3/4					
	Mean $\pm$ SE	54.2 ± 1.2	55.4 ± 1.4	51.1 ± 1.9	47.3 ± 1.2	52.0 ± 1.8
	SD	5.8	6.9	9.1	5.9	3.6
	N	23	26	22	23	4

Table 4. Pulmonary ventilation for the different workers at presses 29 and 30. The mean values $\pm$ the error of the mean (SE), standard deviations and number of measurements are stated. The corresponding values for all the subjects were 15.9 ± 0.8 , SD = 2.2, N = 8.

Press	Week/day	Pulmonary ventilation in liter/min (BTPS ^a)			
		1st printer	2nd printer	3rd printer	Helper
30	2/1—2/4				
	Mean $\pm$ SE	16.7 ± 0.9	15.9 ± 0.9	14.5 ± 1.1	12.7 ± 1.0
	SD	3.1	3.2	3.7	2.7
	N	11	12	11	7
29	3/1—3/4				
	Mean $\pm$ SE	18.0 ± 1.1	15.2 ± 1.2	19.5 ± 1.2	14.3 ± 1.0
	SD	3.1	3.3	3.5	2.7
	N	8	8	8	8

^a BTPS = temperature of 37°C, ambient pressure, saturated with water vapor at 37°C.

Table 5. Toluene concentration in the blood of workers at presses 29 and 30 after work. The mean value of the blood concentrations found after work amounted to 0.77 mg/kg (SD = 0.17; N = 8) for all the workers studied.

Press	Week/day	Milligrams of toluene per kilogram of blood					Mean	SD
		1st printer	2nd printer	3rd printer	Helper			
30	2/1	0.56	0.68	0.50	—		0.58	0.09
30	2/2	0.65	0.47	0.62	0.36		0.53	0.14
30	2/3	0.57	0.75	0.53	0.87 ^a		0.68	0.16
30	2/4	0.50	1.21	0.70	1.14		0.89	0.34
30	2/1—2/4							
	Mean	0.57	0.78	0.59	0.79			
	SD	0.06	0.31	0.09	0.40			
29	3/1	0.22	0.10	0.42	0.38		0.28	0.15
29	3/2	0.72	0.70	0.46	0.53		0.60	0.13
29	3/3	1.50	1.68	0.82	1.65		1.41	0.40
29	3/4	0.79	1.70	0.72	1.21		1.11	0.45
29	3/1—3/4							
	Mean	0.81	1.05	0.61	0.94			
	SD	0.53	0.78	0.20	0.59			

^a Four hours of exposure to toluene.

disclosed that the concentration of toluene in arterial blood could be calculated from the alveolar concentration. In order to determine whether or not the arterial concentration could be calculated in a corresponding manner in this study, we took samples of alveolar air and arterialized, capillary blood simultaneously. It should be noted that in all cases blood samples were taken in the decay phase both immediately after exposure to toluene and the next day before the start of work. The final alveolar air sample taken from the subjects at home before starting for work

was utilized in the calculation with the blood samples taken immediately before the start of work. The time lag between these air and blood samples amounted to about 1 h. The changes in concentration during this period were estimated to be too small to be of any significance.

The results are shown in table 5. There was a high correlation between the blood concentration and the alveolar air concentration (fig. 7). No increase in the toluene concentration in blood towards the end of the week could be demonstrated in samples taken before the start of work.

Fig. 7. Toluene concentration in blood in relation to alveolar air concentration. (— = laboratory study (4); --- = present study; each dot represents one value from the present study)

DISCUSSION

Direct measurements employing the Douglas bag method yielded a mean value of 47 for the percentage uptake of toluene. Previous laboratory experiments (4) have shown that the uptake of toluene in the lungs as the percentage of the amount supplied in relation to the alveolar concentration is the percentage of the concentration in inspiratory air is in accordance with the following equation: $y = -0.6x + 72.9$. The correlation is natural, and it is valid for many solvents (1). In the present measurements, the mean alveolar air concentration amounted to 35 % of the concentration in inspiratory air. This value introduced into the equation results in an uptake of about 50 %. Accordingly prediction of toluene uptake in the body can be made with a comparatively simple method.

In the calculation of the amount of toluene taken up by the body, a representative value is needed for pulmonary ventilation in addition to a value for percentage uptake. The actual work load was relatively light in this study, with pulmonary ventilations of about 16 l/min. For field studies a Wright respirometer can be used for measuring the pulmonary ventilation of workers. The mean value for pulmonary ventilation during, for instance, 1 h can then be estimated with sufficient accuracy.

Significant impairment of performance capability was shown when central nervous functions were tested during exposure under controlled conditions (5). This impairment made its debut after a total exposure duration of about 80 min and a total uptake of about 170 mg of toluene (3). In the present study the mean total uptake during a workday was calculated to

be about 1,150 mg of toluene. Even if the effect of the metabolism of toluene on central nervous functions is considered, the results show that after 80 min of work, the calculated uptake in this study was about 190 mg. This value can be compared to the 170 mg which led to impaired reaction time in the aforementioned experiments. Thus, functional impairment may have taken place.

With alveolar air samples, percentage uptake in the body can be calculated if the exposure is known. Blood concentrations can also be calculated from alveolar air samples. However several samples must be taken before the mean value of percentage uptake can be estimated. Thus, we recommend alveolar air sampling as a method for biologically monitoring toluene uptake.

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