# Qualitative Assessment of Isocyanate Skin Exposure in Auto Body Shops: A Pilot Study

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**Background** *Little is known about the extent of human isocyanate skin exposure in auto body shops and the effectiveness of personal protective equipment. Animal studies have suggested that skin exposure to isocyanates may be an important risk factor for respiratory sensitization leading to asthma. This study provides initial data on hexamethylene diisocyanate skin exposure in three auto body shops.*

**Methods** *Three auto body shops of different size which use different paint systems were examined for the presence of aliphatic isocyanates on environmental surfaces and workers' skin and for breakthrough of personal protective equipment. Qualitative detection of contamination by isocyanates was conducted using a wipe-sampling technique. Assessment focused on the painters and their tasks, although other auto body repairers were also evaluated.*

**Results** *Environmental surfaces such as painters' workbenches, spray equipment, and cleaning tools were found contaminated with isocyanates. Painters had frequent contact with contaminated surfaces, often without wearing gloves. Moderate to heavy contamination of some skin surfaces was found with painters from two of the three auto body shops. Latex gloves used for skin protection showed significant penetrations by isocyanates even after a single painting session.*

**Conclusions** *Contaminated environmental surfaces and skin exposure to isocyanates were documented in several auto body shops. Latex gloves were not adequate protection for workers using isocyanate paints. Further research which would better quantify skin exposure, and its potential relationship to respiratory sensitization and asthma is warranted.* Am. J. Ind. Med. 37:265–274, 2000. *© 2000 Wiley-Liss, Inc.*

***KEY WORDS: isocyanates; HDI; skin exposure assessment; personal protective equipment; wipe sampling detectors; respiratory sensitization; occupational asthma***

## INTRODUCTION

Isocyanate compounds are a group of highly reactive, low molecular weight aromatic and aliphatic chemicals, the most common of which are toluene diisocyanate (TDI), methylene bisphenyl isocyanate (MDI), and hexamethylene diisocyanate (HDI). They are widely used, especially in the manufacture of polyurethane foam and in paints [Tarlo et al., 1997]. It is estimated that 280,000 U.S. workers are either occupationally or potentially exposed to isocyanates in

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various industries [NIOSH, 1996]. With dramatically expanded use of polyurethane paints, plastics, foams, and coatings, diisocyanates have emerged as the most commonly identified cause of occupational asthma in developed countries [Brooks, 1977; Chan-Yeung and Malo, 1995]. It is estimated that about 5–20% of exposed workers develop asthma [Seguin et al., 1987; Mapp et al., 1988; Tornling et al., 1990]. A number of studies have described cases of asthma in auto body spray painters [Cockcroft and Mink, 1979; Belin et al., 1981; Clarke, 1981; Malo et al., 1983; Nielsen et al., 1985; Selden et al., 1989]. However, exposure characterization in auto body workers, particularly painters, has been limited and strictly confined to airborne exposures [Pisaniello and Muriale, 1989; Janko et al., 1992; Lesage et al., 1992].

Experience with isocyanates has shown that monomeric, prepolymeric, and polyisocyanate species are all capable of producing asthma in exposed workers [Seguin et al., 1987; Liss et al., 1988; Vandenplas et al., 1992]. The mechanism by which exposure to these isocyanates causes asthma is, however, still not clear. It has been assumed, until recently, that the primary route of exposure and sensitization is via the respiratory tract. Recent animal studies have, however, suggested that dermal exposure to isocyanates may also produce respiratory sensitization [Erjefalt and Persson, 1992; Rattray et al., 1994]. TDI has been found to induce pulmonary sensitization in guinea pigs after dermal exposure [Karol, 1981]. Intradermal or topical exposure to MDI has been effective in inducing sensitization of the respiratory tract of guinea pigs [Rattray, 1994]. Although similar studies have not been conducted with HDI, it is likely that skin exposure to HDI can also result in respiratory tract sensitization.

HDI is the most common isocyanate in auto body paints. Available exposure data has shown high levels of airborne HDI polyisocyanates during spray application [Janko et al., 1992; Rudzinski et al., 1995]. However, the numerous opportunities for skin exposure have not been documented. Auto body workers regularly mix and apply paints. Direct skin contact with isocyanate-containing paint products and/or contaminated environmental surfaces, and deposition from airborne isocyanates during the spray application is common. It is important that not only airborne exposure to isocyanates be characterized, but skin exposure be assessed as well.

Various direct measurement methods have been developed to evaluate surface contamination and dermal exposure to chemicals. Exposure pads were placed on skin or clothing to evaluate dermal exposure to pesticides [Gold et al., 1982; Leavitt et al., 1982; Chester and Ward, 1984; Methner and Fenske, 1994] and polycyclic aromatic hydrocarbons [VanRooij et al., 1994]. Wipe sampling has been commonly used to assess surface contamination by cadmium [Tartre, 1992], lead [Chavalitnitikul, et al., 1984; Farfel et al., 1994], and other chemicals [Rappe et al., 1985; Fenske et al., 1987]. Indirect methods using biological monitoring of urine to determine the skin contribution to total exposure have also been applied [Durham et al., 1972; Brooks et al., 1980]. Chemical breakthrough of gloves and protective clothing by solvents and pesticides has been investigated [Zellers and Sulewski, 1992; Methner and Fenske, 1994]. However, little has been reported in the literature on surface and skin contamination by isocyanates in auto body shops. This may be partially because such wipe sampling tools for isocyanates were not available until recently when calorimetric sampling pads were developed. These pads qualitatively detect surface and skin contamination of aliphatic and aromatic isocyanates by changing colors when in contact with specific isocyanates. The sampling tool has been recommended by Occupational Safety and Health Administration (OSHA), Salt Lake City Technical Center, Utah for the evaluation of surface and skin contamination by isocyanates in auto body shops [OSHA, 1999].

As part of an on-going cross-sectional epidemiologic study to determine the relationship of respiratory exposure to HDI and the development of asthma (Survey of Painters and Repairers of Auto Bodies by Yale or SPRAY), an exposure-assessment strategy to assess airborne exposure to HDI has been developed. Because of the apparent epicutaneous exposure and possible sensitization via the skin route, a pilot study was conducted in three shops. The objectives of this initial study were to (1) identify environmental surfaces contaminated with HDI in auto body shops; (2) qualitatively assess skin exposure of workers to HDI in auto body shops; (3) identify possible determinants of skin contamination; and (4) identify possible HDI breakthrough of gloves and coveralls used in auto body shops.

## MATERIALS AND METHODS

### Process Description and Shop Selection

Auto body repair work can be classified as paint-related tasks and tasks with no direct contact with paints (Non-paint-related tasks). The latter include car cleaning and washing, shop floor cleaning, mechanical work (assembling and disassembling, light and muffler change, electrical repair, and brake work), frame and sheet metal straightening, bondo[1] work, masking the car (covering the areas not to be painted with plastic sheeting, paper, and tape), and office work. Depending on the extent of damage, each car may

[1] Bondo® is a filler-material used to repair dents in cars. It is a two part system. The larger fraction is composed of an unsaturated polyester, other inert filler material, and some styrene, which gives it a characteristic smell. This is mixed on small pallets or pieces of cardboard with a hardener containing benzoyl peroxide applied with a spatula, allowed to dry, and then sanded. The sanding creates quantities of dust, but the material contains no diisocyanates.

undergo several of these tasks before the paint coating is finally applied. Paint-related tasks include mixing of paints, application of coatings, cleaning of spray equipment, removing masking material of painted cars, sanding dry isocyanate-containing paints on the car, and buffing, polishing and compounding. Painting a car usually requires three layers of coating: (1) primer or sealer coat (or both) which usually contains isocyanate hardeners; (2) base coat, where the color itself does not contain isocyanates; and (3) clear coat which usually includes the isocyanate hardeners. Two to three coats of each are applied by using a high volume low pressure (HVLP) spray gun. The duration of each coating task depends on the surface area of the car to be painted. Application of two to three coats of clear coating may take from 5 minutes to about 1 h, including preparation of the equipment and the car, paint mixing, spraying, and waiting in between coats.

Three shops were selected from the SPRAY project. Each shop used a different paint system, all with isocyanate-containing hardeners added to the primer, sealer, and clear coatings. Various brands of latex gloves were used. Each auto body shop was evaluated for surface contamination, skin exposure, and breakthrough of personal protective equipment (PPE) on a single day. The evaluation focused primarily on paint-related tasks, although other non-paint-related tasks were also assessed. The days sampled represented typical painting days in terms of the car type and size being painted, the level of job difficulty, and the type of paints used.

## Evaluation of Environmental Surface Contamination

### *Surface selection*

Surfaces that might have been contaminated with isocyanate paints were identified. Selected surfaces included work benches for paint mixing, mixing scale and computer panels for the weighing and formulating of base coat paints, spray gun handles, thinner container caps for gun cleaning fluid, spray booth door handles, respirator surfaces and air hoses for supplied air respirators, and glove surfaces.

### *Sampling procedures*

SWYPE™ surface sampling pads from Colormetric Laboratories, Inc. (Des Plaines, IL), specific for the detection of aliphatic isocyanates, were used according to manufacturer's specifications. The investigator wore a pair of N-Dex polynitrile gloves during the sampling and changed for another pair after each positive detection. SWYPE™ surface sampling procedure required spraying on a surface with the provided developing solution to ensure the surface was wet. The developing solution allowed the isocyanate on a rough surface to be in better contact with the sampling pad. After 30 seconds of spraying the developing solution, the surface SWYPE™ pad was used to wipe the surface 2–3 times. Two to three minutes were allowed for color development. An orange to red color indicated aliphatic isocyanate contamination. Color change was identified and reported as positive (+) if any orange to red color was observed. Otherwise, color change was recorded as negative (−). Color was also distinguished as light contamination (orange color), moderate contamination (red color), and heavy contamination (deep red color). This procedure was followed for all environmental surface samples. The same investigator recorded all the color changes.

As a positive control for color development, the isocyanate-containing hardeners and paints mixed with hardeners were tested for color change. Base coat paints without hardeners were tested as negative controls.

## Evaluation of Skin Contamination

### *Selection of workers and tasks*

One designated painter in each shop, who worked more than 50% of time on painting, was selected for skin wipe sampling and evaluation of paint-related tasks. Two to three other repair workers with no direct paint contact were selected for the evaluation of non-paint-related tasks. In each shop, tasks selected were based on actual tasks available on the day. One office worker from Shop 3 was also selected for evaluation.

### *Skin sampling procedures*

SWYPE™ wipe sampling patch, specific for detecting skin contamination by aliphatic isocyanates, was used. It had a cloth portion and a color detection strip. Each SWYPE™ sample was taken after the worker had completed a target task. For painters, samples were taken, after each task, from the forearms, hands (both sides), and faces separately, depending on which was available. No skin wipe samples were taken under the protective equipment. For non-painters, samples were taken only from the hands. The anatomically defined regions were the basis for skin wipe sampling, such as the whole forearm, whole face and hands (both sides), with each of them wiped separately. The skin area was wiped once with the cloth portion of the skin SWYPE™ pad. The skin SWYPE™ pad was then placed in a cup with 1 ml of developing solution, cloth end down and color detection strip up. An orange to red color developed if contamination by aliphatic isocyanates was present. Color change was recorded as noted above for the detection of surface contamination.

## Evaluation of Personal Protective Equipment (PPE)

### Selection of subjects, PPE, and tasks

Only painters were selected for PPE breakthrough evaluation. Latex exam gloves used in the shops were tested. Major paint-related tasks were sampled. One sample was also taken under the painter's coverall (protective clothing).

### Sampling procedures

Permea-Tec pads from the Colormetric Laboratories were applied. Workers were instructed to wear the first pair of gloves they used for their work. One or more Permea-Tec patches (pad side out) were placed on the palmar side of fingers, palm, (or leg under the coverall). Another glove to be evaluated was worn over the first glove and the sampling pads. After working for a single coating or a car job, the worker removed his outside pair of gloves for evaluation of color change. If permeation or penetration by the solvent containing aliphatic isocyanates occurred, a reaction turned the pad into an orange to red color. If not, 10 drops of tap water were slowly dropped on the pad for color change because water was needed for color development when the penetration was light. The color report was based on the similar judgment as in surface and skin analysis. The evaluation was conducted after a single coating session of 2–15 min which included paint mixing and spray equipment cleaning.

## Collection of Task Information

A sampling log was developed to collect information related to wipe samples. It included the location of surface sampling, possible sources of contamination, type of contamination, and frequency of paint contact. Information on the location and duration of each task, type and quantities of paints and hardeners used, type of spray guns used, gloves or coveralls worn, and ventilation was also collected.

## RESULTS

The survey was conducted in May 1998 when the weather was relatively warm. Shop 1 and 2 were similar in size and number of employees (n = 7 and n = 9, respectively), whereas Shop 3 had more number of employees (n = 15) and more painting work. Each shop used a different brand of auto body coating system commercially used in the repair. The hardeners all contained HDI monomers and polymers. Workers in each shop used respirators from different manufacturers with supplied air respirator used in Shops 1 and 3 for painting and a half-mask respirator of organic vapor cartridges and paint pre-filters used in Shop 2. Painting was conducted in booths. Latex medical exam gloves were used in all three shops although brands and manufacturers varied. All painters wore gloves during the sampling day. Most general repair and office workers did not wear any gloves. Paint manufacturer-provided body coverall and head hood was used during painting in Shop 3, whereas no paint coveralls or work uniforms were worn for painting during sampling in Shops 1 and 2. Painters in these two shops wore short-sleeve T-shirts and pants. General repair workers in Shop 3 wore long-sleeve work uniforms. Repair workers mostly wore short-sleeve shirts in Shops 1 and 2. Office workers mostly wore long-sleeve shirts or suits.

## Surface Contamination

Table I shows results of environmental surface sampling. Locations of contamination varied from shop to shop, but contamination was present in most shops in areas routinely touched by ungloved hands. Spray gun handles were found highly contaminated in all shops. Light (orange color) to heavy (deep red color) contamination was found in Shops 2 and 3 on benches where clear coats with hardeners were mixed. Gun washer cap in Shop 2 was heavily contaminated. Spray painters' gloves were found heavily contaminated in both Shops 2 and 3. More surfaces in Shops 2 and 3 were found to be contaminated than those found in Shop 1. As positive controls, the isocyanate-containing hardeners and spray paints mixed with hardeners, all demonstrated a very deep red color change, whereas testing with base coat paints revealed no color change. No contamination was found on base coat mixing scales, computer screens used for mixing base coat paints, and office desks.

**TABLE I.** Surface Contamination in Auto Body Shops[a]

| Surface evaluated | Shop 1 | Shop 2 | Shop3 |
|---|---|---|---|
| Bench for clear coat mixing | − | + | + |
| Bench for primer mixing | − | − | NE[b] |
| Spray gun handle after clear coating | + | + | + |
| Spray gun handle after priming | NE | − | NE |
| Gun washer cap | NE | + | NE |
| Spray booth door handle | NE | − | NE |
| Full-face supplied air respirator hose | − | − | NE |
| Half-mask cartridge respirator after priming | NE | − | NE |
| Half-mask cartridge respirator after clear coating | NE | − | − |
| Spray painter's gloves | NE | + | + |
| Computer screen for base coat mixing | − | NE | NE |
| Balance for base coat mixing | NE | NE | − |
| Office desk | NE | NE | − |

[a]Color change code: — no color change; + light orange to deep red color change.
[b]NE: Not evaluated.

## Skin Contamination

### Shop 1

Table II presents the results of skin exposure-assessment during various coating sessions, clear coat mixing, and other task performances in Shop 1. Three brief (< 8 min) clear coating sessions were conducted in the booth before each skin wipe sample was taken from the painter. The painter wore no protective clothing, but did wear powdered latex exam gloves and a supplied air respirator. None of the painting sessions resulted in any skin contamination at detectable levels with SWYPE™ sampler (Tasks 1–3), possibly due to the short duration of painting and spray-away work position. The painter was tested when mixing clear coat paints and untaping the painted car with no gloves (Tasks 4–5). A light color change was found on one of his hands during the clear coat mixing. Plastic fillers with no isocyanate-containing hardeners were used for bondo work. Skin was tested on a general repair worker after he completed sanding the bondo (Task 6). No color change was detected.

### Shop 2

Painting work conducted in Shop 2 on the day of sampling was on a large van. It consisted of two sessions of sealer coating (Tasks 1–2, Table III), a base coating and a clear coating (Task 3). Since the base coat did not contain isocyanates, no sampling was attempted. The painter did not wear any protective coveralls. With these longer (20–55 min) paint sessions, red to deep red color changes were found during the two sealer coatings and one clear coat application (Tasks 1–3) indicating a moderate to heavy skin contamination. Removing the masking materials on the van later without any gloves also resulted in light contamination on one of the hands of the painter (Task 4). Light contamination was also found on a general repair worker who conducted a 4-minute priming outside the booth where no gloves were worn (Task 6). No skin contamination was detected while sanding the primer (Task 7).

### Shop 3

Three painting sessions were carried out inside the booth in this shop and each was tested for skin contamination (Table IV). The painter was well-covered in nylon body coverall, head hood, gloves, and a half-mask supplied air respirator. The first two sessions were very brief and resulted in no skin contamination (Tasks 1–2). The third involved a 5-minute sealer coating followed by a 9-minute clear coating on the van (Task 3). After this third task, moderate skin contamination (red color) was detected on the uncovered face area around eyes. A number of other non-

**TABLE II.** Skin Contamination in Shop 1

| Task number | Task performed | Exposure | Skin evaluated | Color change[a] |
|---|---|---|---|---|
| 1 | In-booth painting, 3 bumpers | HDI | Left forearm | – |
| | 6-minute clear coating | | Right forearm | – |
| | Gloves, no coverall | | Face | – |
| 2 | In-booth painting, 1 bumper | HDI | Left forearm | – |
| | 5-minute clear coating | | Right forearm | – |
| | Gloves, no coverall | | | |
| 3 | In-booth painting, 1/2 car | HDI | Left hand | – |
| | 7-minute clear coating | | Right hand | |
| | Gloves, no coverall | | | |
| 4 | Mixing clear coats | HDI | Left hand | + |
| | About 2 minutes | | Right hand | – |
| | No gloves, no coverall | | | |
| 5 | Untaping 1/2 painted car | Dried HDI paints | Left hand | – |
| | Less than 3 minutes | | Right hand | – |
| | No gloves, no coverall | | | |
| 6 | Sanding bondo | Dust, no HDI | Left hand | – |
| | 5 minutes | | Right hand | – |
| | No gloves, no coverall | | | |

[a]Color change code: – no color change; + light orange to very deep red color change.

**TABLE III.** Skin Contamination in Shop 2

| Task number | Task performed | Exposure | Skin evaluated | Color change[a] |
|---|---|---|---|---|
| 1 | In-booth painting | HDI, IPDI[b] | Left forearm | + |
| | Whole van | | Right forearm | + |
| | 20-minute sealer coating | | Face | − |
| | Gloves, no coverall | | | |
| 2 | In-booth painting | HDI, IPDI | Left forearm | + |
| | Whole van | | Right forearm | + |
| | 47-minute sealer coating | | Face | + |
| | Gloves, no coverall | | | |
| 3 | In-booth painting | HDI, IPDI | Left forearm | + |
| | Whole van | | Right forearm | + |
| | 55-minute clear coating | | Face | + |
| | Gloves, no coverall | | | |
| 4 | Untaping | Dried HDI/IPDI paints | Left hand | + |
| | Whole van | | Right hand | − |
| | No gloves, no coverall | | | |
| 5 | Out-booth priming | HDI | Left forearm | − |
| | Left rear panel | | Right forearm | − |
| | 3 minutes | | | |
| | Gloves, no coverall | | | |
| 6 | Out-booth priming | HDI | Left hand | + |
| | 2 right rear panels | | Right hand | − |
| | 4 minutes | | | |
| | No gloves, no coverall | | | |
| 7 | Sanding primer | HDI | Left hand | − |
| | Near spray | | Right hand | − |
| | No gloves, no coverall | | | |

[a]Color change code: — no color change; + light orange to very deep red color change.
[b]IPDI: isophorone-diisocyanate.

paint-related tasks, such as sanding dried primer, mechanical work, car cleaning, and office work (Tasks 4–8), were also tested in this shop where no gloves were worn. No skin contamination was detected.

## Evaluation of PPE

Gloves and coverall breakthrough may allow the direct contact of skin with contaminated surfaces in auto body shops to happen and result in the failure of adequate protection. Table V shows that no breakthrough was found of gloves in Shop 1 after 1 h of painting and other related tasks. After another 2 h, the gloves were still protective with no breakthrough detected. Moderate breakthrough was detected after latex gloves were worn for 2.5 h in Shop 2. Moderate to heavy breakthrough was detected under the gloves in Shop 3, even when the coating duration was only several minutes. A single sample collected under the nylon coverall showed no breakthrough by isocyanates.

# DISCUSSION

By employing a novel, direct reading colorimetric sampling technique, we document isocyanate-contaminated environmental surfaces, skin contamination, and the inadequacy of latex protective gloves in preventing epicutaneous exposures to isocyanates in auto body spray paint operations. Environmental surfaces in all three auto body shops, especially those which painters routinely and frequently had contact with, were contaminated with isocyanates. Contamination was especially common on spray equipment and cleaning tools. Contamination of workbenches for paint mixing appeared to be sporadic and likely depended on the work practices of the painter. Although a quantitative relationship between the direct contact with contaminated surfaces and skin exposure has not been established in this study, skin contamination by isocyanates to various extents in painting sessions clearly occurred, despite the use of PPE. Currently little is known about the dynamics of dermal

**TABLE IV.** Skin Contamination in Shop 3

| Task number | Task performed | Exposure | Skin evaluated | Color change[a] |
|---|---|---|---|---|
| 1 | In-booth painting | HDI, HMDI[b] | Left foream | – |
| | Left front fender | | Right foream | – |
| | 1-minute sealer coating | | Left hand | – |
| | Gloves, body coverall[c] | | Right hand | – |
| | Head coverall | | Face | – |
| 2 | In-booth painting | HDI, HMDI | Left forearm | – |
| | Left front fender | | Right forearm | – |
| | 1-minute sealer coating | | Left hand | – |
| | Gloves, body coverall | | Right hand | – |
| | Head coverall | | Face | – |
| 3 | In-booth painting | HDI, IPDI | Left arm | – |
| | Large van, hood | | Right arm | – |
| | And two bumpers | | Face | + |
| | 5-minute sealer coating | | | |
| | 9-minute clear coating | | | |
| | Gloves, body coverall | | | |
| | Head coverall | | | |
| 4 | Sanding primer | HDI, IPDI | Left forearm | – |
| | Hood, 10 minutes | | Right forearm | – |
| | No gloves, no coverall | | Left hand | – |
| | | | Right hand | – |
| 5 | Mechanical work | No HDI | Left hand | – |
| | Near spray | | Right hand | – |
| | No gloves, no coverall | | | |
| 6 | Mechanical work | No HDI | Left hand | – |
| | Far spray | | Right hand | – |
| | No gloves, no coverall | | | |
| 7 | Car cleaning | No HDI | Left hand | – |
| | Far spray | | Right hand | – |
| | No gloves, no coverall | | | |
| 8 | Office work | No HDI | Left hand | – |
| | Two samples in separate rooms | | Right hand | – |
| | No gloves, no coverall | | | |

[a]Color change code: – no color change; + light orange to very deep red color change.
[b]HMDI: Dicyclohexylmethane 4,4-diisocyanate.
[c]Coverall was 100% nylon.

exposure to isocyanates, the contribution of surface contamination by isocyanates to total exposure, and whether or not skin exposure may contribute to the development of asthma. Epicutaneous exposure without absorption might contribute to HDI sensitization and asthma.

Surface and skin contamination by isocyanates may be affected by several factors, such as the type of hardeners used, job size of painting and spray duration, effective use of PPE (gloves and paint coveralls), type of spray booth ventilation and airborne exposure levels. Although only three shops were evaluated, this study suggests that larger job sizes with longer spray duration result in more skin contamination as shown in Shop 2 (20–55 min coatings). Good workplace hygiene and work practices may significantly reduce environmental surface contamination and skin exposure to isocyanates. For example, preventing hardeners and hardener-containing paints from collecting on the workbench surfaces will reduce the direct skin contact with isocyanates. A laboratory study conducted by Carlton and Flynn [1997] indicated that spray orientation to the air

**TABLE V.** Gloves/Coverall Breakthrough Indication

| Shop evaluated | Task involved | PPE evaluated | Color change[a] |
|---|---|---|---|
| Shop 1 | In booth paint work | Gloves worn for 1 hour | |
| | Two clear coatings | Left thumb | − |
| | Some touch up | Left index finger | − |
| | | Right palm | − |
| | In booth paint work | Same gloves worn for 2 more hours | |
| | Two clear coatings | | |
| | Some touch up | Left thumb | − |
| | | Left index finger | − |
| | | Right palm | − |
| Shop 2 | In booth paint work | Gloves worn for 2.5 hours | |
| | A whole van | Right thumb | − |
| | 67-minute sealer coating | Right index finger | + |
| | 28-minute base coating | Left palm | − |
| | 55-minute clear coating | | |
| Shop 3 | In booth paint work | Gloves worn for one paint job | |
| | Left front fender | Right thumb | − |
| | 1-minute clear coating | Left index finger | + |
| | | Left palm | − |
| | In-booth painting | Gloves worn for one paint job | |
| | Big van, hood | Right thumb | + |
| | And two bumpers | Left middle finger | + |
| | 5-minute sealer coating | Right leg under coverall | − |
| | 9-minute clear coating | | |

[a]Color change code: — no color change; + light orange to very deep red color change.

stream could have significant effect on breathing zone concentrations, with lower exposure levels at 180° orientation down the air stream and higher exposures at 90° orientation. This spraying position may also affect the isocyanate aerosol deposition on the skin and epicutaneous exposure. While hand contamination may come from both direct contact with work surfaces and vapor/aerosol deposition, arm and face contamination is more likely to result from vapor/aerosol deposition during painting. Therefore, not standing in between the spray source and the booth exhaust may reduce skin exposure to aerosolized isocyanates. In Shop 1, the painter maintained a tidy bench and kept the spray source away from breathing zone. Although he was not wearing any gloves and protective clothing, HDI was not detected on his arms and face. In Shop 2, the painter did not maintain this spray-away position while spraying on a large van. The result was a significant level of skin contamination.

The proper use of adequate personal protective clothing and correct type of clothing may protect painters and general repair workers from skin contamination by isocyanates. In Shop 3, the painter wore a nylon coverall and a head hood. His arms and the face under the hood were not found contaminated in any paint sessions, although his unprotected face was contaminated. However, painters may not always wear the protective clothing, especially during warm weather. Painters in two out of three shops in this pilot study did not wear protective clothing (paint coveralls). Our data also suggest that most latex gloves that painters and repair technicians currently use in auto body shops do not adequately protect them from skin contamination and exposure to isocyanates. Breakthrough of latex gloves used by painters was found in two out of three shops. Gloves were also torn apart after a car job or even a single coating task. Paint solvents may act as a vehicle for the isocyanates to pass through and enhance their penetration even when gloves are not torn apart [Gunderson et al., 1989]. Nitrile non-latex gloves have been recommended by OSHA Salt Lake City Technical Center, Utah for use in conducting isocyanate sampling [OSHA, 1999], but this has not been yet required of the auto body shops. It is therefore warranted that shop owners and workers be educated to wear truly protective gloves, for example, nitrile gloves.

Although little has been reported on isocyanate surface and skin contamination, previous studies have examined various methodology issues in surface and skin contamination by other chemicals. One of the main issues involving wipe sampling is the removal efficiency, or ability of the wipe to pick up surface contaminants. Effort is made to distinguish between total amount of residue on the surface and the amount that is actually available for transferring to the skin. Using a mass balance method, Geno et al. [1996] determined the amount of pesticides transferred to the hands from aluminum foil spiked with pesticides as the difference between applied amount on the surface and recovered mass remaining in place after subjects' direct contact with the aluminum foil. A removal efficiency of 104% and 92% was reported for chlorpyrifos and pyrethin, respectively. Using a surgical gauze pad to sample indoor pesticides, Fenske et al. [1991] found coefficiency of variation for the recovery rate ranging from 40–60% for carpet surfaces and removal efficiency of 86–96% for spiked aluminum foils. Apparently, surface smoothness affected the removal efficiency and the recovery. Other factors that affect the collection of surface samples include surface concentration, contact pressure, length of sampling time, and variation among people who perform the sampling [McArthur, 1992]. In our study, there was a wide range of surface roughness. The removal efficiency for various surfaces in the shops was not known. The developing solution allowed a better contact of isocyanates with the coating agent of the sampling pads so that isocyanates in the porous holes could be sampled. In this way, it increased the removal efficiency. Further research in the field using standard spiking on various surfaces may help determine the actual removal efficiencies quantitatively.

Another important aspect of surface wipe sampling is the surface area wiped. OSHA [1999] recommends $100\,cm^2$ of surface be wiped with maximum pressure in decreasing concentric squares. The Environmental Protection Agency recommends the wiping of five 5-cm diameter circles ($98\,cm^2$ total area) in one method and a $2500\,cm^2$ area in another method, both using cotton swab for sampling [McArthur, 1992]. We did not measure areas sampled in this pilot study, which is a major limitation. Different color intensities from orange to deep red were detected on various environmental and skin surfaces after different painting tasks in the three shops. An independent validation by Miles Laboratory (unpublished laboratory report available from CLI) on this sampling pad showed that the method has a limit of detection of 10–25 μg (very light color). The color change was more easily observed at 50 μg. A more intense color developed at the 200 μg level. However, since surface area was not defined here, we were unable to compare the color intensity across surfaces and painting tasks.

Another limitation of this study has been our inability to quantify the actual level of skin exposure due to the qualitative nature of the sampling equipment/method available for this assessment. In addition, due to the small sample size of shops, subjects, and surface/skin samples, it is difficult to quantitatively assess the relationship between surface contamination and skin exposure. The isocyanate surface and skin contamination detected in this study demonstrates the importance of developing a more quantitative method to better characterize skin exposure. A better sampling strategy and better quantitative analytical methods are being developed for use in all shops participating in SPRAY study. Sampling and analysis of urinary HDI metabolite are also being planned and should help assess the systemic absorption of HDI.

## CONCLUSIONS

Although this pilot study is limited in size and uses a qualitative sampling and analysis method, it documents HDI contamination on a number of surfaces in auto body shops. In addition, we have shown evidence of substantial epicutaneous exposure to HDI in auto body shop workers and the inadequacy of latex gloves in preventing such exposures. Further studies to better quantify skin exposure, to characterize exposure determinants, and to investigate the systemic absorption of HDI into the body using biological monitoring are planned. These findings, along with air monitoring data, should be able to provide a better evaluation on the auto body repair workers' total exposure to HDI and support subsequent studies of HDI sensitization and asthma.

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