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A Study on Monitoring Techniques for Dermal Exposure to Hazardous Chemicals

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Abstract : Due to dermal exposure to hazardous chemicals causing potential adverse health symptoms through skin absorption, dermal monitoring has had an important role in assessing such exposure. This paper overviews comparatively a number of studies of dermal monitoring with different methodologies such as surface monitoring, skin wiping, skin washing, adhesive methods and tape stripping, fluorescence and infrared spectroscopy, skin patches, pads and clothing, video exposure monitoring and dermal exposure assessment toolkits and models. However, there is a lack of information on the relationship between exposure levels and adverse health symptoms. Therefore, more specific strategies for dermal exposure monitoring should be developed and standardized with further development of biological and ocular monitoring.

Key words: Dermal Exposure Monitoring, Hazardous Chemicals, Ocular Monitoring, Chemical Protective Clothing, Sampling method

1. Introduction

There are potentially many chemical substances that may be absorbed through the main exposure routes such as inhalation, skin absorption and ingestion. If inhalation is the only significant route of entry into the body, then the results of air sampling in the "breathing zone may provide a good indication of personal health risk. Air sampling approaches, equipment and analytical procedures are well documented [1,2].

Although inhalation has traditionally been considered as a main route of exposure, skin absorption can be important in many cases, [3] and variety of direct and indirect approaches have been developed to assess the significance of the dermal route in the early 20th century. Even though there are various biological monitoring techniques available for looking at chemical exposure, biological monitoring can not provide accurate information on exposure routes or body locations of exposure.

In recognition of this, ACGIH(American Conference of Governmental Industrial Hygienists) and other standard setting bodies, have introduced skin notations for substances that readily permeate through the skin. The ACGIH-TLV(threshold limit values) Booklet identifies various classes of substances [4]. Approximately 27% of substances on the ACGIH-TLV list have a skin notation indicating the significance of the issue.

At present, there are no dermal exposure standards, although some attempts have been made to develop quantitative dermal occupational exposure limits, complementary to inhalational exposure limits. However, the extent of exposure by the skin is not always well understood, and semi-quantitative dermal monitoring has been considered.

A range of dermal sampling methods has been described [5-7]. This paper outlines some common techniques for chemical exposure assessment through the skin, such as dermal exposure assessment ;

- skin wiping
- skin washing
- adhesive tape stripping
- fluorescence and infrared spectroscopy
- video exposure monitoring (VEM)
- skin patches, pads and clothing, and
- dermal exposure assessment toolkits and models.

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2. Monitoring Techniques

2.1 Skin Wiping

Skin wiping is a convenient method of assessing dermal exposure. It may serve to indicate the potential for dermal exposure to chemicals. It is, however, an indirect measurement and relies on an understanding of skin contact time and transfer efficiency.

Surface monitoring for radioactive contamination has been widely used for decades, but has been relatively uncommon for general chemicals [6]. In some cases, surface monitoring data can display good correlations with reported symptoms, e.g. surface monitoring of deposited glass fibres may be better correlated with reported dermatitis than air monitoring [7].

Whatman Smear Tabs were used for skin wiping [8]. Different types of prepacked hand wipes like Wash 'n' Dri Soft Cloths, Moist Toweletters, Washkin's Hospital Packettes, Walgreen's Brand Wet Wipes, Lehn and Fink's wet ones and baby size wet ones have been evaluated [9]. In the study of lead contamination, the effectiveness of wiping depends not only on the type of wipe, but also on the number of repetitive wipes. Commercial paper towel premoistened with benzalkonium chloride and alcohol were used for wiping hands, fingers and palms at a battery plant [10]. Commercial baby wipes have also been used for skin wiping [11].

Wipes with polyethylene glycol(PEG) were used for assessing methylene dianiline(MDA), because MDA is soluble in PEG and PEG is soluble in water [12].

However, skin cleaning should be conducted prior to wiping, because there may be pre-existing chemical residues in the layers of the skin like the stratum corneum. Such precontamination should not be removed by waterless cleaners containing lanolin, or abrasive cleansers. In addition, skin barrier cream should not be used on the day of sampling, because it may contain lanolin resulting in the acceleration of the penetration of contaminants [7]. Skin wipes may not collect all contaminants deposited, because contaminants can penetrate into the epidermis during exposure [5]. Volatile components may also evaporate from the skin surface.

Wiping with solvents may itself pose a risk to the worker, especially during time-consuming wiping activities associated with fingers and fingernails. In addition, the solvents may affect the absorption and permeation rates of chemicals being monitored. Wiping has been reported to underestimate exposure, compared with hand washing and a glove method [13]. However, much better recoveries were found in another study when isopropanol was used as a wiping solvent instead of a water-surfactant mixture [14].

Commonly, wiping technique is a useful method to assess potential skin exposure levels. However, several complications need to be highlighted, because current wipe sampling methods could not provide accurate outcomes to determine surface contamination, such as the condition of surface material, wiping materials, contaminant loading and potential reaction like decomposition with surface sampling media [6,15] In addition, skin wipes may not collect all contaminants deposited, because contamianats can penetrate into the epidermis during exposure. Therefore, Ness(1994) introduced alternative wiping techniques using cloth towels, gauze or cotton puff moistened with solvent [7]. However, for all chemicals residue on the skin, sampling techniques are not suitable. Thus, overall, skin surface contamination assessment is problematic and better methodologies are required due to lack of concern about skin contamination from working tools, clothing and skin surfaces [6,7,16].

2.2 Skin Washing

Skin washing is one of the most common removal methods. This method has been used for washing the hand, wrist, arm, foot and ankle. However, this method cannot be used for pesticides which have high rates of dermal absorption. The hand washing procedure has been standardized [17].

Polyethylene bags were used and this was found to be more reliable than the swab method [18]. However, physical characteristics of chemical substances should be considered, such as whether they are soluble or degraded by solvents [19]. For example, the recovery rates of parathion from the hand were 77-94% for the first rinse and 89-98% for the second rinse. Three rinses were recommended to reach a high efficiency [18]. The efficiency range for chloropyrifos using water-alcohol mixtures was 23 to 96% (median 73%) [20].

The Cup method, being a modified aerosol spray delivery system, has been used [21]. When the actuator button is pressed, the propellant is sprayed onto the surface of the skin and the rinse liquid from the contaminated skin surface is collected in a bottle. It has been suggested that this method would provide more accurate results compared with hand washing or skin wiping [7].

The Pouring method is essentially a hand wash involving a stream of solvent [21]. Even though this method is not standardized, it can provide faster sampling collection than the bag method [7].

However, washing techniques are not easily applicable to the assessment of total body exposure, [20] as they

may affect the integrity of the skin, and may provide an underestimation, e.g. in the case of pesticides. Removal efficiency should be studied as a part of quality assurance with a number of variables, such as the field conditions, exposure patterns, relevant time of residence of the contaminant on the skin and relevant levels of skin loading present [20]. It is also thought that there should be a disadvantage of diluting contaminants in any washing media. Therefore, there should a preliminary study to determine the extent of removing contaminants using washing medium.

2.3 Adhesive Tape Stripping

As a surface sampling technique, adhesives have been used to measure skin contamination by particulate substances. Pre-weighed self-adhesive labels were used to measure exposure levels of lead from contaminated soil on the palms of children [22].

In order to collect fibres causing itching and localized rashes in a data processing computer room, transparent tape was used on the skin [23]. Adhesive tapes like Scotch Tape and forensic tape were used and demonstrated that this technique [24].

The chemical concentration profile within the layers decreases with the increase in tape stripping application [25]. In a recent study, tape stripping was used to assess dermal exposure to Jet fuel(JP-8) during aircraft maintenance with naphthalene as a marker [26]. This adhesive tape stripping is a useful assessment method for the determination of the amount and distribution of chemicals in the stratum corneum, although this technique was originally designed to assess surface contamination of fibrous dust like asbestos [7]. This technique is also more effective than surface wiping technique, especially when plywood samples are collected from surfaces [10].

2.4 Fluorescence and Infrared Spectroscopy

Some compounds are naturally fluorescent, e.g. polycyclic aromatic hydrocarbons, and the extent of surface and skin contamination can be assessed with a hand held UV light in a dark room.

A FIVES(Fluorescent Interactive Video Exposure System) was introduced [27]. A fluorescent tracer was used for dermal exposure from contaminated surfaces [28]. By using fluorescent tracers, they were able to identify primary and secondary sources of contamination. This method, however, is costly and has not been widely used.

Dermal absorption rates were measured with ATR-IR (Attenuated Total Reflectance Infrared Spectroscopy) [29]. This technique is comparable with pre-existing sampling techniques (i.e. wiping method) and can support real time exposure during working hours.

However this technique is not widely used at the moment, because of a lack of non-toxic fluorescent tracer compounds and its high cost compared with other techniques for examples, skin wiping, washing, patches, stripping. More consideration should be given to the ratio between contaminant levels and tracer deposition on the skin surface, decomposition rate of tracer with sunlight intensity and quenching on the skin causing inappropriate proportional to deposition on the skin [7,30,31].

2.5 Video Exposure Monitoring

Visualization monitoring was considered by NIWL (National Institute for Working Life) for real-time monitoring. This technique is referred to as quantitative analysis and combined with fluorescent tracer. The quantitative analysis relies on the amount of fluorescence emitted from the skin. It was firstly applied to spray painters exposed to organic solvents. A bar graph in the video picture was applied to the technique in 1989. In 1993, the name of VEM was used by NIOSH. The use of VEM was reviewed as PIMEX-PC in Sweden, Exposure Level Visualization-ELV in UK, FINN-PIMEX in Finland, CAPTIV in France, KOHS PIMEX in Austria, VEM in USA and GRIFFITH PIMEX in Australia, for technical aspects, and applications [32].

For this technique, a variable background reflectance from the skin and images of the various body parts need to be monitored to compare with the results after the exposure to contaminants. Rapid analytical results for the proportion of contaminants over the body regions can be obtained.

2.6 Skin Patches, Pads and Clothing

Simple methods involving pads, patches and clothing have been used to measure the potential for dermal exposure, e.g. from residue transfer or aerosol deposition.

In assessing the deposition of pesticides on the skin, surgical gauze patches were used [30]. Skin patch sampling usually only addresses a small section of the body [33].

As a direct detection method in workplaces using isocyanates, Permea-Tec™ Pads were used to evaluate the exposure of the skin under protective gloves [34]. Charcoal cloth was used to measure potential dermal exposure to a range of solvents [35]. It is a useful approach in judging the effectiveness of personal protective cloth-

ing against chemicals, and in the determination of where the main exposure occurs on the body. In 2005, electrostatic wiping cloths were used for the measurement of surface contaminants like endotoxin and dusts [36]. This method was described as a simplified dust sampling method, which was conducted by the residents.

Gloves are complementary to patches and pads, but, may under- or over- estimate the potential for exposure due to absorptive properties [13,31]. Protocols have been developed for the estimation of total dermal exposure, e.g. based on patches or the use of overalls [37].

Skin patch sampling can only assess the exposure for the site which the patch was located on the body [33]. However, researchers should always consider their measurement results with care, because of the collection efficiency of the sampling medium and the absorption of chemical contaminants and the characteristics of skin patches. In addition, the characteristics of surrogate skin patchs should be concerned like the skin, because the sampling results will differ when the skin is sweating (likely due to temperature, work rate humidity, air conditioning), wrinkling, calluouses and smoothness [7].

2.7 Dermal Exposure Assessment Toolkits and Models

A DREAM(Dermal Exposure Assessment Method) was developed and provides a systematic description of dermal exposure pathways and a guide to the most appropriate measurement strategies [38]. This semi-quantitative method considers company, department, agent, job, task, exposure route, exposure module, exposure status, physical and chemical characteristics, exposure part and protective condition.

Dermal risk assessment toolkits have been developed [39]. The toolkits consider the hazardous properties of the chemical in use, exposure conditions, and control status to assess dermal risks in workplaces. Even though, input data are not always reliable [40], there are exposure surveys conducted with the variable components [41,42]. Other approaches have been used:

The European Predictive Operator Exposure Model, known as EUROPOEM has been developed for operator exposure assessment in pesticide application work [43]. Like DREAM, the assessor's expertise is an important consideration. A PHED(Pesticide Handlers Exposure Database) has been used in the US and Canada [44].

The knowledge-based EASE (Estimation and Assessment of Substance Exposure) model was designed for assessing exposure to new and existing chemicals in the European Union. The model ranks the workplaces in broad bands of exposure, and, therefore, it always assumes homogeneous exposure within the workplace [45]. Exposure determinants should be included [46].

A modified multivariate linear regression modelling was introduced for both determinants of pesticide exposure and affected body regions in terms of observational and visual scoring techniques [47].

In general, toolkit models should consider the hazardous properties of the chemical in use, exposure condition, dermal risks and control status to determine a risk assessment in workplaces. Although dermal exposure toolkits are developed, these could not provide precise information yet, because the input data are not reliable. Thus, it is thought that there should be ongoing concerns about practical or predictive risk assessment with more specific factors, such as different workplaces, tasks, working conditions, physical properties, working practices, human factors, substances used, equipment used and controls.

3. Conclusion

The exposure assessment or risk assessment is the overall process of risk evaluation to determine the frequency of specified events, the magnitude of risks and the management of priorities by comparing with predetermined standards, target risk levels or other criteria.

In order to assess excessive exposure to chemicals, there are ambient sampling and monitoring methods for air, surface and dermal sampling.

Although inhalation and ingestion are traditionally considered as the main exposure routes of entry, dermal exposure is another important route of exposure that needs to be emphasized, because of a lack of understanding about dermal exposure to hazardous chemicals and its complexity. A number of studies have developed methods for dermal exposure assessment. This paper briefly overviewed previous studies regarding dermal exposure monitoring for hazardous substances.

A number of studies indicate exposure levels in terms of different monitoring methods. However, for assessing dermal risks in workplaces, there is a need to develop monitoring methods with more sensitive personal sampling, for example, various body regions and personal details including medical history and personal habits, working conditions and work practices. There should also be more extensive skin surface sampling methods to assess effects on the skin and absorption through the skin.

Due to the difficulty of biological monitoring providing information on exposure routes or body locations of exposure, more study regarding the relationship between the excretion levels of the metabolite and the identification of adverse health symptoms will be required to

provide further information on exposure and adverse health symptoms. For better understanding of exposure routes causing adverse health symptoms, dermal exposure levels need to be compared with both inhalational exposure levels, biological monitoring results and medical symptoms. In addition, ocular monitoring strategy should be researched as there as poor understanding of chemical absorption through the eye.

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