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Exposure of Workers Engaged in Furniture Stripping to Methylene Chloride as Determined by Environmental and Biological Monitoring

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In response to reports of adverse reproductive effects of exposure to methylene chloride, investigators from the National Institute for Occupational Safety and Health conducted an industrial hygiene survey of a cohort of 14 furniture strippers exposed to methylene chloride in five furniture stripping shops. Both environmental and biological monitoring of the workers were conducted. Personal time-weighted average (TWA) concentrations of methylene chloride were determined. Pre- and postshift alveolar breath samples were analyzed for carbon monoxide and methylene chloride. Postshift venous blood samples were analyzed for carboxyhemoglobin and methylene chloride. Methylene chloride TWA exposures of the workers ranged from 15 to 366 ppm, while exposures to other solvents were well below their respective evaluation criteria. The highest average exposures to methylene chloride by job category were strippers (191 ppm) followed by washers (145 ppm) and refinishers (31 ppm). Postexposure breath concentrations of methylene chloride ranged from 2.3 to 167 ppm, while blood concentrations ranged from 0.1 to 8.8 ppm. Linear regression analysis showed that the TWA methylene chloride exposure concentrations were quadratically correlated to postshift alveolar breath ($r = 0.98$) and blood concentrations ($r = 0.87$) of methylene chloride. This high degree of correlation between the biological and environmental concentrations suggested that the major route of exposure was inhalation. Serious problems with ventilation of sprayer-based furniture stripping operations were found. Deficiencies in work practices and personal protective equipment were also noted. Recommendations are made for reducing exposures to methylene chloride during furniture stripping. McCammon, Jr., C.S.; Glaser, R.A.; Wells, V.E.; Phipps, F.C.; Halperin, W.E.: Exposure of Workers Engaged in Furniture Stripping to Methylene Chloride as Determined by Environmental and Biological Monitoring. *Appl. Occup. Environ. Hyg.* 6:371-379; 1991.

Introduction

A recent clinical case report described low and abnormal sperm findings in four workers who had been exposed to

methylene chloride in a plant that manufactured plastic automobile bodies.⁽¹⁾ These workers complained of testicular pain and were found to have sperm concentrations ranging from 2 to 26 million/ml (average population values range from 20 to 200 million/ml). The workers cleaned molds and finished plastic auto bodies with rags soaked with methylene chloride. No gloves were worn during this operation. Elevated blood levels of the methylene chloride metabolite, carbon monoxide (measured as percent carboxyhemoglobin, %COHb), in all four workers indicated that they had absorbed a considerable amount of methylene chloride. This case report, suggesting that methylene chloride was a reproductive toxin, was supported by the National Toxicology Program (NTP) carcinogenesis assay which found that exposure to methylene chloride caused testicular atrophy in one of two animal species tested.⁽²⁾

In light of these reports, researchers from the National Institute for Occupational Safety and Health (NIOSH) decided to survey a small cohort of workers exposed to large amounts of methylene chloride and to assess the effects of the exposures upon testicular function. In a preliminary survey, workers engaged in furniture stripping activities had been identified as having the potential for exposure to extremely high levels of methylene chloride. Short-term, breathing-zone samples (1- to 2-hour) of the head furniture strippers in three shops had indicated exposures to methylene chloride ranging from 2160 to 297 ppm. Furniture stripping generally also involves manual application of methylene chloride, and thus, there is considerable opportunity for uptake by dermal routes as well. Since furniture strippers are at risk for absorption of very large

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amounts of methylene chloride, they represent a suitable cohort for investigation of the adverse reproductive effects of exposure to the solvent.

In view of the results obtained in the preliminary survey, a pilot study of the exposures of 14 workers to methylene chloride in five furniture stripping shops was undertaken. Breathing-zone concentrations of methylene chloride were determined; the concentrations of methylene chloride and its metabolite, carbon monoxide, were measured in breath and blood samples obtained from the workers. Reproductive function tests were also performed to assess potential negative effects of methylene chloride uptake upon testicular function. The findings of the reproductive study have been published elsewhere.⁽³⁾

In this article, the results of the industrial hygiene survey of these furniture stripping shops are presented. The general stripping processes and control technology observed in the shops are described. The biological concentrations of methylene chloride and carbon monoxide (or %COHb) are compared with the environmental concentrations of methylene chloride. Problems with personal protective measures or work practices, which may have contributed to very high exposure levels among the furniture strippers, are discussed. Recommendations are made for personal protective equipment, work practices, and ventilation to control exposures to methylene chloride in furniture stripping operations.

Toxicology of Methylene Chloride

Methylene chloride is a colorless, volatile, nonflammable liquid with a penetrating, ether-like odor that is detectable at about 300 ppm in air.⁽⁴⁾ It has a vapor density three times that of air. The compound is an excellent solvent and is especially attractive as a cleaning solvent because of its effectiveness and nonflammability. Repeated skin contact with liquid methylene chloride may result in dermatitis, while the vapor is irritating to the eyes, skin, and upper respiratory tract.⁽⁵⁾ Methylene chloride acts as a central nervous system depressant. Symptoms of exposure include headache, dizziness, nausea, giddiness, stupor, irritability, numbness, and tingling in the limbs. Severe exposure may result in pulmonary edema, toxic encephalopathy with hallucinations, coma, and even death.⁽⁶⁾ Methylene chloride is converted in the liver to carbon monoxide which then binds to hemoglobin in the blood to form carboxyhemoglobin. Once the carboxyhemoglobin is formed, the hemoglobin is unavailable for oxygen transport. The release of oxygen from oxygenated hemoglobin is consequently affected. This may result in various cardiovascular effects or place additional stress on persons with existing cardiovascular diseases.⁽⁴⁾

The emphasis of methylene chloride toxicity has recently centered around its carcinogenic effects. A 1985 NTP animal study indicated, in part "... that there was clear evidence of carcinogenicity of dichloromethane [methylene chloride] for male and female B6C3F1 mice as shown by increased incidences of alveolar/bronchiolar neoplasms

and of hepatocellular neoplasms."⁽²⁾ The 1986 Current Intelligence Bulletin (CIB) by NIOSH concluded that methylene chloride should be considered a potential occupational carcinogen⁽⁶⁾ based primarily on the NTP study and the criteria for classification of carcinogens specified in the U.S. Occupational Health and Safety Administration (OSHA) Cancer Policy.⁽⁷⁾ In addition, the U.S. Environmental Protection Agency (EPA) has classified methylene chloride as a Probable Human Carcinogen (Group B2). The Group B2 designation is for agents for which there is sufficient evidence of carcinogenicity from animal studies but insufficient evidence from human studies.⁽⁸⁾

Evaluation Criteria

Environmental Concentrations

The current OSHA Permissible Exposure Limit (PEL) for methylene chloride is 500 ppm as an 8-hour time-weighted average (TWA), with a ceiling of 1000 ppm and a maximum peak concentration of 2000 ppm.⁽⁹⁾ However, OSHA has recently published an Announced Notice of Public Rulemaking for methylene chloride and is evaluating the need for a new PEL. The 1976 NIOSH Recommended Exposure Limit (REL) for methylene chloride was 75 ppm as a TWA for up to a 10-hour workday with a 500-ppm peak exposure concentration as determined over any 15-minute sampling period.⁽¹⁰⁾ NIOSH further recommended that permissible levels of methylene chloride be reduced when carbon monoxide is present due to an additive effect on the level of carboxyhemoglobin. NIOSH currently recommends that worker exposure to methylene chloride be controlled to the lowest feasible limit based on classification as a potential occupational carcinogen.⁽⁶⁾ In 1986, the American Conference of Governmental Industrial Hygienists (ACGIH) published a Notice of Intended Change to lower the Threshold Limit Value-TWA (TLV-TWA) for an 8-hour workday from 100 ppm to 50 ppm and deleted the Short-Term Exposure Limit (STEL) of 500 ppm. ACGIH further classified methylene chloride in this notice as an A2 carcinogen (an industrial substance suspect of carcinogenic potential for man).⁽¹¹⁾

Biological Matrix Concentrations

A postshift, biological exposure index of less than 40 ppm carbon monoxide in alveolar breath (or less than 8% COHb in blood) has been recommended by ACGIH.⁽¹¹⁾ NIOSH recommends a postshift, blood carboxyhemoglobin level of less than 5 percent.⁽¹²⁾ For methylene chloride, Lauwers⁽¹³⁾ recommends a maximum permissible value of 0.8 mg/L in blood and 35 ppm in breath.

Worker Study Group

The 14 workers monitored in this survey were male Caucasians, ranging in age from 26 to 64 years (mean = 36.7, standard deviation = 12.7 yr). Five (36%) of the subjects were smokers. Prior to conducting the survey, each subject received a complete physical from a NIOSH

physician. Approval to conduct the project was granted by the NIOSH Human Subjects Review Board. Informed consent to collect the biological specimens was obtained from each subject.

Process Description

The paint stripping formulations encountered in this study varied considerably in type and composition. Three of the shops surveyed (shops 2, 3, and 5) bought commercial preparations from three main suppliers, while shops 1 and 4 prepared their own stripping solution. These solutions, whether prepared commercially or in-plant, contained 50–90 percent methylene chloride in combination with methanol, toluene, xylene, caustic (sodium hydroxide), acetone, and other organics. The exact proportions and specific organic chemicals varied by manufacturer. There were also a large number of other organic compounds in use in the furniture refinishing shops, particularly those in the lacquer finishes.

There were two basic methods observed in the stripping of paint from various materials, i.e., primarily wood furniture. The procedure used in shops 1 and 4 involved the immersing of parts into dip tanks. These tanks are approximately 8 feet long, 4 feet high, and 3 feet wide; usually have two lids which cover each tank when not in use; and have liquid levels of approximately 18–24 inches.

During the stripping operation, painted parts were allowed to sit in the stripping solution, with occasional turning, until the paint was loosened. The worker then leaned over the tank and scrubbed the part with a brush or pointed object to remove the paint. A drain board was sometimes placed on the top of the tank so that the part could be scrubbed and then drained prior to being moved to the adjacent wash area. The concrete floors in the wash areas were banked and sloped with a drain at the low point of the floor. The part was washed by spraying with pressurized water to which different detergents or cleaners were added. The remaining painted areas were again scrubbed or scraped until the part was as clean as required. Occasionally, parts with stubborn areas of paint were returned to the dip tank or were treated by hand with a gel stripping compound. Depending on the type of wood, the freshly stripped piece was sometimes bleached using oxalic acid. The cleaned parts were stored until dry, then sanded, repaired (as necessary), and refinished.

The second method of furniture stripping encountered (shops 2, 3, and 5) used a forced stream of stripping solution applied to furniture on an elevated, banked table. The table was sloped to allow the excess solution to flow to one corner where it drained into a reservoir (usually an open 5-gallon pail). The solution was pumped from the reservoir with either a mechanical or pneumatic pump and then out through a scrub brush onto the furniture.

Categorization of Workers

Workers were divided into three main job categories:

strippers, washers, and refinishers. Strippers spent the majority of their day applying stripping solution or dipping wood pieces in stripping solution. In two of the three larger shops, where full-time strippers were employed, there was generally also a washer who cleaned the recently stripped parts with the pressurized detergent solution (described above). Refinishers were those workers who spent the majority of their day repairing and refinishing wood furniture. There were also workers who spent only part of their day refinishing and the rest of the time on pickups and deliveries. These workers were also classified as refinishers. In the smaller shops with only one or two people, all three tasks (stripping, washing, and refinishing) were often done by the same person. These individuals were classified by the task which took the majority of their time (usually stripping) during our involvement with them.

Analytical Methods

Air samples for methylene chloride were collected and analyzed according to NIOSH Method 1005.⁽¹⁴⁾ Samples were collected at a flow rate of 20 cc/min using two 150-mg charcoal tubes connected in series. The first tube was the primary collection element, while the second tube acted as a backup collector. After collection, the samples were separated and placed into a refrigerator until analysis. The samples were then desorbed with carbon disulfide and analyzed by a gas chromatograph (GC) equipped with a flame ionization detector (FID).

Blood samples obtained from the furniture strippers were analyzed for methylene chloride and carboxyhemoglobin (COHb). End-expired breath was analyzed for methylene chloride and carbon monoxide. The methods used for sampling and analysis of the blood and breath are described in detail in the companion article by Glaser et al.⁽¹⁵⁾ published in the same issue of this journal.

Results and Discussion

Comparison to Standards

Table I is a summary of all the exposure parameters for all 14 workers including the TWA methylene chloride air exposures, postshift breath and blood levels of methylene chloride, and postshift carbon monoxide and blood %COHb levels. While environmental concentrations of methylene chloride did not exceed the current OSHA standard of 500 ppm at any of the shops monitored, the proposed ACGIH standard of 50 ppm was exceeded for 10 (71%) of the 14 workers monitored. Since the lowest feasible level of control for methylene chloride is unknown, no comparison can be made to the current NIOSH REL.

In the absence of further control, the environmental concentrations reported for these shops may actually be among the *lowest* observed throughout the workyear. Since this study was conducted in the summer, the shop doors were open, allowing for increased ventilation. On the other hand, the preliminary survey discussed in the Introduction was conducted during the winter. The very high exposure

TABLE I. Summary of Exposure to Methylene Chloride as Measured in Air, Breath, and Blood for Furniture Strippers

Shop No.	Job/Title	Methylene Chloride ^A									
		Worker		Breath				Breath CO ^A			Hours Monitored
		No.	Smoker?	Air	Pre	Post	Blood	Pre	Post	%COHb	
1	Lead Stripper	1	Y	124	0.4	37	3.3	4.6	14	4.5	8
	Washer	2	N	68	ND ^B	6.2	0.1	— ^C	18	2.2	8
	Refinisher	3	N	27	ND	12.8	1.2	12	19	3.8	8
2	Stripper/Washer	4	Y	277	3.0	94.3	4.6	47	83	13.5	8
	Refinisher	5	Y	22	0.7	10.3	0.5	40	50	9.9	8
	Refinisher	6	Y	74	— ^C	8.9	0.7	— ^C	37	9.2	8
	Stripper	7	N	122	5.4	10.1	0.5	76	45	4.2	6
3	Head Stripper	8	N	366	ND	167	8.8	49	31	5.9	5
	Stripper Asst.	9	N	303	ND	107	6.6	17	36	7.7	5
	Washer	10	N	221	ND	93.7	4.3	10	20	4.3	5
4	Stripper/Washer	11	N	88	ND	10.4	1.5	14	21	3.9	8
	Refinisher	12	Y	15	1.3	2.3	0.5	39	22	8.1	8
	Refinisher	13	N	17	— ^C	2.6	3.8	— ^C	15	2.4	5
5	Stripper/Washer	14	N	57	ND	6.4	4.3	12	14	2.1	4

^AAll concentrations are parts per million (ppm).

^BND = not detected.

^CNot determined.

levels obtained in that survey were largely related to reduced ventilation of the work area when the shop doors were closed due to cold weather, and movement of air through the shops was minimal.

The postexposure breath methylene chloride concentrations exceeded Lauwerys' guideline of 35 ppm for five (36%) of the workers; postexposure blood methylene chloride concentrations exceeded Lauwerys' guideline of 0.8 mg/L for nine (64%) of the workers. The NIOSH recommended guideline of 5 percent COHb was exceeded for 6 (43%) of the 14 furniture strippers; the ACGIH guideline of 8 percent COHb (40 ppm carbon monoxide) was exceeded for 4 (29%) of the 14 workers. If smokers were excluded from the data analysis, no workers exceeded the ACGIH-recommended blood COHb level, whereas one worker (7%) exceeded the ACGIH-recommended alveolar air carbon monoxide guideline. A similar analysis showed that two workers (14%) exceeded the NIOSH recommended blood COHb guideline.

Exposure by Job Class

Figure 1 is a bar graph comparing by worker occupation the normalized concentrations of biomonitored analytes and breathing zone concentrations of methylene chloride. This figure shows that the concentrations of all analytes monitored were highest for those workers most directly involved with the application of methylene chloride, i.e., strippers, followed by those workers engaged in washing the newly stripped wood, then by those workers in the adjacent areas primarily engaged in refinishing operations. The postexposure blood and breath concentrations of methylene chloride paralleled the environmental concentrations, whereas breath carbon monoxide and blood COHb concentrations did not, except when smokers were removed from the data analysis. Note that removal of the smokers from this analysis reduced the number of workers categorized as refinishers (from n = 5 to 2).

The number of workers classified as washers was unaffected but still small (n = 2). Furthermore, these job characterizations are quite general. This industry is primarily comprised of very small businesses of 1 to 2 people. In the larger shops surveyed (1, 2, and 4), there were full-time furniture strippers, washers, and refinishers. In the smaller shops, the owners were involved in all facets of the business including office work and making deliveries, as well as stripping, washing, and refinishing of the furniture.

Exposure by Type of Stripping Operation and by Ventilation Controls in Place

Figure 2 is a bar graph comparing the mean worker environmental exposures to methylene chloride at each

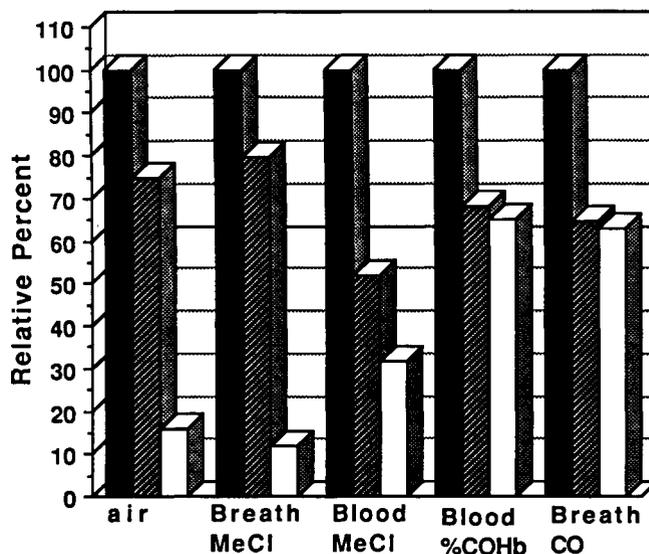


FIGURE 1. Normalized environmental and biological concentrations of monitored analytes in air, breath, and blood samples by job category. The values for %COHb and CO were determined by excluding smokers from the data analysis. KEY: Solid = strippers; diagonal strip = washers; white = refinishers.

of the five shops surveyed. Generally, the level of the environmental exposures at the shops could be directly related to the type of stripping process used and to the lack of engineering controls in place.

The mean exposure levels at shops 1 and 4 were relatively low: 73 ppm (SD = 49 ppm) and 40 ppm (SD = 42 ppm), respectively. These shops used only dip tanks for stripping furniture. The dip tanks were located in open-bay sections of the shops and were generally covered while the furniture was soaking. Both shops had installed local exhaust ventilation systems on the dip tank: a slot ventilation system with two takeoffs at shop 1 and a 3-inch exhaust hose inserted in the vapor zone of the dip tank at shop 4; both systems were connected to small exhaust fans and vented to the outdoors. A floor-level exhaust fan was also used at shop 4 to vent the heavier-than-air methylene chloride vapors from the vicinity of the dip tank. Since this survey was conducted in the summer months, the bay-doors in both shops were open.

It is worth noting that the preliminary survey had indicated extremely high exposures to methylene chloride (mean = 854 ppm, SD = 1138 ppm) at shop 1; however, that survey was conducted in cooler weather (when shop ventilation was significantly compromised) and prior to the installation of any controls. Furthermore, the volume of methylene chloride had been reduced from 55 to 26 percent in the stripper solvent formulation used at this shop. Thus, the increased local and general ventilation of the shop and dip tank, as well as modification of the stripping solvent formulation, had produced a tenfold reduction in the mean exposure levels at this shop.

The high mean exposure concentrations of 124 ppm (SD = 110 ppm) and 297 ppm (SD = 73 ppm) observed respectively at shops 2 and 3 illustrate the problems which may be encountered in stripping furniture when using improperly vented spray systems. These systems readily produce large amounts of methylene chloride vapor during operation. At shop 2, the high mean TWA exposure to methylene chloride was primarily influenced by the results obtained for the head furniture stripper (worker 4). His very high exposure resulted from use of the spray system on an open worktable in a small room that was vented to the outdoors via a small fan mounted in the wall 7 feet above ground. An open doorway separated this room from the adjoining room where the furniture was refinished. Ventilation of the furniture-stripping room was so poor that methylene chloride vapors were pulled through the door into the refinishing area when the ventilation fan on a lacquer spray booth in the refinishing room was activated. While the physical isolation of the stripping operation from the refinishing operations may have reduced the exposures of the workers in the refinishing area, the poor ventilation of the stripping room resulted in increased exposure to these workers when the spray booth was in operation.

At shop 3, all three workers received very high and comparable exposures to methylene chloride. The spray system at this shop was used with an open worktable that

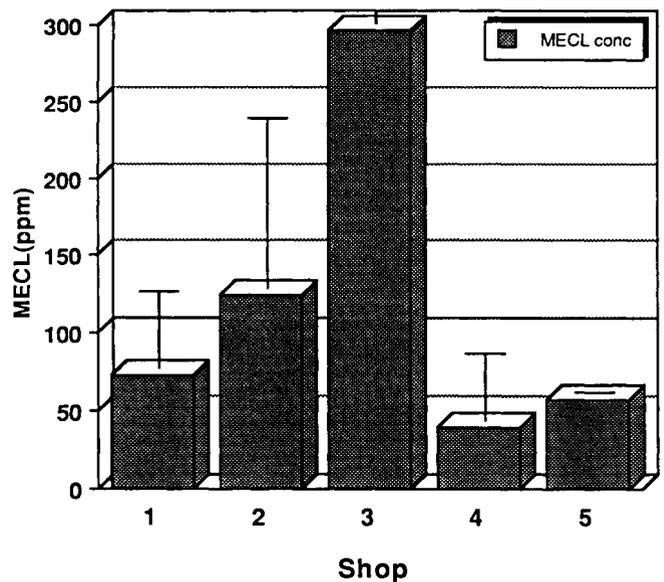


FIGURE 2. Arithmetic mean exposure concentration to methylene chloride at each of the five furniture stripping shops surveyed. Standard deviations (T) are also shown.

was located in a corner of a small (10-foot wide \times 12-foot long \times 8-foot high) room. The drain pail under the table was uncovered during the stripping operation. There was no ventilation of the workroom other than a floor fan which sat in a doorway that opened to the outdoors. A smoke bomb test showed that this fan was not effective in removing the vapor generated in the work area from the room. Since stripping and washing were primarily carried out in this poorly ventilated room, the three workers at this shop received the highest average environmental exposures to methylene chloride observed in any of the shops surveyed.

Although a spray system was also used for stripping furniture at shop 5, the TWA exposure of the furniture stripper (worker 14) to methylene chloride was relatively low (57 ppm). The spray system was located in an open section of the shop that was ventilated with a large floor fan. The front and rear shop doors were also open, and a steady breeze also ventilated the work area throughout the day. Worker 14 was the shop owner and worked on the spray pump for the first 1.5 hours of the shift, stripped furniture for the next 1.0 hour, then attended to other duties; however, he was monitored for 4–5 hours. Thus, significant exposure to methylene chloride was only possible for the first half of the monitoring period.

Work Practices and Personal Protective Equipment

Poor work practices were observed at all of the shops surveyed. Many of the furniture strippers smoked on the job, thus compounding the risk of cardiovascular stress from uptake of carbon monoxide. At several of the shops, containers of stripping solution and drain pails under the spray system were left open in inadequately vented rooms. Paint scrapings were permitted to dry in open buckets. Workers reached into the bottom of dip tanks to retrieve

small parts or lost tools. Occasionally, workers placed themselves between the vapor source and exhaust fans and reduced the overall ventilation of the work area. In the preliminary survey, worker 1 leaned over the dip tank so far as to enter the methylene chloride vapor layer, a major reason why he received such a high exposure to methylene chloride (TWA = 2160 ppm) in that survey.

Personal protective equipment used in these operations varied considerably; however, the best equipped shops used rubber gloves, rubber aprons, safety glasses (usually without sideshields), and rubber boots. Often the various protective garment materials were in poor condition. For example, the gauntlet-style rubber gloves used by washers were frequently contaminated on the inside with methylene chloride. Strippers sometimes used torn or punctured gloves or wore only one glove during the stripping operation. The strippers at shops where the spray systems were in use often wore no eye protection even while the sprayer was in operation. Most of the workers wore industrial-style uniforms. However, due to the summer heat, the workers at shops 3 and 5 wore shorts and short-sleeved shirts on the job and, thus, risked significant dermal absorption if the stripping solution were to splash on exposed skin.

Comparison of Biological to Environmental Concentrations

Figures 3 and 4 are plots comparing, respectively, the postshift blood and breath concentrations of methylene chloride to the TWA concentrations of methylene chloride. The smooth curves regressed through the data points in each of the plots obey the quadratic equation:

$$Y = Ax + Bx^2 + C$$

In this equation, Y is the postshift, alveolar breath or blood

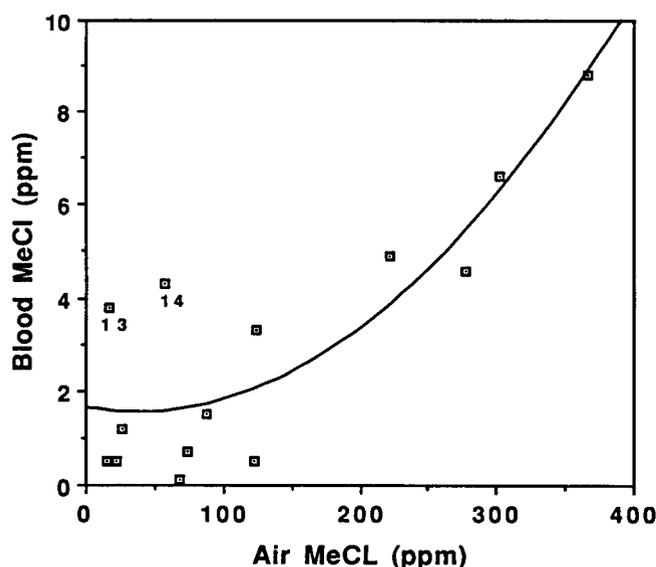


FIGURE 3. Time-weighted average air concentrations of methylene chloride versus blood methylene chloride concentrations. Data from Subjects 13 and 14 are outliers.

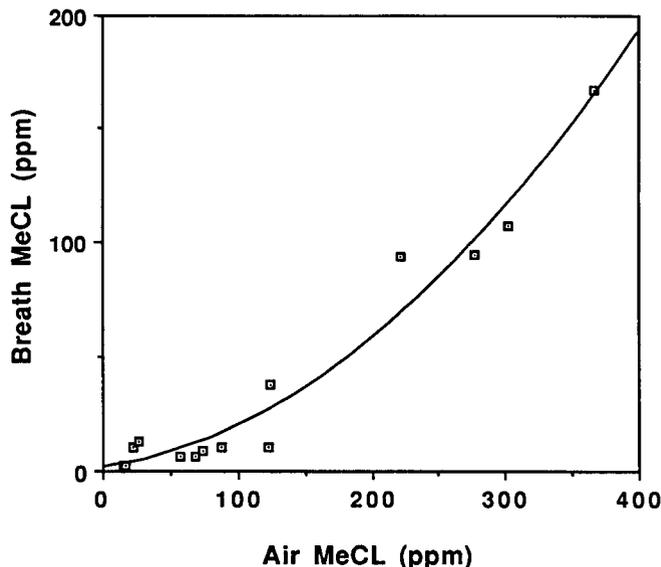


FIGURE 4. Time-weighted average air concentrations of methylene chloride versus breath methylene chloride concentrations.

concentration of methylene chloride; x is the TWA exposure concentration of methylene chloride; and A, B, and C are constants. For the breath:environmental concentrations, the quadratic correlation coefficient (r) was 0.98 and A, B, and C were 0.082, 0.001, and 1.57, respectively. The blood and environmental concentrations were less well correlated quadratically (r = 0.87); the coefficients A, B, and C were 0.008, 0.000074, and 1.74, respectively. Both data sets were less well correlated if fit to a simple linear equation. The linear correlation coefficients (r) for the breath:environmental and blood:environmental data sets were 0.96 and 0.82, respectively.

It might be expected that the postshift breath and blood concentrations would have been directly proportional to the environmental concentrations if the exposure concentrations were relatively constant throughout the workday. The quadratic curvature to this data is primarily due to the results obtained from four workers (4, 8, 9, 10) who had higher apparent bioburdens of methylene chloride relative to TWA exposure concentrations than did other workers. These workers may possibly have been exposed to very high levels of methylene chloride in the time period immediately prior to sampling. Alternatively, absorption due to dermal or ergonomic factors may have played a role here. As discussed above, workers 8, 9, and 10 at shop 3 did have the opportunity for significant dermal exposures. Ergonomic factors, i.e., increases in cardiac rate and breathing rate in response to heavier workloads, may also have increased the amount of solvent absorbed. Thus, the quadratic curvature of Figures 2 and 3 may reflect either dermal or ergonomic influences upon solvent uptake for these workers. Modeling of the inhalation uptake of methylene chloride may provide a better estimate of the magnitude of dermal or ergonomic influences on uptake. However, such modeling is beyond the scope of this article.

The relatively high degree of statistical correlation be-

tween the biological and environmental concentrations of methylene chloride suggests that inhalation was the primary source of exposure to the solvent. The lower correlation between the blood and environmental concentrations of methylene chloride is primarily due to the results obtained for subjects 13 and 14, who had very high blood concentrations of methylene chloride relative to environmental concentrations. The data from these two subjects, noted on Figure 3, are statistical outliers using a normalized residuals t-test; if these data are excluded, the blood and environmental concentrations are much more highly correlated ($r = 0.96$ for a quadratic fit and 0.94 for a linear fit).

In the absence of other information, the relatively high blood concentrations observed for these two workers would generally suggest substantial dermal uptake. Observation of worker 13 on the job, however, did not substantiate this premise. This worker was a shop owner and did no furniture stripping on the day of the survey. He did prepare a small (5–10 gal) batch of methylene chloride-based furniture stripping solvent in a well-ventilated area approximately 1 hour prior to the time that he contributed the blood and breath samples. He wore a standard industrial-style uniform (long-sleeve shirt and slacks) and received no apparent dermal exposures to methylene chloride. Thus, his high blood methylene chloride concentration is perplexing.

For subject 14, the high blood concentrations of methylene chloride relative to environmental concentrations may be more understandable. Due to the summer heat, this worker wore shorts and a short-sleeved shirt. At the beginning of the day, he had trouble getting the device on his spray system to work properly. He spent about 1.5 hrs trying to get the partially-clogged pump working. While priming the pump, he splashed a significant amount of stripper solution on his hands, forearms, and legs. The concentration in the blood sample may have been biased high if it had been taken from a contaminated area of this subject's arm. If significant dermal absorption had occurred, it is not clear why elevated alveolar breath concentrations of methylene chloride were not also observed.

Overall, the methylene chloride TWA air exposures were not correlated with the postexposure %COHb levels ($r_{\text{linear}} = 0.32$) or with alveolar carbon monoxide levels ($r_{\text{linear}} = 0.40$). However, when the data from those five workers who smoked were removed from the analysis, the linear correlation between %COHb and environmental concentrations of methylene chloride improved substantially ($r_{\text{linear}} = 0.85$). The correlation between alveolar carbon monoxide and environmental concentrations of methylene chloride was also improved by removing the smokers from the data analysis ($r_{\text{linear}} = 0.55$). Exclusion of the two outlying alveolar carbon monoxide measurements (subjects 7 and 12) from the data analysis further improved the correlation between alveolar carbon monoxide and exposure levels ($r_{\text{linear}} = 0.87$). The outlying data is addressed in the companion piece immediately following this article in this journal.

Such comparisons should be made cautiously. The average postshift alveolar carbon monoxide levels of 30.4 ppm (all workers) and 24.6 ppm (excluding smokers) were not much different from the average preshift levels of 29.2 ppm (all workers) and 27.1 ppm (excluding smokers). In fact, for some of the subjects, the postshift concentrations of alveolar carbon monoxide were actually lower than the preshift levels. For example, alveolar carbon monoxide levels for worker 7 decreased from a preshift concentration of 76 ppm to a postshift concentration of 45 ppm. This nonsmoking worker had done a considerable amount of furniture stripping on the day prior to the survey. The very high preshift carbon monoxide concentrations found for this worker suggests that he had absorbed a large quantity of methylene chloride on the previous day.

Linear regression analysis showed that breath and blood levels of methylene chloride and carbon monoxide were reasonably well correlated ($r_{\text{linear}} = 0.87$ and 0.84 , respectively). An in-depth discussion of the blood:breath data along with a discussion of the new breath sampling technique is also presented in the companion article. It should be noted that some analytical problems were encountered in the measurement of alveolar carbon monoxide and are discussed in detail in that companion article.

Conclusions

This study has demonstrated that furniture strippers may not only be exposed to high concentrations of methylene chloride but may absorb significant amounts of the solvent while working with methylene chloride-based furniture stripping solvents. Environmental concentrations in five small furniture stripping shops, ranging from 15 to 366 ppm (mean = 127 ppm, S.D. = 117 ppm), were documented. The highest exposures to furniture strippers were found in shops where poorly ventilated spray systems were the primary mode of furniture stripping. Workers most directly involved in handling of the stripping solution, i.e., strippers, had the highest overall time-weighted average exposures to methylene chloride (mean = 191 ppm). The other exposures fell off with increasing distance of the workstation from the source of the stripping solvent, with a mean exposure to washers of 145 ppm and to refinishers of 31 ppm. Biological monitoring of alveolar breath and venous blood for methylene chloride corroborated this trend, with mean blood (breath) concentrations of 4.2 ppm (60 ppm), 2.2 ppm (48 ppm), and 1.3 ppm (7.1 ppm), respectively, for strippers, washers, and refinishers. If smokers were excluded from the data analysis, blood COHb levels and breath carbon monoxide levels decreased in the same order. For those workers, environmental concentrations of methylene chloride were reasonably correlated with postshift %COHb levels ($r_{\text{linear}} = 0.85$) but less well correlated with alveolar carbon monoxide levels ($r_{\text{linear}} = 0.55$).

Regression analysis showed that the time-weighted average methylene chloride exposure concentrations were quadratically related to postshift alveolar breath ($r = 0.98$)

and blood concentrations ($r = 0.87$) of methylene chloride. This degree of correlation between both biomonitoring procedures and the environmental concentrations indicated that inhalation was the primary route for uptake of methylene chloride. The contribution of dermal exposure to the overall bioburden of methylene chloride is not clear from this study. The possibility of significant dermal absorption was suggested for two subjects who had extremely high blood concentrations of methylene chloride relative to their environmental exposures. However, on-the-job observation of these subjects indicated that significant dermal exposure was possible for only one of them.

The quadratic curvature to the data may itself be an indicator of significant dermal exposure (or of ergonomic influences) upon worker uptake of methylene chloride. As discussed below, inhalation models may provide useful insights into the contributions from each route of exposure.

The high environmental exposures of furniture strippers to methylene chloride and the resulting body burdens of methylene chloride and carbon monoxide indicate serious needs for improved engineering controls, especially for the sprayer-based stripping operations. Since the environmental concentrations observed in this survey may be the lowest of the workyear due to seasonally influenced shop ventilation (e.g., open doors), the engineering controls must address the potential for very high exposures to methylene chloride during cooler weather. Detailed recommendations for control of exposures to methylene chloride are given below.

Recommendations for Control of Exposures

The control of exposures to methylene chloride within the furniture refinishing industry is possible using many classical methods including substitution, engineering controls, process changes, proper work practices, and the use of personal protective clothing and equipment. All these elements are well detailed in a 1986 OSHA publication.⁽¹⁶⁾

Substitution

Several new compounds have been or are being developed as potential substitutes for methylene chloride, but none of these products have been accepted by the furniture refinishing industry primarily due to their increased cost. Some of the shops that use a hot caustic dip tank report that it can be substituted for the methylene chloride-based dip tank in all but the most stubborn paint removal jobs. The hot caustic tends to take longer to remove paint and is generally more damaging to the wood.

The amount of methylene chloride in the stripper solution can be reduced and replaced with other less hazardous solvents. Vapor retarders (usually a paraffinic wax) may be used to lower exposure levels by reducing evaporation of methylene chloride. In some of the newer formulations, ammonia has been added as a warning agent. As the concentration of methylene chloride increases, the ammonia concentration also increases, causing irritation and warning the user of the high vapor levels.

Engineering Controls

Local exhaust ventilation at the source of methylene chloride is still the best primary control of vapors. The appropriate form of local exhaust will depend on the application method. General room ventilation must also be considered as a necessary secondary control method, especially if the opportunity for vapor accumulation may occur. This is most common in small shops that close up tight overnight yet have methylene chloride evaporating from an open tank or pail. Accumulated paint scrapings which are still wet with stripping solution should be placed in a ventilated area until dry or sealed in an airtight container.

Process Changes

Although there were too few examples in our study population to draw firm conclusions, it appears that a well-controlled dip tank offers the chance for lower exposures to methylene chloride than a spray system or hand application. Perhaps if the spray table were located in a well-ventilated, confined area, e.g., a spray booth, exposures could be better controlled. The key to control is still exhaust ventilation. Other small process changes that help lower exposures include the use of a split lid on a dip tank, a drying rack on the top of the dip tank to get rid of excessive stripper solvent before washing, an enclosed container for collecting the drainings on a spray system, and a slower liquid flow rate on spray systems to reduce splash and overspray.

Work Practices

A stick or pole should be used to turn objects in the dip tank or to retrieve small parts on the bottom of the tank. A removable metal basket can be immersed into the liquid to provide a retrievable holder for smaller parts. Any clothing that becomes soaked with stripper should be removed immediately to reduce skin irritation and dermal absorption. Workers should be instructed to wear industrial-type uniforms rather than abbreviated clothing such as shorts and short-sleeved shirts in order to further minimize dermal exposure to methylene chloride. Workers should be apprised of the additive effects of methylene chloride and smoking on carboxyhemoglobin levels and should not be permitted to smoke while stripping furniture with methylene chloride-based solvents.

Personal Protective Clothing

Workers should wear solvent-impermeable gloves, aprons, and shoe covers; safety glasses (and goggles) and face-shields where appropriate. Viton material has the best resistance to permeation by methylene chloride but tends to have low mechanical strength and is quite expensive. Other materials, such as neoprene, butyl rubber, nitrile rubber, or polyvinyl chloride, may provide limited protection against methylene chloride and may be used with caution for short-term contact.⁽¹⁴⁾ Gloves should be inspected regularly and discarded at any sign of leakage or deterioration.

Respirators

Positive-pressure supplied air respirators or self-contained breathing apparatus are recommended whenever respirators are required.⁽⁶⁾ Due to the short breakthrough times of organic cartridges and the lack of an adequate odor warning property of methylene chloride, air-purifying respirators are not generally recommended for use for methylene chloride.

Biomonitoring Recommendations

This limited study was not intended as a basis for establishing a definitive biomonitoring strategy for workers exposed to methylene chloride. A primary reason for biomonitoring was to determine the maximum body burden of methylene chloride and carbon monoxide. For methylene chloride, it was assumed that this maximum burden would be manifested immediately postexposure. It was further assumed that comparison of the concentration of the biomonitored analyte to the time-weighted average concentration would provide an indication of dermal uptake.

Of the biomarkers evaluated, Lauwerys' BEI,⁽¹³⁾ based upon immediate postshift monitoring of exhaled methylene chloride, was the best indicator of environmental exposure. This reflects the findings of others.^(17,18) However, since the solvent is rapidly eliminated via the lungs, the breath sample must be collected as close to the cessation of exposure as possible to provide an estimate of the maximum body burden of methylene chloride. In addition, where the worker is exposed to fluctuating environmental concentrations, the immediate postexposure breath concentration will reflect the most recent exposure. Stewart⁽¹⁸⁾ recommends a breath sample, collected in the immediate 2- to 4-hour postexposure period, as the best estimate of the time-weighted average exposure to methylene chloride. In the present study, collection of such samples was not feasible for all workers.

Monitoring of alveolar carbon monoxide or blood %COHb is of value in prevention of cardiovascular stress. However, the relation between this biomarker and environmental concentrations of methylene chloride is confounded by worker smoking. Exclusion of smokers from the data analysis indicated postexposure blood %COHb to be more useful as an indicator of exposure than exhaled carbon monoxide. However, alveolar carbon monoxide and environmental concentrations of methylene chloride were well correlated if two outlying data points were also excluded from the analysis. The outlying breath data were caused by a problem with the analytical method for exhaled carbon monoxide which is discussed in the companion article.

Comparison of blood and environmental sampling data indicated the possibility of dermal or ergonomically influenced uptake. However, these data were very limited and not supported by breath sampling results. Further research

is indicated. For the present, the best estimate of dermal or ergonomically influenced absorption may be obtained by comparison of postexposure breath methylene chloride concentrations to those determined from inhalation models⁽¹⁷⁾ that have been empirically derived from comparable exposures to sedentary subjects.

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