DERMAL EXPOSURE TO CHEMICALS IN THE WORKPLACE: JUST HOW IMPORTANT IS SKIN ABSORPTION?

S Semple

Occup Environ Med 2004;**61**:376–382. doi: 10.1136/oem.2003.010645

The study of occupational and environmental exposure to chemicals has traditionally focussed on the quantity of dust, aerosol, or vapour inhaled. This has been driven by the high historic prevalence of respiratory illness among those in mining and manufacturing industries. The large proportion of respiratory physicians working in occupational medicine reflects this. Other exposure routes are often overlooked when evaluating the impact of chemicals on health. It is important to remember that in addition to inhalation, chemicals may enter the body by ingestion, by injection, or by uptake through the unbroken skin (dermal absorption).

Often dermal exposure is viewed purely in terms of percutaneous uptake of chemicals. There are however three types of chemical-skin interactions, and an understanding of these is required to characterise the nature of any dermal exposure taking place. Firstly, the chemical may pass through the skin and contribute to the systemic load. Alternatively, the chemical can induce local effects ranging from irritation through to burns or degradation of the barrier properties of the skin. Lastly, the chemical can evoke allergic skin reactions through complex immune system responses that can subsequently trigger responses in the skin at both the point of contact and at skin sites remote to the contact. There is also concern that skin contact may cause respiratory sensitisation. In any given exposure scenario there may be interactions between these modes of action. For example, a chemical can irritate the skin surface leading to increased percutaneous penetration of that, or other, chemicals. However, in each case the substance must diffuse through the outer layers of the skin before any adverse effect is possible.

This article aims to highlight the importance of the dermal exposure and absorption route in occupational settings, identify some of the factors that influence exposure and absorption, and describe methods currently used for the measurement and assessment of dermal exposure.

HOW IMPORTANT IS DERMAL EXPOSURE?

The ability of organic materials such as tetra-ethyl lead to enter the blood after contact with the skin was recognised as early as the 1920s. However, much of the current understanding of dermal exposure and uptake has come from researchers investigating the health effects of pesticides. The importance of dermal exposure has been recently highlighted by a special edition of the journal *Annals of Occupational Hygiene*[1] and an international conference on occupational and environmental exposures of skin to chemicals held by the US National Institute of Occupational Safety and Health (http://www.cdc.gov/niosh/topics/skin/conference/).

Dermal exposure to chemicals occurs in a wide variety of occupations spanning agriculture, manufacturing, and service sectors. Jobs where dermal exposure may be significant are as diverse as degreasers, painters, hairdressers, and fruit pickers. The degree of exposure may vary from small quantities of dilute material deposited accidentally on small areas of skin through to repeated immersion of the hands and forearms in concentrated solutions. Environmental and consumer exposures also take place from bathing and swimming in water containing chemicals and from handling or touching surfaces contaminated with pesticides or biocides.

Pesticides, solvents, and polycyclic aromatic hydrocarbons (PAHs) are some of the main chemical groups that have been recognised as posing health problems by dermal absorption. Pesticides generally have a very low volatility and the amount of material inhaled is likely to be low unless a particularly vigorous application results in significant aerosol formation. Workers in market gardens and greenhouses can experience high dermal exposures during application or ''harvest'' or ''re-entry'' processes where handling of vegetation coated with pesticide residues takes place.[2] Pesticides are also used in industrial and domestic settings to prevent plant growth or remove insects or fungi. Infants and children playing in environments treated with pesticides have been the subject of recent dermal exposure research.[3]

The use of organophosphate based sheep-dips has been implicated in the onset of a range of illnesses such as chronic fatigue syndrome. It is believed that a significant proportion of the

Correspondence to:
Dr S Semple, Department of Environmental & Occupational Medicine, University of Aberdeen, Foresterhill, Aberdeen AB25 2ZD, UK;
sean.semple@abdn.ac.uk

Figure 1 Worker using solvents to clean sludge from barrel.

Figure 2 Worker in coverall washing spray lance.

biological dose received during sheep dipping comes via the dermal route with the primary determinant of exposure being the handling or mixing of sheep dip concentrate rather than the amount of contact with diluted sheep-dip.[4]

There is growing interest in the dermal uptake of organic solvents. Solvents are used as thinners, degreasants, de-icers, and paint coatings. In Britain an estimated two million workers have regular contact with solvents, and approximately one in three workers report having worked in a job where they were exposed to these chemicals at some stage in their working lives. Several hundred million tonnes of solvents are used worldwide per year; the vast majority of use involves ethanol, isopropanol, acetone, toluene, xylene, or mixtures of these. Organic solvents used more commonly in the past include benzene and carbon tetrachloride. Despite their widespread use, solvents are known to be toxic to a number of target organs within the body including the kidneys, liver, and nervous system. In terms of neurotoxicity, high exposures are known to cause acute symptoms including dizziness and nausea. They may produce long term irreversible damage to the central nervous system causing behavioural and personality changes. As solvents tend to be volatile, measurement of exposure has primarily focused on inhalation of vapour. However, the highly lipophilic nature of most solvents can also result in dermal uptake when deposited on the skin.

Skin absorption has also been shown to be a primary determinant of the internalised dose of PAHs in many circumstances.[5] Many other materials may also be absorbed through the skin in significant amounts. These include mercury, isocyanates, polychlorinated biphenyls (PCBs), acrylates, and pharmaceutical products such as steroids and nicotine.[6] Table 1 lists some chemicals where dermal uptake can significantly increase body burden.

Table 1 Selection of common chemicals with significant percutaneous absorption

Acrylamide	Benzene
Carbon disulphide	Carbon tetrachloride
Cresols	Diazinon
Dichloromethane	Dichlorvos
Dimethyl sulphate	Ethylene glycols
Hydrazine	Hydrogen cyanide
Isocyanates	Malathion
Metallic mercury	Nicotine
Paraquat	Parathion
PCBs	Tetraethyllead
Toluene	Xylene
White spirit	

This list is not exhaustive. There are over 160 chemicals that have a skin notation assigned by the ACGIH.[8]

EXPOSURE LIMITS AND SKIN NOTATION

Unlike inhalation exposure there are no occupational exposure limits (OELs) for dermal exposure. Instead various national regulatory authorities assign a skin notation for a variety of substances. The intention of the skin notation is to identify substances that can contribute substantially to total body burden by uptake via the unbroken skin and cause serious systemic health effects. Bos and colleagues[7] have recently proposed the concept of quantitative dermal occupational exposure limits (DOELs) to replace the qualitative skin notations. This work investigates the concept of a limit related to the total dose deposited on the skin during a working shift. Difficulties in calculating absorption rate or absorption percentage, a lack of a standardised measurement method for most chemicals, and limited information on the likely health effects that can occur from dermal exposure and uptake have prevented this concept from being further developed.

The qualitative skin notation is defined by the American Conference of Governmental Industrial Hygienists (ACGIH)[8] as applying where there is ''potential significant contribution to the overall exposure by the cutaneous route, including mucous membranes and the eyes, either by contact with vapours or, of probable greater significance, by direct skin contact with the substance''. A review of the use of the skin notation employed by many of the world's health and safety authorities identified inconsistencies.[9] The UK Health and

Safety Executive (HSE) currently assigns a skin notation to over 120 chemicals, while the ACGIH apply the ''skin'' note to over 160 substances. These inconsistencies are due to a lack of information on dermal absorption rates of chemicals and the absence of clearly defined criteria to determine the significance of dermal absorption.

Other investigators have argued for standardised guidelines for assigning skin notations.[10] For example, the Netherlands use the criteria that dermal exposure to the hands and forearms for one hour must lead to uptake exceeding 10% of that received by inhalation for eight hours at the occupational exposure limit. This raises the potential problem of assigning an ''overprotective'' skin notation in the situation where the occupational limit value has been assigned to protect against respiratory irritation rather than any systemic effect.

UNDERSTANDING DERMAL ABSORPTION

The skin is composed of two layers. The outer dead layer of squamous keratinocytes is a thin layer called the epidermis or the stratum corneum. This layer is highly hydrophobic and provides the protective barrier function of skin. Beneath the epidermis is a much thicker living layer of cells including blood vessels, nerves, hair follicles, and sweat glands. The uptake of chemicals through these two skin layers is controlled by diffusion. There are no active transport mechanisms. Chemicals deposited on the outside of the skin set up a concentration gradient between the outer skin concentration and the concentration within the richly perfused dermis. This gradient produces a mass transfer that is dependent on the physical properties of the skin at that site and also the chemical properties of the substance. Diffusion across the complex membrane of the skin is therefore regulated by Fick's law, which states that the rate of diffusion across a barrier will be directly proportional to the concentration gradient.

The intensity of exposure from inhalation hazards is the airborne concentration ($mg.m^{-3}$ or ppm) and, as described earlier, the driving force for dermal uptake is similarly the concentration of the substance on the skin surface ($mg.cm^{-3}$). Unfortunately the methods developed to measure dermal exposure have generally used mass as an exposure metric and this can lead to difficulties when we try to use these measures to calculate or estimate the absorption into the body. A large mass of dilute material splashed on the hands may leave a higher mass residue than a small quantity of concentrated liquid spilled over a smaller area, but the diffusion rate across the skin of the concentrated material will, by Fick's law, be greater. Many studies focus on the quantity of material deposited on the workers' skin as the factor regulating dermal uptake. This measurement is a skin loading ($mg.cm^{-2}$) and is not a concentration, and while it is true that dermal absorption cannot physically exceed the mass of material on the skin, it is the concentration of the substance that drives the diffusive process. The fact that the flux through the skin is determined not by the mass but by the concentration of material on the skin is described in work by Cherrie and Robertson.[11]

The transfer of a chemical substance through the skin can therefore be defined by two measurements. The lag-time is the time taken from initial contact with the skin until the material enters the blood supply, while the flux is the steady state diffusion rate of the material when the lag-time is complete. The flux (J) is measured in units of mass per unit area per time period ($mg.cm^{-2}.h^{-1}$). The flux is directly proportional to the concentration gradient and the rate is regulated by the chemical specific permeability constant (k_p). The equation to calculate dermal uptake for a steady state diffusion process is thus:

$$U_{sk} = k_p.C.A.t$$

where:

U_{sk} is the mass of chemical absorbed through the skin (mg)
k_p is the permeability coefficient ($cm.h^{-1}$)
C is the concentration on the skin ($mg.cm^{-3}$)
A is the area exposed (cm^2)
t is the duration of exposure (h).

To examine the potential impact of dermal exposure, we can consider an example of a painter who is spray painting in a room with a paint containing 300 $mg.cm^{-3}$ xylene. The task lasts 10 minutes and the average airborne concentration is 100 ppm (441 $mg.m^{-3}$). If about 10 cm^2 of the painter's skin is covered by paint, the paint droplets take 10 minutes to dry, and the xylene concentration in the deposited paint is the same as the initial mix, then the approximate dermal uptake is likely to be about 6 mg.

$$U_{sk} = 0.012\ cm.h^{-1} \times 300\ mg.cm^{-3} \times 10\ cm^2 \times 0.167\ h$$
$$U_{sk} = 5.8\ mg$$

When compared with the inhalation uptake of 110 mg over the same time period it is evident that the dermal route is not contributing a significant additional body burden. The comparable uptake by inhalation is calculated by multiplying the exposure level in $mg.m^{-3}$ (C) by the breathing rate in $m^3.h^{-1}$ (B) and the duration of exposure in hours (t).

$$U_{inh} = C.B.t$$
$$U_{inh} = 441\ mg.m^{-3} \times 1.5\ m^3.h^{-1} \times 0.167\ h$$
$$U_{inh} = 110\ mg$$

If however the painter also washes his or her hands in neat xylene thinners (with a xylene concentration of 900 $mg.cm^{-3}$) for one minute at the end of the task, this will add a further 130 mg of xylene to her internalised amount. This would now mean that the dermal route had contributed more than one-half of the painter's xylene uptake.

$$U_{sk} = 0.012\ cm.h^{-1} \times 900\ mg.cm^{-3} \times 720\ cm^2 \times 0.0167\ h$$
$$U_{sk} = 130\ mg$$

FACTORS AFFECTING ABSORPTION

The passage of a chemical through the skin barrier is dependent on many factors. The skin is not uniform in terms of thickness, epidermis to dermis ratio, density of hair follicles, and many other parameters that will affect permeability. The amount of material that may be absorbed will, as a consequence, vary depending on the anatomical site of the exposure. For example, exposure to highly permeable sites such as scrotal skin can result in uptake some 50 times greater than the same exposure applied to the thicker, less permeable skin of the legs and abdomen.[12]

Another important influence on uptake is occlusion. This can occur when liquid becomes trapped between the skin and clothing. It is often apparent in workers who wear gloves that allow fluid to spill over the cuff and into the space between the skin and the inside of the glove. The occlusive process results in the liquid being unable to evaporate from the skin surface, and the quantity of material absorbed may be as

Table 2 Factors affecting the amount of chemical that is absorbed through the skin

Exposure factors
Type of task
Duration
Area of skin exposed
Use of protective clothing
Concentration of the chemical
Hygiene: washing and wearing of contaminated clothing
Chemical factors
Molecular weight
Solubility in water
Solubility in oils
Structure
Irritancy
Presence of other chemicals
Skin factors
Skin thickness
Skin type and condition
Anatomical location of exposure
Temperature and humidity
Occlusion
Skin perfusion
Hairiness, pore density and sweating
Skin metabolism

much as five times that from a similar non-occluded exposure.[12]

Other factors that can play an important role in determining the degree of uptake include temperature and the presence of other materials on the skin. The complex effect of mixtures of substances, and the effects of the vehicle that a substance is contained within, are poorly understood, but a common example is the greatly increased uptake of one chemical due to the skin irritation caused by another chemical. For example, Brand and co-workers[13] have carried out work investigating how the active ingredients of sunscreens may promote the penetration of herbicides through the skin of agricultural workers.

The hierarchy of control principle central to occupational hygiene states that personal protective equipment should only be used as a last resort to manage worker exposure. Despite this the use of chemical protective clothing and gloves is common across a wide range of occupations handling hazardous liquids. While gloves and protective overalls can offer a degree of protection, their selection and use is typically poorly managed. It is also worth noting that current standards for testing gloves and overalls do not take into account how the clothing will perform in workplace conditions nor the influence of chemical mixtures, temperature, and physical stresses.[14]

Protective clothing can also confer a false sense of security on a worker and may lead to behaviours that can result in increased exposure. For example, an ungloved worker washing parts in degreasing solvent may use a tool to remove parts from the degreasing bath. Wearing gloves, however, may cause the worker to become complacent and dip his or her hands in the bath. A final issue in using gloves or protective clothing to reduce dermal exposure is that of proper removal. Studies have illustrated the importance of instruction and training on how to use and remove gloves to reduce the amount of material deposited on the worker's skin.[15] Table 2 provides a comprehensive listing of factors that should be considered when evaluating uptake.

DERMAL EXPOSURE ASSESSMENT

Just like any assessment of exposure to airborne hazards there are a number of exposure parameters that should be measured to characterise dermal exposure and to determine uptake. The exposure intensity and the surface area exposed together with the duration of skin contact and frequency of skin cleaning or repeated exposure are all required to understand the mass of substance likely to be absorbed.

Measurement of dermal exposure has developed in a piecemeal and often chemical or use specific manner with much of the methodology centred around measurement of pesticide residues on the skin. Current methods can be divided into five main types.[16] Surrogate skin and patch methods use whole body suits or representative patches to capture the potential exposure. Removal methods use washing, wiping, or skin stripping techniques to determine the amount of material on the skin at a given time point. Visualisation uses fluorescence to determine the area of exposure and quantify the mass deposited on the skin. Biomonitoring can be used to indirectly determine the amount of dermal uptake and from this provide an estimate of the amount of actual exposure. Dermal exposure modelling utilises statistical or deterministic methods to help estimate the amount of chemical likely to be deposited on the skin.

A review by Soutar and co-workers[17] describes the range of surrogate skin and patch methods in use for the assessment of dermal exposure. The two most commonly used sampling protocols are published by the World Health Organisation (WHO) and the Organisation for Economic Cooperation and Development (OECD).

Each type of surrogate skin sampling techniques has a variety of advantages and disadvantages and each measures a different fraction of exposure. For example, patches measure the amount of material deposited over a selected area and, by proportion, can be used to provide an estimate of the total dermal exposure. Differences in the type of material used for patch samplers, the body locations sampled, and the patch-substance interaction will all increase the variability of any measurement made.

Removal techniques aim to sample the mass of material remaining on a worker's skin at a particular point in time. Wipe sampling and washing techniques can show a high degree of variability in recovery efficiency and are also of limited use when the substance under study is either highly volatile or likely to be rapidly absorbed by the skin.[18] Tape stripping involves the physical removal of outer layers of the epidermis and can be used to provide a picture of the quantity of material that has already been absorbed into the skin. Others have reported this technique for the measurement of jet fuel, isocyanates, and acrylate exposure.[19]

Visualisation of workers' exposure can be achieved by the addition of fluorescent tracer to the material being handled or processed.[20] The 'Fluorescent Interactive Video Exposure System' (FIVES) or similar 'Video Imaging Technique to Assess Dermal Exposure' (VITAE) system allow uniform illumination of the body surface and can provide information on both the amount of surface area exposed and, by correlation with the image intensity, a quantification of the mass of chemical on the skin.

All of these dermal measurement processes tend to provide data on the mass sampled rather than the concentration of material present on the skin. Lindsay and colleagues[21] have reported the development of a novel sampler that measures

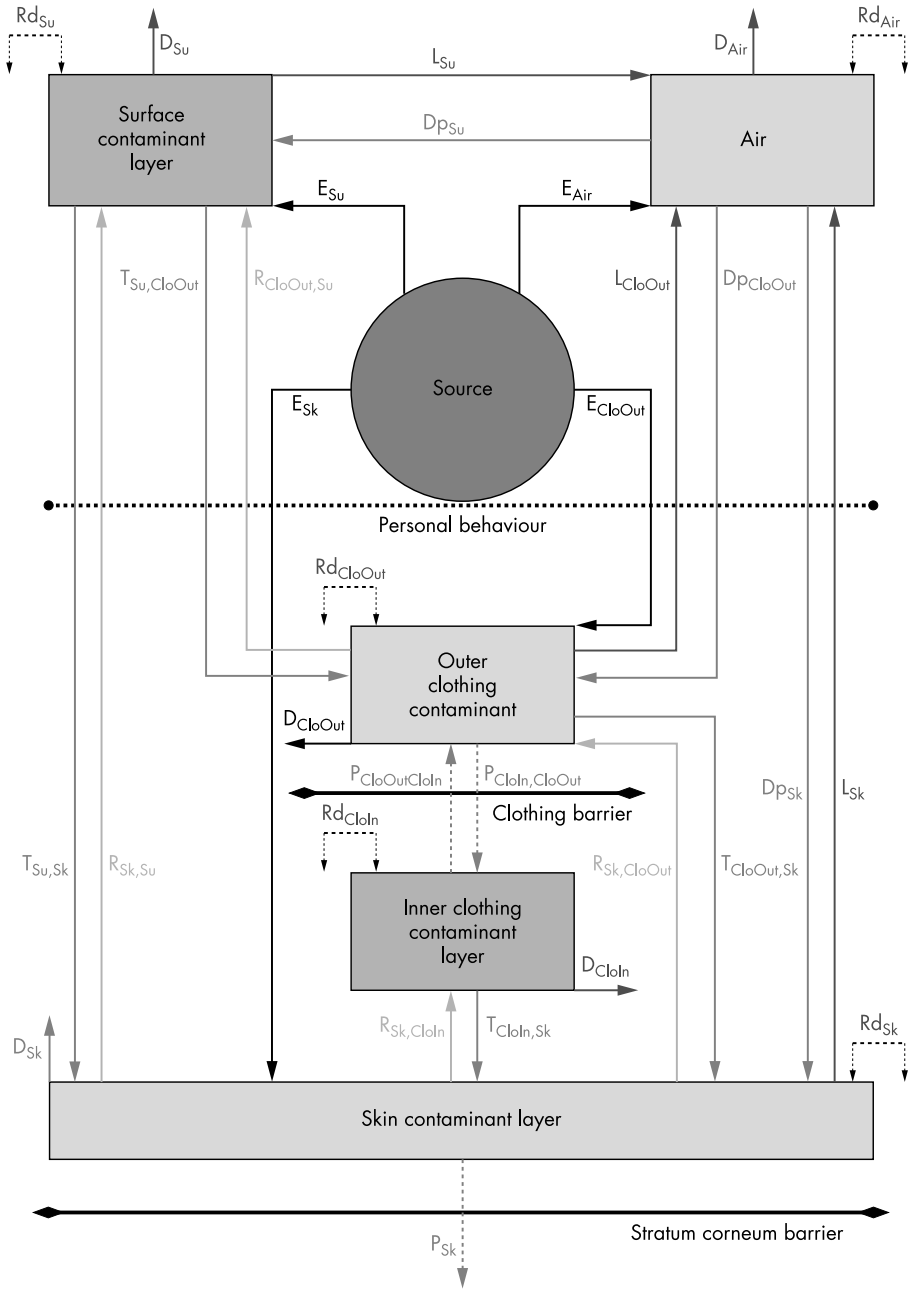

Figure 3 The conceptual model of dermal exposure (see Schneider *et al*[23] for full description).

solvent exposure using a surface membrane designed to reflect the uptake of solvent through the skin. This concept of combining measurement of exposure and uptake holds significant promise for the future and would address many of the problems associated with measuring surface mass contamination.

Biomonitoring for chemicals or their metabolites in the breath, blood, or urine of workers is another option for the assessment of dermal exposure. Using chamber experiments researchers are able to expose given areas of skin to liquids.[22] By separating the subject from the material and ensuring that his or her inhaled atmosphere is solvent free, biological monitoring can be used to determine how much material is absorbed dermally. While biomonitoring can provide valuable information on dermal uptake in controlled conditions it must be used with care in assessing the amount of exposure in the workplace where the internalised material may be additionally absorbed by the inhalation or ingestion exposure routes. Observation of the worker and work practices is important in determining the routes of exposure to understand results from biological monitoring. Knowledge of the chemical half-life and metabolism is also required and inter-worker variability in metabolism can make it difficult to compare exposures from biological monitoring data.

MODELLING EXPOSURE AND UPTAKE

A conceptual model of dermal exposure has been created to help those involved in controlling and evaluating the importance of this route to identify the key transport processes.[23] This model divides the worker's environment into six compartments: the source, the air (Air), the surface contaminant layer (Su), the outer clothing layer (CloOut),

Key points

- Many chemicals can cross the unbroken skin.
- Workers exposed to pesticides or solvents can receive most of their body burden via the dermal route.
- Uptake is controlled by chemical concentration, area of skin exposed, and duration of exposure.
- Skin site, temperature, humidity, and other chemicals can all influence dermal uptake.
- Dermal exposure assessment can be done by surrogate skin method removal techniques, visualisation, biomonitoring, or modelling.

the inner clothing layer (CloIn), and the skin (Sk). Movement of a chemical within the environment is then characterised by the following transport processes: emission (E), deposition (Dp), resuspension/evaporation (L), transfer (T), removal (R), decontamination (D), penetration/permeation (P), and re-distribution (Rd). Figure 3 illustrates the compartments and transfer processes of the conceptual model.

This conceptual model has been utilised to identify pathways of dermal exposure among workers employed in the rubber manufacturing industry.[24] Others have also used the conceptual model to develop a computer based questionnaire to provide the user with data on how to control dermal exposure.[25]

Quantifying the variability in a measurement is an important part of any modelling process. Kromhout and Vermeulen have used their DERMDAT database of 6400 observations to show that total, within-worker, and between-worker variability in dermal exposure measurements across 20 surveys from a wide range of industries was very similar to that found for inhalation exposure.[26]

Modelling of uptake of chemicals through the skin is also important. Work by Wilschut and co-workers[27] reviews five mathematical models used to predict the skin permeation of chemicals based on their physical and chemical properties. Others have further advanced these methods, and Patel and colleagues[28] have published work on the optimal physicochemical parameters to employ in a quantitative structure-activity relation (QSAR) approach to predict skin permeation rates.

THE FUTURE

There is evidence that occupational physicians, hygienists, and epidemiologists are becoming more aware of the importance of dermal exposure and uptake when taking a history or evaluating the effect of chemicals on health. Our understanding of the factors controlling dermal exposure and the percutaneous uptake of chemicals is increasing, and there is great potential for new developments in dermal measurement methodologies.

Some recent work has suggested that a concentration gradient may not be the sole driving force in percutaneous uptake. Experimental findings that aqueous solutions of 2-butoxyethanol may be absorbed more rapidly than concentrated solutions,[29] and other work indicating that fine powdered solids may penetrate the skin without first entering an aqueous phase[30] are of particular interest. The mechanisms involved in these experiments pose serious questions for those involved in determining the uptake of chemicals through skin and require further exploration.

The importance of dermal exposure in respiratory sensitisation and the development of chronic beryllium disease has also been hypothesised. Recent work has suggested a mechanism where fine and ultrafine metal particles may pass through the epidermis and into the dermis to generate an immune response.[31]

Dermal exposure and uptake of chemicals through the skin is fast becoming one of the most interesting and challenging aspects of environmental and occupational medicine and epidemiology. Great strides have been made in our understanding of the determinants of exposure and the factors driving uptake, but there is still much for us to learn and apply.

REFERENCES

1 **Fenske R**. Dermal exposure: a decade of real progress. *Ann Occup Hyg* 2000;**44**:489–92.
► **Editorial outlining recent advances and introducing a series of important papers in a special issue devoted to dermal exposure.**
2 **Tielemans E**, Louwerse E, de Cock J, *et al.* Exposure to fungicides in fruit growing: re-entry time as a predictor for dermal exposure. *Am Ind Hyg Assoc J* 1999;**60**:789–93.
3 **Cohen Hubal E**, Sheldon L, Burke J, *et al.* Children's exposure assessment: a review of factors influencing children's exposure, and the data available to characterize and assess that exposure. *Environ Health Perspect* 2000;**108**:475–86.
4 **Tahmaz N**, Soutar A, Cherrie J. Chronic fatigue and organophosphate pesticides in sheep farming: a retrospective study amongst people reporting to a UK pharmacovigilance scheme. *Ann Occup Hyg* 2003;**47**:261–7.
5 **Van Rooij J**, Van Lieshout E, Bodelier-Bade M, *et al.* Effect of the reduction of skin contamination on the internal dose of creosote workers exposed to polycyclic aromatic hydrocarbons. *Scand J Work Environ Health* 1993;**19**:200–7.
6 **Grandjean P**. *Skin penetration: hazardous chemicals at work*. London: Taylor & Francis, 1990.
► **Comprehensive guide to chemicals that penetrate the skin with a detailed description of how penetration takes place.**
7 **Bos P**, Brouwer D, Stevenson H, *et al.* Proposal for the assessment of quantitative dermal exposure limits in occupational environments: part 1. Development of a concept to derive a quantitative dermal occupational exposure limit. *Occup Environ Med* 1998;**55**:795–804.
8 **American Conference of Governmental Industrial Hygienists**. *TLVs and BEIs*. Cincinnati, OH: ACGIH, 2003.
9 **Fiserova-Bergerova V**, Pierce J, Droz P. Dermal absorption potential of industrial chemicals: criteria for skin notation. *Am J Ind Med* 1990;**17**:617–35.
10 **Czerczak S**, Kupczewska M. Assignment of skin notation for maximum allowable concentration (MAC) list in Poland. *Appl Occup Environ Hyg* 2002;**17**:187–99.
11 **Cherrie J**, Robertson A. Biologically relevant assessment of dermal exposure. *Ann Occup Hyg* 1995;**39**:387–92.
► **Important paper highlighting that concentration and not mass drives dermal uptake.**
12 **Bowman A**, Maibach H. Percutaneous absorption of organic solvents. *Int J Occup Environ Health* 2000;**6**:93–5.
13 **Brand R**, Spalding M, Mueller C. Sunscreens can increase dermal penetration of 2,4-dichlorophenoxyacetic acid. *J Toxicol Clin Toxicol* 2002;**40**:827–32.
14 **Evans P**, McAlinden J, Griffin P. Personal protective equipment and dermal exposure. *Appl Occup Environ Hyg* 2001;**16**:334–7.
15 **Rawson B**, Wheeler J, Roff M, *et al.* The routes and consequences of internal contamination of gloves. Presented at the International Conference on Occupational and Environmental Exposure of Skin to Chemicals: Science and Policy, Washington DC, 8–11 September, 2002.
16 **Vermeulen R**, Stewart P, Kromhout H. Dermal exposure assessment in occupational epidemiologic research. *Scand J Work Environ Health* 2002;**28**:371–85.
► **Recent review of methods of dermal exposure assessment used in epidemiology.**
17 **Soutar A**, Semple S, Aitken R, *et al.* Use of patches and whole body sampling for the assessment of dermal exposure. *Ann Occup Hyg* 2000;**44**:511–18.
18 **Brouwer D**, Boeniger M, van Hemmen J. Hand wash and manual skin wipes. *Ann Occup Hyg* 2000;**44**:501–10.
19 **Nylander-French L**. A tape stripping method for measuring dermal exposure to multifunctional acrylates. *Ann Occup Hyg* 2000;**44**:645–51.
20 **Cherrie J**, Brouwer D, Roff M, *et al.* Use of qualitative and quantitative fluorescence techniques to assess dermal exposure. *Ann Occup Hyg* 2000;**44**:519–22.
21 **Lindsay F**, Cherrie J, Robertson A. Development of a method to assess biologically relevant dermal exposure. Contract Research Report RR117, HSE Books, Sudbury, UK. Available online at http://www.hse.gov.uk/research/rrhtm/rr117.htm.
22 **Kezic S**, Monster A, van de Gevel I, *et al.* Dermal absorption of neat liquid solvents on brief exposures in volunteers. *Am Ind Hyg Assoc J* 2001;**62**:12–18.

23 **Schneider T**, Vermeulen R, Brouwer D, *et al*. A conceptual model for assessment of dermal exposure. *Occup Environ Med* 1999;**56**:765–73.
► **Important paper outlining the mechanisms by which dermal exposure takes place. Attempt to standardise the language used in dermal exposure assessment.**
24 **Vermeulen R**, Heideman J, Bos R, *et al*. Identification of dermal exposure pathways in the rubber manufacturing industry. *Ann Occup Hyg* 2000;**44**:533–41.
25 **van-Wendel-de-Joode B**, Brouwer D, Vermeulen R, *et al*. DREAM: a method for semi-quantitative dermal exposure assessment. *Ann Occup Hyg* 2003;**47**:71–87.
26 **Kromhout H**, Vermeulen R. Temporal, personal and spatial variability in dermal exposure. *Ann Occup Hyg* 2001;**45**:257–73.
27 **Wilschut A**, ten Berge W, Robinson P, *et al*. Estimating skin permeation. The validation of five mathematical skin permeation models. *Chemosphere* 1995;**30**:1275–96.
28 **Patel H**, ten Berge W, Cronin M. Quantitative structure-activity relationships (QSARs) for the prediction of skin permeation of exogenous chemicals. *Chemosphere* 2002;**48**:603–13.
29 **Jakasa I**, Mohammadi N, Kruse J, *et al*. Percutaneous absorption of neat and aqueous solutions of 2-butoxyethanol in volunteers. *Int Arch Occup Environ Health* 2004;**77**:79–84.
30 **Sun C**, Wong T, Hwang T, *et al*. Percutaneous absorption of inorganic lead compounds. *Am Ind Hyg Assoc J* 2002;**63**:641–6.
31 **Tinkle S**, Antonini J, Rich B, *et al*. Skin as a route of exposure and sensitisation in chronic beryllium disease. *Environ Health Perspect* 2003;**111**:1202–8.

QUESTIONS (see answers on p 288)

Please indicate if the following statements are true or false.

(1) Dermal uptake
(a) Tends to be greater from vapours than from concentrated fluids
(b) Refers to the transfer of contamination from the hands to the mouth
(c) Is an active transport process
(d) Occurs only through the sweat glands
(e) Is controlled by dermal occupational exposure limits

(2) Measurement of dermal exposure
(a) Involves pumped samples set at 2.0 litres per minute
(b) Can be achieved by stripping the outer epidermis
(c) Is advisable when assessing workers' exposure to solvents
(d) Is best done using biomonitoring results
(e) Is not necessary when the airborne levels are very low

(3) The skin notation
(a) Is assigned only to substances that are skin irritants
(b) Requires workers handling that substance to wear gloves
(c) Has the same criteria across the EU
(d) Indicates the material can penetrate unbroken skin
(e) Is commonly assigned to solvents and pesticides

(4) Factors influencing the amount of chemical that will be absorbed through the skin include
(a) Temperature
(b) Skin condition
(c) The presence of polarised light
(d) Humidity
(e) Other chemicals on the skin surface

(5) Dermal exposure is likely to be a significant exposure route among
(a) Call centre employees
(b) Market gardeners
(c) Painters
(d) Hairdressers
(e) Rubber manufacturing employees