PEER REVIEWED

Dermal exposure sampling methods: An overview

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Abstract

Although a total of 174 and 117 substances have been listed with a skin (Sk) notation in the Regulations for Hazardous Chemical Substances and Regulation 22.9 of the Mine Health and Safety Act respectively, dermal sampling is not used frequently to assess exposure to these substances. A variety of measurement methods and strategies have been developed during the past forty years to assess dermal exposure. These methods include interception methods (also referred to as surrogate skin methods), removal of contaminant (substance) methods and *in situ* detection methods (also referred to as fluorescent tracer methods). The aim of this paper is to give an overview of the different dermal sampling methods. Furthermore, the applicability of each method for sampling different hazardous chemical substances will be highlighted in order to assist Occupational Hygienists in choosing the correct dermal sampling method.

Introduction

Exposure to hazardous chemical substances occurs primarily through inhalation, ingestion or skin contact. With a few exceptions Occupational Hygiene has traditionally focused on inhalation exposure because it is generally considered to be the most important route of exposure.[1] Furthermore, until the mid-1960s, the skin was incorrectly considered as an almost impermeable barrier for chemicals. Since then, skin absorption has been demonstrated for a number of hazardous occupational and environmental chemical substances.[2]

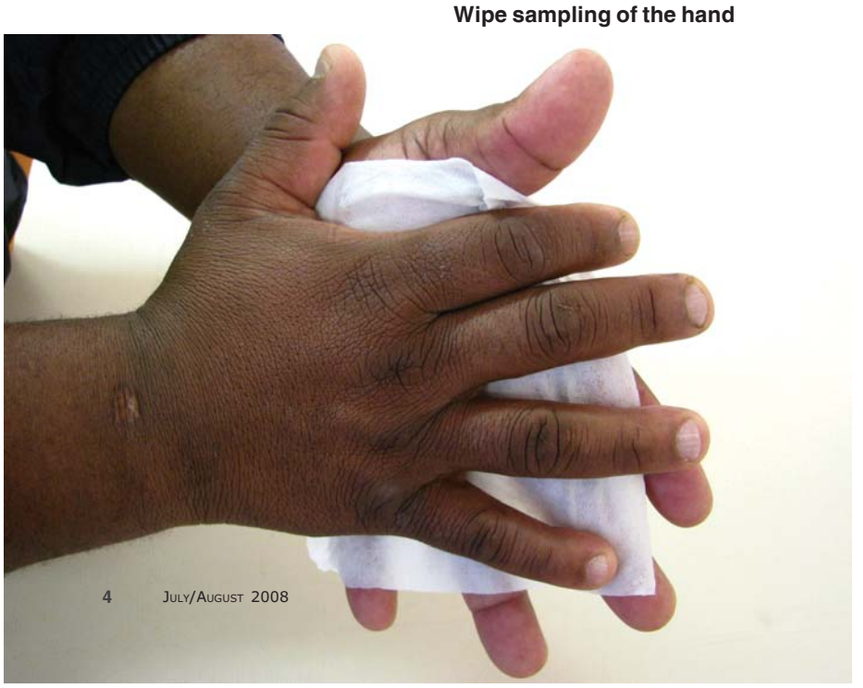
The Regulations for Hazardous Chemical Substances lists 174 substances and Regulation 22.9 of the Mine Health and Safety Act lists 117 substances with a skin (Sk) notation. This Sk notation refers to a substance's ability to penetrate the intact skin and thus being absorbed into the body. However, dermal sampling in comparison to air sampling and biological monitoring is not used frequently.

Dermal exposure normally occurs by one of three pathways, namely direct contact with contaminants (substances) through immersion or spillages, indirect contact with contaminated surfaces or clothing and deposition of contaminants directly from air.[1,3,4]

To date, a variety of measurement methods have been developed to assess dermal exposure. These methods can be grouped into three categories, namely (i) surrogate skin methods, (ii) removal of contaminant methods and (iii) fluorescent tracer methods.[3,5-7] More recently, the use of 'interception methods' as replacement terminology for 'surrogate skin methods' and '*in situ* detection methods' as replacement terminology for 'fluorescent tracer methods' has been introduced.[8]

The aim of this paper is to give an overview of the different dermal sampling methods. Furthermore, the applicability of each method for sampling different hazardous chemical substances will be highlighted in order to assist occupational hygienists in choosing the correct dermal sampling method.

Wipe sampling of the hand



1. Interception methods (surrogate skin methods)

Interception methods estimate the amount of a contaminant that is deposited on the skin or clothing. This is accomplished by placement of a collection medium on the

" Interception methods … measure the potential exposure to a contaminant"

skin or clothing that is capable of collecting and retaining a contaminant in a manner similar to skin, which can then be analysed after extraction from the collection medium. Therefore, these methods measure the potential exposure to a contaminant and include patches, gloves and whole body suits as collection media.[3,7,9]

1.1 Patch sampling

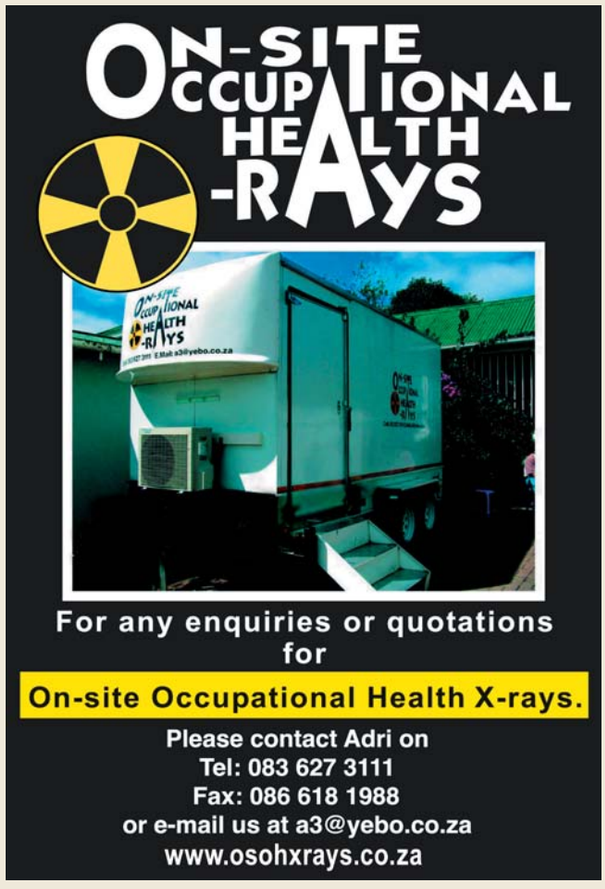
A patch dosimeter is arguably one of the most frequently used dermal sampling methods, in particular to quantify skin exposure to pesticides.[7,10] It has also been used to quantify skin exposure to chromium, copper oxide, metal working fluid, polyaromatic hydrocarbons and dusts.[7,11-16] Several organisations such as the World Health Organization (WHO), Environmental Protection Agency (EPA) and Organization for Economic Co-operaration and Development (OECD) have established "standard" methods for patch sampling.

The type of material used as patches is primarily determined by the contaminant to be collected and the environment in which sampling is conducted. Alpha-cellulose paper has been used as patches to assess skin exposure to pesticides, metal working fluid and chromium.[7,11-13] Polypropylene pads have been used as patches to assess exposure to polyaromatic hydrocarbons, while charcoal cloth may be used to assess exposure to volatile compounds. For dusts and other dry particulate matter, porous patches constructed with layers of surgical gauze are recommended. Other materials used include cotton, polyester/cotton, rayon/polyester, dracon/cotton, flannel, filter paper, filter paper impregnated with lanolin and polyurethane foam pads. Patches are generally backed with a waterproof material such as aluminium foil or polyethylene in order to prevent contamination of the patches by contaminants on the skin/clothing and to prevent collected contaminants from moving through the patch onto the skin.[7]

Several different sizes of patches have been used. The most common size used is 10 x 10 cm (100 cm^2). Smaller sizes have also been used, but this is not recommended. Larger patches may be used for body parts with a large surface area (such as the back or chest).[7]

The number of patches used per worker differ between methods and range from a minimum of six suggested by the WHO and 13 suggested by the OECD. These patches are placed on body parts where possible exposure is expected. The most common positions are on the top of the head, on top of the shoulders, on the back of the neck just below the lower edge of the collar, on the upper chest close to the jugular notch or on the sternum, on the back between the shoulder blades, on the left and right upper arm, on the left and right forearm (midway between wrist and elbow), on the left and right upper leg and on the left and right lower leg.[7,10-13] Patches may also be attached underneath clothing to determine possible contaminant penetration through clothing. Patches are attached to the different body parts with safety pins, staples, skin tapes, clothing tapes or open net smocks, which are now commercially available.

After use, patches must be removed and stored separately from other patches in such a way as to minimise contaminant loss prior to analysis. Exposure is obtained from the product of the mass of contaminant collected on

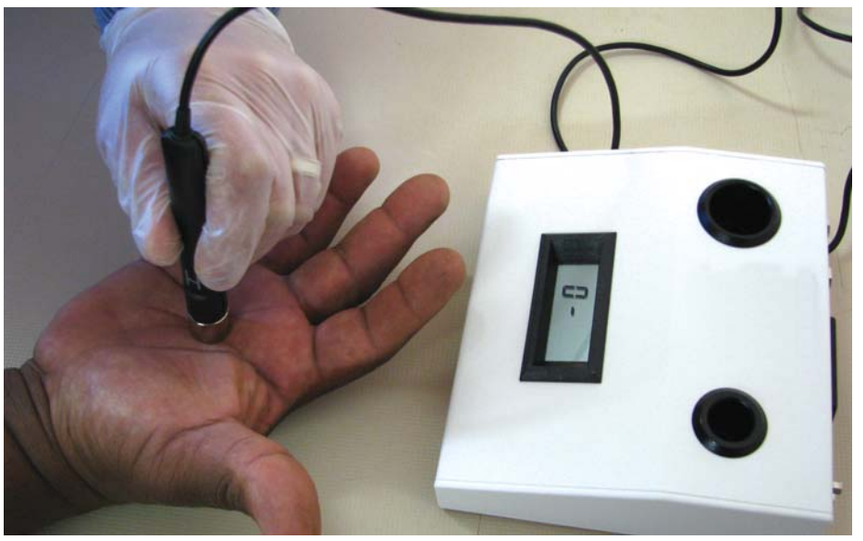


the patch and the ratio of the patch area to the body part area.[7]

The major limitation of this method is that it only estimates the amount of contaminant deposited on a particular surface area. An assumption is also made that contamination is uniformly distributed, which might not always be the case. The patch (or patches) represents only a small proportion of the total body surface area and therefore could lead to an under- or overestimation of exposure.[7] In certain cases this could be overcome by using larger patches. Furthermore, in reality the adherence of contaminants to patches and human skin differs, which could also lead to estimation errors. It is therefore important to establish the ability of patches to capture (absorb) and retain a contaminant. This is done through conducting retention and recovery efficiency studies in laboratories or other controlled environments prior to field sampling. The aim of a retention efficiency study is to evaluate the ability of the collection material (e.g. an alpha-cellulose patch) to retain a contaminant, while a recovery efficiency study evaluates the efficiency of removal of the contaminant from the collection material for analysis.[3,7] Advantages of this method include its ease of use and lower cost of analysis when compared to other surrogate skin methods.[7]

1.2 Cotton glove sampling

Thin cotton gloves may be used to assess dermal exposure to low levels of exposure to viscous low volatility liquids and pesticides.[9,17] These gloves are worn on the hands or over other personal protective gloves during a work shift, whereafter the gloves are removed for analysis. The whole glove (or sections) of the glove is analysed for contaminants. This method has several limitations which include tearing of the gloves, which may impair work and create hazards as well as being prone to saturation by liquid contaminants, thereby overestimating exposure to liquids.[9,12,17] Furthermore, analysis of the whole glove requires large volumes of acid for digestion,[18] making it expensive.



Dermal sampling measurement system to measure the hydration level of the skin. The lower the value, the drier the skin. Cracked and damaged skin may influence absorption of HCS through skin

1.3 Whole body suit sampling (whole body dosimetry)

Whole body dosimeters are typically sets of lightweight, cotton or cotton/polyester mix overalls/underwear that cover the body, arms and legs. Exposure to the head can be measured by attachment of a hood or hat, while exposure to the hands and feet can be measured by using gloves and socks, respectively.[7] To date, their use has been confined to assess pesticide exposure. The main advantage of this method is that no assumptions relating to the uniform distribution of contaminants have to be made when compared to patches.[3] After use, a whole-body dosimeter may be dissected into portions covering individual body parts for separate analysis.[7,19] As with gloves, analysis of the complete suit is expensive.[7] Limitations of this method include susceptibility of suits to breakthrough, the possibility of the worker experiencing heat stress and as with gloves, expensive analysis due to the large volumes of acid required.[3,7]

1.4 Biological dermal sampler

Recently a prototype IOM (Institute of Occupational Medicine) dermal sampler was developed to mimic uptake of contaminants through the skin. It consisted of an adsorbent sandwiched between a permeable membrane and an impervious backing. The concentration of contaminant on the membrane surface may be estimated from the mass collected on the adsorbent and the known permeation rate through the membrane. The sampler gave reproducible results in laboratory and field trials, but the adsorbent became rapidly saturated and the mean permeation rate of membrane was much higher than the permeation rate through skin. The future use and success of this method is dependent on finding a less permeable membrane, which has characteristics closely resembling human skin.[7,20]

2. Removal of contaminant methods

Contaminants can be removed from the skin by wiping, washing/rinsing, tape stripping of the skin or by making use of specialised removal devices. The amount of contaminant that is removed represents the actual amount of contaminant present on the skin at the time of sampling (actual exposure).[5,9] Due to the low costs of sampling materials, analysis thereof and ease of use, these methods

" 174 and 117 substances have been listed with a Sk notation, yet dermal sampling is not performed frequently."

have frequently been used to assess dermal exposure to pesticides.[3,5] All of these removal methods are most suited to low volatility contaminants and to contaminants which remain on the skin surface for a significant period of time. However, it is important to establish the ability of sampling materials and devices in removing contaminants from the skin. This is done through conducting retention and recovery efficiency studies as described in section 1.1.

2.1 Skin wipe sampling

The wipe sampling of skin method is similar to or adapted from general surface sampling methods published by OSHA and US EPA.[5] Similar to hand washing, contaminants are removed from the skin by a combination of mechanical forces and wet chemical action. As with surfaces in general, the skin is not a smooth surface and may have imperfections such as furrows, whorls, scars and calluses that will most likely influence removal of contaminants.[21] Hand wipes are less effective in removing contaminants from the skin when compared with hand wash sampling.[22] Skin wipe sampling has been successfully used and validated to quantify exposures to pesticides, polyaromatic hydrocarbons, isocyanates, nickel, lead, zinc and antimony trioxide.[9,23,24]

A wide variety of sampling or collection media have been used and some are commercially available. They differ in terms of type, surface size and the presence or absence of wetting liquids in the sampling medium. Cellulose, cotton fabric, filter paper (Whatman 542 or 41), nonwoven polyester fabric, cotton balls, sponges, cellulose smear tabs and 12-ply cotton surgical pads have been used as sampling media.[5,24] For isocyanates, wipes are impregnated with polypropylene glycol in order to improve recovery of unbound isocyanates from the skin surface.[23] The size of the collection media (4,8 – 25 cm^2) varies according to the type used.[5,21] Dry collection media is considered to be less efficient than wet or moist collection media.[21] Soaked or wetted (moist) sampling media have also been used in skin wipes sampling. Wetting liquids used include deionised water, ethanol, isopropanol, polyethylene glycol and soap.[5] A wetting liquid should be carefully selected so as not to be an irritant to skin, which may be detrimental to the barrier function of the skin.

In general, skin wipe sampling is limited to the hands (palms, fingertips), forearms, forehead and neck.[5,18] The operator must wear gloves that need to be changed after sampling a specific position, in order to prevent contamination of the wipe used. With the exception of the hands, templates are used to indicate the sampling area for other skin surfaces.[5] The surface area depends on the body part and circular, square or rectangular templates have been used. Several different sizes of disposable or reusable templates are also commercially available. The number of passes made with one wipe over a sampling area varies and is dependent on the removal efficiency of the wipe. In some instances more than one wipe (up to six) is performed and pooled together for analysis. It has also been reported that the amount of pressure applied by the operator might influence the efficiency of the method. Where possible, one operator should perform all skin wipes to prevent or reduce inter-operator variability.[25]

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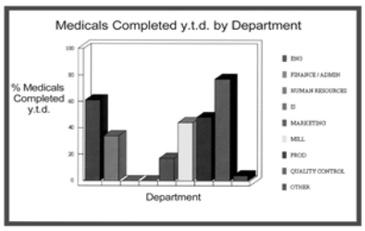

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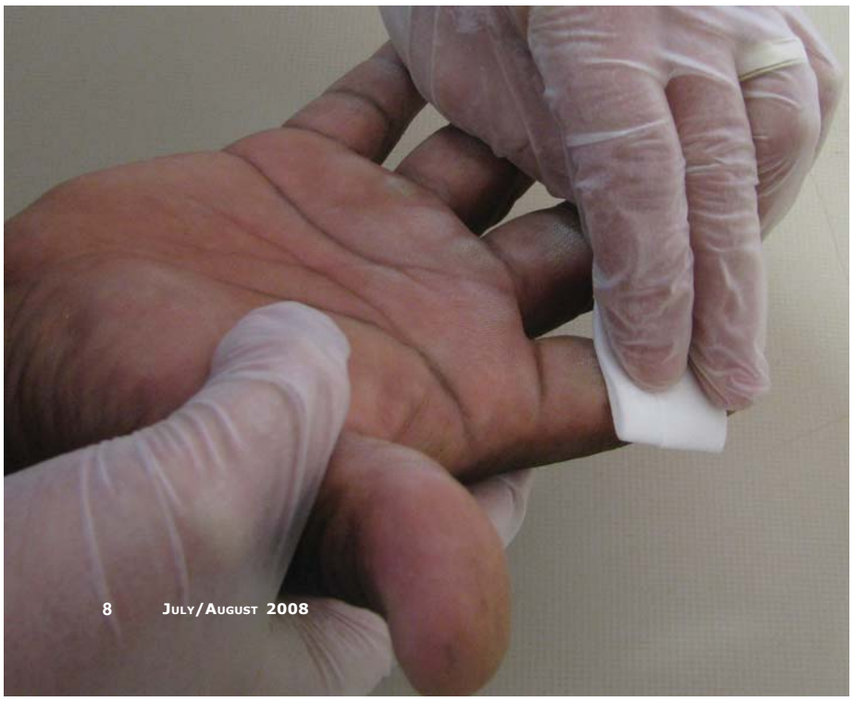
2.2 Tape strip sampling

This quantitative, minimally invasive method has been widely used in dermatology and has been approved by the US Federal Drug Administration as part of a standard method to evaluate topical dermatological dosage forms.[26] To date, this method has been used for dermal and/or surface sampling of acrylates, asbestos fibres, diisocyanates, glass fibres, jet fuel, pesticides, wood resin acids, toxic metals, and fungi in controlled laboratory studies making use of volunteers and in workplaces.[5,25-37] After exposure, pieces of adhesive tape are applied for one to two minutes to exposed skin surfaces such as the hands, forearms, neck and forehead. One to two layers of the stratum corneum (outermost layer of epidermis consisting of dead corneocytes in a lipid matrix) are removed by the adhesive tape and analysed for contaminant content.[5,26,28,29,33,36] As with some other methods, efficiency validation of the method is also required. Numerous different adhesive tapes, with a wide range of efficiencies have been used in various studies. When the removal efficiency with one tape stripping is not efficient, on average two to five consecutive tape strippings are performed to enhance removal of the contaminant. In most instances these strippings are pooled together for analysis.[33]

2.3 Skin wash sampling

Contaminants are removed from the skin by providing an external force that is equal to or exceeds the force of adhesion to the skin. Skin wash sampling is primarily used to remove contaminants from the hands of exposed workers. Three methods, namely hand washing, hand rinsing and finger immersion sampling can be identified.[5] Due to similarities, hand washing and rinsing will be discussed under one heading.

Wipe sampling of the skin, in this instance only the finger



2.3.1 Hand washing/rinsing methods

This method has primarily been used to quantify dermal exposure to pesticides.[17,38,39] The hands of exposed workers are immersed into a bag, bowl or bottle (volume of 250 – 500 ml) containing a washing/rinsing liquid for a predetermined time. With hand washing, the skin is scrubbed by mechanical agitation caused by the movements and pressure of both hands in a washing liquid in a routine washing fashion. The contaminant is removed from the skin by a combination of mechanical forces and wet chemical action (dissolution). Hand rinsing involves pouring of washing liquid over the hands and removal of contaminants by a combination of hydrodynamic drag and dissolution, without using any mechanical force. With the bag-rinsing method specifically, the hand is immersed in rinsing liquid and should be shaken for a fixed number of shakes, a fixed time or a fixed number of shakes in a fixed time to facilitate removal of contaminants. Afterwards, extracts from the washing/rinsing liquid are transferred to a sample tube for analysis. Tap water, distilled or deionised water, water in combination with commercial surfactants, liquid hypoallergenic hand soaps, ethanol and 10% isopropyl alcohol have been used as washing/rinsing liquids.[5,38] Sampling efficiency tests are necessary to validate the method prior to field work. This could be done through a mass-balance method for non-liquid contaminants or direct spiking method for liquid contaminants.[3,5] Reported sampling efficiencies range from unacceptably low to very high levels and it is evident that the type of washing/rinsing liquid influences efficiency. Furthermore, the use of solvents as washing/rinsing liquid may disrupt the barrier function of the skin, thereby enhancing skin absorption of contaminants. In general, it is difficult to interpret skin wash results in terms of contaminant mass per surface area.[5]

2.3.2 Finger immersion sampling

An adaptation of the above-mentioned methods involve immersion of only the thumbs and index fingers of exposed workers directly into sample tubes containing ultra pure water. Although results are limited, this method shows advantages over wipe testing and tape stripping in terms of extraction efficiency, speed and ease of use in the field.[22]

2.4 Suction methods

Suction sampling has been widely used for more than three decades to assess particulate contamination on surfaces such as floors, but their use for dermal exposure assessment has been limited.[40] Suction samplers

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POSITION AVAILABLE

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2. At least 5 years of clinical experience in internal medicine, more specifically in infectious diseases. Note this experience must be after completion of clinical post-graduate training (Residency or Fellowship). Ongoing clinical care practice is a plus.
3. At least 5 years of experience as an Occupational Health doctor.
4. Professional training or work experience in multiple countries or in a multi-disciplinary setting. Overseas work experience is a plus.
5. Past experience working with medical assistance companies or with ex-pat clients would be a plus.
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7. Excellent communication and organizational skills, plus proficiency in written and spoken English. Fluency in French is a plus.
8. Willingness to travel in the 9 countries of the region and to Washington for an initial training.

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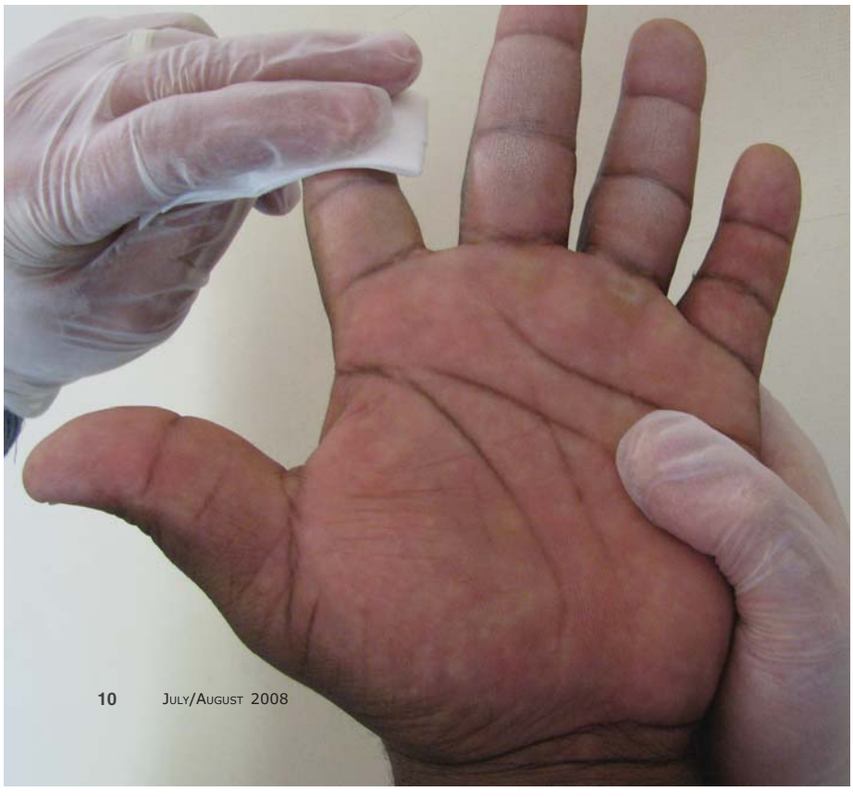
can be divided into vacuum samplers and Smair samplers.

A vacuum sampler is a pump that draws air through a nozzle held on a surface, including the skin. Suction action generates a combination of lift and drag forces that removes particulates when adhesion force between deposited material and the surface is exceeded. Particulates are collected on a 37 mm, 0,8 µm membrane filter or Whatman filter paper. In both suction and Smair samplers, the sampled area is controlled by the dimension of the sampling nozzle and is varied by moving the nozzle from one location to another. A suction sampler can have a wide range of dimensions, but to be effective it must be recognised that the dimensions and the suction flow rate are interdependent. The angle between the vacuum sampler nozzle and the sampled surface was found to influence sampling efficiency. For one such sampler, the optimum angle was found to be 45°.[40]

Smair samplers employ air impingement to redisperse loose contamination from surfaces and dispersed particulates are collected on a membrane filter. A Smair sampler is similar to conventional air samplers with the open end placed against a surface. The air intake is restricted by a series of small holes drilled at angles so as to direct jets of air onto the surface to be sampled.[25]

Both types of samplers enable collection of particulates from large areas and subsequent analysis thereof. Unfortunately, the removal efficiency of vacuum samplers and Smair samplers from skin is very low, relative to other sampling methods such as wiping, but evaluations have been limited to a few studies.[25,40] In comparison with other methods, suction sampling is also more expensive.

Wipe sampling of the skin, in this instance only the finger



3. *In situ* detection method (Fluorescent tracer method)

This method was successfully used to quantify dermal exposure to metal working fluids and pesticides.[6,13,41,42] A fluorescent tracer is added to a specific production process and exposure due to this process will lead to deposition of the contaminant and fluorescent tracer on the skin and/or clothing.[3] The specific location of skin deposition is thus marked by the fluorescent tracer which can be visualised with long-wave UV light and recorded by a video camera. By digitising the analogue camera signal an image consisting of pixels with a 0-256 value (grey level) is generated. The grey levels of before and after exposure are then compared to obtain a decrease in grey level. The relationship between the amount of tracer and grey scale is established and the mass of contaminant deposited on the skin can then be estimated.[42] Used quantitatively this method also provides information on the pattern of contaminant emissions from a source to surfaces and may be the only way to identify and quantify secondary sources of contamination. This method may provide improved accuracy in dermal exposure assessments, since it measures actual skin loading levels and requires no distributional assumptions to be made. It can also identify previously unrecognised exposure pathways and is valuable for worker education and training, because exposure and the patterns thereof can be visualised.[6]

The method requires the introduction of a foreign substance, the fluorescent tracer, into the production system. In many instances, except for agricultural settings, tracer addition to a source is impossible or impracticable. Potential tracer degradation due to sunlight also needs to be evaluated. Implementing the method also involves very high costs which were estimated to be in the order of several hundred thousand rand in 2006.[6]

Conclusions

Dermal sampling is not conducted as frequently as air sampling, partly due to the fact that inhalation as a route of exposure is generally considered to be more important than the skin.[1] Therefore, dermal exposure data from occupational settings is quite scarce and exposure models have often been used in the past as an alternative in risk assessment. Furthermore, dermal exposure sampling is currently a mixture of different methods and relatively few examples of standardisation thereof exist. This makes a comparison of data almost impossible. Some organisations such as the International Council on Mining and Metals, Eurometaux and Eurofer, recently proposed the use of wipe sampling for dermal exposure monitoring of metals in an effort to standardise and validate data in the future.[9] Finally, the potential to conduct dermal exposure monitoring in the southern African industrial and mining sectors is vast and hopefully this review will stimulate the use of dermal exposure sampling as a monitoring strategy.

" The **in situ** *detection method … may be the only way to identify and quantify secondary sources of contamination."*

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