

Exposure to styrene in a polymerization plant

Uptake in the organism and concentration in subcutaneous adipose tissue

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ENGSTRÖM, J., ÅSTRAND, I. and WIGAEUS, E. Exposure to styrene in a polymerization plant: Uptake in the organism and concentration in subcutaneous adipose tissue. *Scand. j. work environ. & health* 4 (1978) 324—329. Three male employees exposed to styrene in the processing of polyester tanks were studied during a work week. From Tuesday to Friday the concentration of styrene in ambient air was measured continuously in the breathing zone. The uptake in the organism was estimated as the product of the time-weighted average of the concentration in inspiratory air, the time-weighted average of 8-h pulmonary ventilation, and the percentage pulmonary uptake. Pulmonary ventilation was measured with the Wright respirometer. Percentage pulmonary uptake was estimated on the basis of the concentrations in inspiratory and alveolar air. The amount of body fat was estimated by an anthropometric method. The concentration of styrene in subcutaneous adipose tissue was determined by gas chromatography after needle biopsy before and after the workshift on Monday, Wednesday and Friday. The time-weighted average of the concentration of styrene in inspiratory air during the work week was 32—85 mg/m³, i.e., below half of the Swedish threshold limit value (210 mg/m³). The mean daily uptake in the organism was 193—558 mg. On Monday morning the concentration of styrene in adipose tissue was 2.8—8.1 mg/kg and on Friday afternoon 4.7—11.6 mg/kg. The concentrations were higher in the two subjects with a higher exposure of longer duration, as compared to the concentrations in the recently employed subject, who was exposed to lower concentrations in inspiratory air. Both of the two former subjects had a considerable estimated amount of body fat (27 and 41 kg). The calculated half-life of the concentration of styrene in adipose tissue after the end of exposure was 5.2 and 2.8 d for these two subjects. Therefore an elimination time of about five weeks is needed by the subject with the slowest elimination before the limit of detection (0.1 mg/kg) is reached.

Key words: adipose tissue concentration, body fat, elimination, exposure, man, polyester industry, styrene, uptake.

The high solubility of styrene in blood and its rapid biotransformation create conditions for considerable uptake in the organism (2, 5). Although the main part of ab-

sorbed styrene is excreted, mainly as mandelic acid in the urine, there is a certain risk of accumulation in the body in occupational exposure because of the high solubility of styrene in fat.

Styrene was detectable in adipose tissue for as long as two weeks after 2 h of experimental exposure to a concentration of 210 mg/m³ (50 ppm) in inspiratory air, i.e., the present Swedish threshold limit value

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(5). The half-life of the styrene concentration in adipose tissue of four subjects was estimated to be 2–4 d (5). Accumulation of styrene in adipose tissue implies indirect exposure of sensitive organs, by release of the solvent from adipose tissue after exposure. Consequently, determinations of styrene concentrations in adipose tissue can be a tool for the evaluation of adverse health effects in occupational exposure to this compound.

Wolff et al. (10) performed needle biopsies and gas chromatographic solvent analyses on subcutaneous fat from 25 workers in a polymerization plant. Low concentrations of styrene, 0.1–1.2 mg/kg of fat, were noted in 13 out of 17 workers exposed to more than 5 ppm in inspired air within the previous 3 d. The concentrations in ambient air were not determined in connection with the study. Exposure was estimated on the basis of a previous survey, which had disclosed excursions up to 160 ppm. Styrene was not detectable in subjects unexposed for more than 3 d.

The aim of the present study was to follow the concentrations of styrene in subcutaneous adipose tissue of employees in a polymerization plant during a work week. The purpose was also to relate these concentrations to the concentration of styrene in inspiratory air and to the amount of solvent taken up in the organism. Finally the results of this field study were compared with those of a previous experimental survey in the laboratory (5).

SUBJECTS, EXPERIMENTAL DESIGN AND METHODS

The study was performed in a plant manufacturing tanks of reinforced polyester plastic. The components of reinforced polyester plastic consist of unsaturated polyester, styrene and fiber glass. The unsaturated polyester compound is dissolved in styrene, which is a reactive monomer. A solid polymer is formed through reaction between the polyester compound and styrene.

During a work week three male employees, aged 23–48 years, were studied. Two of them had been employed in the plant for several years and their tasks were cylinder

and gable processing, respectively. The third person had been employed in the plant for two weeks mounting components for connecting pipes to the tanks.

The amount of body fat of the respective subjects was determined by means of skeletal measurement according to the method described by von Döbeln (3, 4).

From Tuesday to Friday air from the breathing zone was continuously sampled during the whole workday with the aid of a personal sampler. During the same period alveolar air samples were collected at hourly intervals. The quotient between the concentration of styrene in alveolar air and in inspiratory air was used in the calculation of the amount taken up in the body in proportion to the amount inspired. The percentage of uptake was calculated on the basis of each alveolar air sample and the inspiratory air sample collected during the preceding 30-min period. In the calculation of the percentage of uptake (y) the following equation, obtained in laboratory experiments (1), was used:

$$y = -0.86 x + 79.3,$$

where

$$x = \frac{\text{alveolar air concentration}}{\text{inspiratory air concentration}} \times 100.$$

Pulmonary ventilation was measured with a Wright respirometer (Medishield Harlow, Essex CM 195 AB, England). A total of 15–23 determinations was made for each subject during about 5 min on each occasion. Measurements were performed during the various phases of work and during the breaks. The duration of the different periods was studied. The time-weighted average (TWA) of the 8-h pulmonary ventilation over 4 d was calculated.

For the different subjects and the separate workdays the uptake in the organism was calculated as the product of three factors: TWA styrene concentration in inspiratory air, TWA 8-h pulmonary ventilation, and the percentage of uptake. Since the percentage of uptake did not change significantly in the individual during the different workdays or in the course of the work week, the mean of the measurements was used.

Table 1. Task, duration of employment, anthropometric data, time-weighted average (TWA) concentration of styrene in inspiratory air, estimated mean daily uptake of styrene, and concentration of styrene in subcutaneous adipose tissue at the beginning and end of the work week of three employees in a styrene polymerization plant.

Subject	Body weight (kg)	Body height (cm)	Estimated amount of body fat (kg)	TWA concentration in inspiratory air (mg/m ³)	Estimated mean daily uptake (mg)	Concentration in adipose tissue (mg/kg)	
						Monday morning	Friday afternoon
1 (cylinder processing, 4.5 years)	73.5	159	26.7	65	343	8.1	11.6
2 (gable processing, 4.5 years)	102.0	182	41.2	85	558	4.0	7.7
3 (mounting, 2 weeks)	74.0	179	13.1	32	193	2.8	4.7

The methods employed in the present study in the calculation of exposure levels and amounts of styrene taken up in the body were evaluated in a study of subjects exposed to toluene in a printing office (9). The estimated uptake values were in close agreement with the results obtained with the Douglas bag technique. A more-detailed description of the methods used in the present study for the estimation of exposure and uptake has been presented in a separate report (7).

Needle biopsy of subcutaneous adipose tissue was performed before and after the workshift on Monday, Wednesday and Friday. The methods employed in sampling and analysis were the same as in connection with a previous experimental exposure in the laboratory (5).

RESULTS

Anthropometric data, the tasks and the durations of employment of the three subjects studied are presented in table 1. Subjects 1 and 2, who had been occupied with styrene polymerization for several years, were obese, whereas the recently employed third subject had a normal body weight.

During the 4 d of study the 8-h TWA styrene concentration in the breathing zone varied between 22 and 93 mg/m³. The TWA concentration in the inspiratory air over the four workdays did not exceed half of the threshold limit value in any of the subjects studied (table 1). Detailed results of the exposure measurements have been reported in the aforementioned separate report (7).

In the three subjects the mean percentage of uptake was 60, 61 and 62, respectively. Within the group and during the different phases of the workday, pulmonary ventilation varied between 17 and 32 l/min. The TWA pulmonary ventilation of the three subjects over the four workdays was 17, 20 and 21 l/min, respectively. The individually estimated inspired and retained amounts of styrene during the different workdays are presented in fig. 1. The mean daily uptake in the organism was 193–558 mg.

A successive decrease in the daily uptake was noted in subjects 1 and 3 from Tuesday to Thursday. In all cases the uptake value was higher on Friday than on Thursday. On Friday the capacity of production was fully utilized in the factory. This was not the case earlier in the week.

At the beginning and end of the work

week the concentrations of styrene in subcutaneous adipose tissue were higher in the two subjects who had been exposed for a longer time and to higher concentrations in the ambient air, as compared to subject 3 (table 1). Subject 2, who had been exposed to the highest average concentration of styrene, did not have the highest concentration of the solvent in adipose tissue. This fact could be due to the large volume of distribution.

The concentrations of styrene in adipose tissue at different times during the work week are presented in fig. 2. The changes in exposure and uptake during the week make the evaluation of the adipose tissue concentrations difficult. The pattern of the concentrations in adipose tissue and the relation between this pattern and the uptake measurements could not be analyzed statistically because of the small number of observations. It should also be pointed out that after short-term exposure in the laboratory the error of the method for determining the adipose tissue concentration of styrene was 48 %, including the biological variations in concentration within the specimens. However, it can be stated that all determinations in the two subjects with heavier exposure showed higher values in comparison to those of subject 3. A tendency towards an increase in the concentrations during the week was especially noted in subject 2. In all cases the highest value was noted on Friday afternoon.

DISCUSSION

In a previous laboratory study (5), seven subjects were exposed to 210 mg of styrene per cubic meter of inspiratory air for 2 h. The subjects were exposed during 30 min at rest and during three 30-min periods of increased work load, from 50 to 150 W. The mean uptake in the organism during the 2-h exposure was about 500 mg. The mean concentration of styrene 2, 4, and about 21 h after exposure was about 3.5 mg/kg. The three subjects in the present study were exposed to a TWA concentration in inspiratory air that was below half of the concentration applied in the labo-

ratory study. Moreover, the rate of work of the subjects in the present study was lower, i.e., they had a lower pulmonary ventilation and a lower cardiac output. Only in one case was the mean daily uptake in the employees of the plant of the same order (558 mg) as during the 2-h exposure in the laboratory. However, the concentrations in adipose tissue of the subjects in the plant were, on an average, higher than in the experimental study.

The amount of styrene in the total fat depots of the body can be roughly estimated. In such a calculation it is assumed that the concentration of the solvent in subcutaneous adipose tissue is representative of that in the total fat depots. It is also assumed that the total amount of adipose tissue can be calculated from the estimated

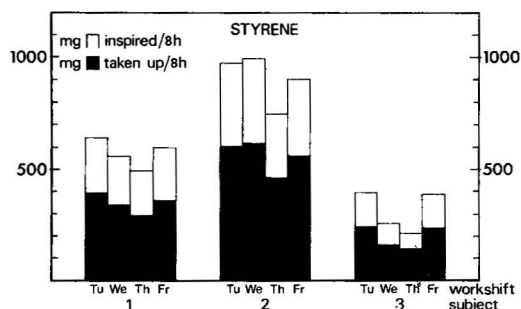


Fig. 1. Estimated amounts of styrene inspired and taken up by three employees during four workdays [Tuesday (Tu), Wednesday (We), Thursday (Th) and Friday (Fr)] in a styrene polymerization plant.

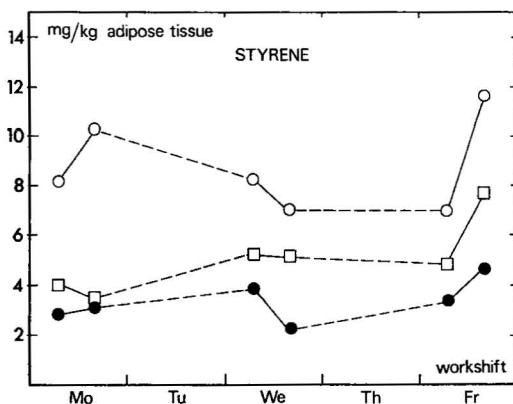


Fig. 2. Concentration of styrene in subcutaneous adipose tissue of three employees (○, □ and ●) before and after the workshift on Monday (Mo), Wednesday (We), and Friday (Fr).

amount of body fat (5). According to such an estimation, the increase of styrene in the fat depots during the work week was about 120, 190 and 30 mg in subjects 1, 2 and 3, respectively. These amounts correspond to 7, 7 and 3 %, respectively, of the amount of styrene taken up in the body during the week.

In the calculation of the weekly uptake it was assumed that the mean daily uptake during the 4 d of study could be applied also to the Monday. The smaller retention increase in adipose tissue of subject 3 could reasonably be explained by a smaller volume and a higher degree of blood perfusion of adipose tissue.

At the time of the study subjects 1 and 2 had both been working for several months without sick leave or vacation. If it is assumed that the concentrations of styrene in adipose tissue followed a steady-state pattern at the time of the study and that the Monday morning concentration obtained was representative also of the following Monday, the half-life can be calculated on the basis of the concentrations on Friday afternoon and Monday morning. Such a calculation results in a half-life of 5.2 d for the concentrations in subject 1 and 2.8 d in subject 2. Therefore about 5 and 2.5 weeks, respectively, are needed after the end of exposure before the concentration of styrene in the adipose tissue of the two subjects reaches the limit of detection.

Of course such calculations yield only tentative results. However, the calculated half-lives of the styrene concentrations in adipose tissue were of the same magnitude as in the previous laboratory study, where the decline of the concentrations was actually measured (5). In three other subjects in a plastic boat factory the half-lives of the styrene concentration in fatty tissue also varied between 2 and 4 d when determined during the summer vacation (unpublished results of Wigaeus et al.).

Engström et al. (6) noted a biphasic urinary excretion of mandelic acid after occupational exposure to styrene. During the first 15–18 h after exposure the median half-time of the concentration was 9.4 and 6.4 h after light (TWA 23 ppm) and heavy (TWA 248 ppm) exposure, respectively. During the second phase (19–64 h

after exposure) the median half-time was 16.6 h (range 9.8–56 h for nine subjects exposed to a TWA of 23 ppm). Mandelic acid concentrations in urinary prework samples of 29 subjects indicated that styrene was not completely eliminated in the 16-h period between daily exposure at work. The authors referred to the proposal of Linch (8) that the body burden reaches an equilibrium within 2 d and does not increase thereafter if the half-time is less than 12 h, i.e., providing the daily variation in exposure is not great.

In the studies of mandelic acid of Engström et al. (6) and in the surveys of styrene in adipose tissue from this laboratory, the limit proposed by Linch (8) is exceeded, in some cases to a considerable degree. It is evident that conditions exist for accumulation of styrene in the body during occupational exposure. However, the extent of accumulation in long-term occupational exposure to concentrations higher than in the present study cannot as yet be evaluated.

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