

Dehydroabietic acid as a biomarker for exposure to colophony

Peter E. J. Baldwin¹, John R. Cain², Ruth Fletcher³, Kate Jones¹ and Nicholas Warren¹

Background	Colophony (rosin) is a natural product derived from the resin of coniferous trees with many industrial applications including soldering fluxes. Exposure to colophony fume through soldering is one of the leading causes of occupational asthma in the UK.
Aims	To assess occupational exposure to colophony from solder fume at selected workplaces in the UK and to investigate the use of dehydroabietic acid (DHA) as a biomarker of exposure.
Methods	Six companies in the UK electronics industry were visited and occupational hygiene assessments of extent and control of exposure to rosin-based solder flux fume were undertaken. Urine samples were analysed for one of the main constituents of rosin, DHA.
Results	There was a positive linear relationship between airborne exposure to solder fume and urinary DHA level. The levels of urinary DHA measured in UK workers were significantly lower than those previously measured in African workers because of the use of appropriate exposure control measures, for example, local exhaust ventilation with fixed ducting and flexible hose, tip extraction, etc. It is suggested that good occupational hygiene practice would result in urinary DHA levels of <3 µmol/mol creatinine in a post-shift urine sample.
Conclusions	Urinary DHA is a valid biomarker of exposure to colophony in solder fume. Further work on the excretion kinetics of urinary DHA, the possibility of skin absorption and further occupational hygiene surveys would be beneficial.
Key words	Biological monitoring; colophony; exposure; rosin; solder fume; urine.

Introduction

Colophony (rosin) is a natural product derived from the resin of coniferous trees; it contains ~90% rosin acids. It has many industrial applications such as cosmetics, adhesives, paints, ink and soldering fluxes. In soldering fluxes, rosin improves the soldering process and reduces oxidation of the soldering joint.

Acute inhalation exposure to rosin-based solder flux fume (RBSFF) can cause respiratory and eye irritation. Chronic exposure to the fume in susceptible individuals can cause asthma. Exposure to RBSFF has been identified as one of the top eight causes of occupational asthma [1]. Manual soldering in particular in the electronics industry is one of the most common sources of exposure. Dermal exposure to solder fume can cause skin irritation leading to dermatitis [2]. Under the Control of Substances Hazard-

ous to Health Regulations 2002 (as amended, 2005 [2]), RBSFF has been assigned a Workplace Exposure Limit (WEL) of 0.05 mg/m³ (50 µg/m³) 8-h Time-Weighted Average (TWA) and a 15-min TWA exposure limit of 150 µg/m³. Because RBSFF is a sensitizer, employers should reduce exposure to as far below the WEL as is reasonably practicable and health surveillance is required.

The chemical constituents in colophony vary but usually consists of resin acids (~90% by weight) and neutral matter. Up to 90% of the resin fraction can consist of abietic acid with the remainder mostly dihydroabietic acid and DHA.

Biological monitoring may be of help in assessing the adequacy of exposure control. A paper by Jones *et al.* [3] details the use of measuring dehydroabietic acid (DHA) in urine as a biomarker of exposure in South African workers exposed to RBSFF. The study involved only one factory and no personal exposures to solder fume were measured but the work carried out was placed into 'exposure ranks' based on the level of exposure potential judged on the work performed and the controls used. A relationship between the exposure rank and the urine biomarker, DHA, was found.

Further work was needed to investigate the correlation between colophony exposure in air, urinary DHA levels

¹Health & Safety Laboratory, Harpur Hill, Buxton SK17 9JN, UK.

²Health & Safety Executive, Marshalls Mill, Leeds LS11 9YJ, UK.

³Health & Safety Executive, Newcastle, UK.

Correspondence to: Kate Jones, Health & Safety Laboratory, Harpur Hill, Buxton SK17 9JN, UK. Tel: +44 1298 218435; fax: +44 1298 218172; e-mail: kate.jones@hsl.gov.uk

and exposure control measures used to evaluate the utility of biological monitoring and to assist in the development of a biological monitoring guidance value.

This paper reports a survey of six companies in the UK electronics industry that were visited to measure personal inhalation exposure to RBSFF, measure urinary DHA concentrations in workers exposed to solder fume, study the relationship between the concentrations of urinary DHA and RBSFF exposures, assess the suitability of DHA as a biological marker of exposure to RBSFF and assess the measures used to prevent or control exposure to solder fume.

Methods

Six companies were identified in the UK electronics industry known to be undertaking work involving hand soldering and using rosin-based solder flux. Companies were chosen at random within the North East region of the UK. Details of the companies visited and the solder in use are given in Table 1. The exposure control measures in use are given in Table 2.

In total, 30 personal airborne samples were collected from the six companies visited to measure exposure to RBSFF. The workers sampled were volunteers who were mainly carrying out manual soldering and those likely to be exposed to solder fume, for example, working on flow soldering and working in the vicinity of someone soldering. The samples were collected during their normal soldering work and using the exposure control measures provided. Samples were collected over a sampling period between 36 and 225 min (average 142 min). The sampling time did not include breaks when the pumps were switched off.

The sampling was performed in accordance with methods for the determination of hazardous substances 83 [4]. This method uses a Swinnex sampling head attached to the frame of a pair of safety glasses. The sample flow rate is set to 1 l/min at the start of the sample collection and checked periodically throughout the sampling period. The filter in the sampling head is then analysed for total resin acid by gas chromatography with flame ionization detection. This enables the various rosins present to be identified and the total rosin acid determined for the sample.

A urine sample was also collected from each worker monitored for airborne RBSFF. Ethical approval was not sought as the monitoring was undertaken as part of their exposure assessment; however, all workers gave fully informed written consent agreeing to be involved. The urine samples were collected as close to the end of the working shift as possible. The samples were stored in a refrigerator prior to being sent to the laboratory for analysis.

The analytical method used to determine the DHA levels has been previously reported [3]. Standards were prepared in urine from unexposed persons; heptadeca-

noic acid was used as an internal standard. Aliquots of urine were hydrolysed at $\sim 90^{\circ}\text{C}$ for 1 h with concentrated hydrochloric acid. Samples were then extracted into diethyl ether and evaporated under nitrogen. The residue was derived using dimethylformamide dimethylacetal. The samples were analysed by gas chromatography with mass spectrometric detection using positive electron impact ionization and selected ion monitoring.

At each workplace, a sample of the solder wire was collected to enable the rosin acids present to be determined. The solder wire was heated to produce fume, which was then analysed for the rosins present using the same analytical method as that used for the air samples.

Results

Thirty personal exposures were measured during hand soldering or working in the vicinity of hand soldering in six companies. All the calculated exposures are based on the assumption that the workers were exposed to the measured RBSFF for their entire shift. The exposures ranged from less than the limit of detection ($1\text{ }\mu\text{g}/\text{m}^3$) to a high of $107.5\text{ }\mu\text{g}/\text{m}^3$ 8-h TWA with a mean of $24\text{ }\mu\text{g}/\text{m}^3$ 8-h TWA. The WEL of $50\text{ }\mu\text{g}/\text{m}^3$ 8-h TWA was only exceeded once (a long-term exposure of $107.5\text{ }\mu\text{g}/\text{m}^3$ during touch-up, next to a surface mount machine in company C).

The DHA urine concentrations ranged from 'none detected' to a high of $7.2\text{ }\mu\text{mol}/\text{mol}$ creatinine measured in the urine of a worker in company C. The 90th percentile level of the concentrations measured in this survey is $3.4\text{ }\mu\text{mol}/\text{mol}$ creatinine.

Each company used a different solder wire because of the job specifications and therefore they varied in their rosin content. The rosin content ranged from 0.2% by weight at company D that manufactures PCBs to 2.0% by weight at company F that manufactures remote controls (see Table 1).

There were three main types of rosin acids measured in the wires: DHA, tetrahydroacids and dihydroacids. Other acids measured included palustric acid, dienic acids and neoabietic acid. The proportion of DHA present in the rosin fraction varied from 9 to 62% (see Table 1). Despite the variation in DHA content, there was a good correlation ($r = 0.67$) between total rosin in air and the proportion of DHA.

Figure 1 shows a plot of the calculated long-term personal inhalation exposures against the urinary DHA concentrations measured during the survey (both are plotted on a natural logarithm scale). Using least squares regression analysis, the correlation coefficient is 0.66. Using this correlation, an 8-h exposure at the WEL ($50\text{ }\mu\text{g}/\text{m}^3$) would be expected to give rise to a post-shift urinary DHA result of $2.8\text{ }\mu\text{mol}/\text{mol}$ creatinine (95% CI 2.2– $3.4\text{ }\mu\text{mol}/\text{mol}$ creatinine).

Table 1. Descriptions of companies visited and solder fluxes used

Company	No. of workers (no. soldering) [no. sampled]	Use	% rosin content (% DHA in rosin)
A	80 (8 hand soldering) [4]	Manufacture of electrical braking systems.	1.36 (9)
B	38 (12 hand soldering) [7]	Manufacture and repair of hearing aids.	0.98 (10)
C	>280 (40 hand and flow soldering, mostly non-colophony flux) [2]	Manufacture of printed circuit boards.	1.43 (11)
D	170 (20 hand and flow soldering) [3]	Manufacture of printed circuit boards.	0.61 (11)
E	90 (18 hand and flow soldering) [9]	Production of lighting units with high-frequency converters.	0.2 (50)
F	60 (25 hand and flow soldering) [5]	Manufacture of television control panels and infrared remote controls.	2 (62)

Table 2. Exposure control measures in place at the various companies

Company	General ventilation	LEV	PPE/RPE
A	Roof air vents, roof air supply fans, portable fans.	Tip extraction. Free-standing fume absorbers (not used).	None for general work. Rubber gloves and disposable half-mask FFP2 when changing filters.
B	Open window/door.	Flexible ducting/hood i.e. a moveable arm at each workstation leading to a single filtration unit.	None for general work.
C	Open roller shutter doors.	Flexible ducting/hood at each bench leading to single filtration unit. Tip extraction (not always used) on one line.	None for general work. Rubber gloves and full-face mask with a A1 cartridge during solder bath cleaning.
D	Open doors, portable fans.	Flexible ducting/hood at each bench. Flow soldering machines with LEV.	Apron and safety glasses for general work. Cotton gloves when using flow solder machines.
E	Roof air vents, portable fans.	Flow soldering machine with LEV (no filtration). Tip extraction with filtration unit at each bench.	White overalls and nitrile-coated cotton gloves. Gloves not worn for intricate work. 'Welding' gloves and a half-mask E2P3 for maintenance work on flow solder machines.
F	Roof supply/extraction fans.	Tip extraction and filtration at each workstation. Flow soldering machine with LEV.	None for general work. Rubber gloves for setting up flow solder machine. Half-mask FFP2 supplied but not used.

PPE, personal protective equipment; RPE, respiratory protective equipment; FFP2, disposable respirator (coarse dust/aerosols); E2P3, filter for inorganics and highly toxic dusts/aerosols.

Discussion

All the companies visited in this survey had several measures to control exposure to solder fume [e.g. a combination of local exhaust ventilation (LEV) and general ventilation] but nevertheless an exposure over twice the WEL was measured at one firm and exposures above half the WEL were measured at two other firms. These higher exposures were likely to be due mainly to the ineffective placing of the LEV captor hood and poor maintenance of the LEV systems being used, e.g. not cleaning the tips or not replacing filters.

All companies used either fixed ducting with flexible hose/hood at the workstation and/or tip extraction with a 5-mm bore during hand soldering. There was no use of free-standing fume extraction boxes though one company was deciding whether to purchase them to replace tip

extraction. All flow soldering machines were fitted with extraction. There was evidence that some of the LEV systems were not being well maintained by the companies, e.g. filters not being replaced regularly and fans not being cleaned, resulting in a reduction in their overall capture efficiency. The major problem with the tip extraction was a failure to clean the build up of residue in the tip. Some workers preferred not to use tip extraction even though provided by the employer. Recently, it has been shown by the UK Health & Safety Executive (HSE) that increasing the bore of the tip extraction to 7 mm from the accepted industry standard of 5 mm and increasing extraction flow rate can substantially increase the effectiveness and ease of use of the system [5].

Gloves were not worn during hand soldering because most of the work was intricate. There were alleged reports of dermatitis at several companies possibly from

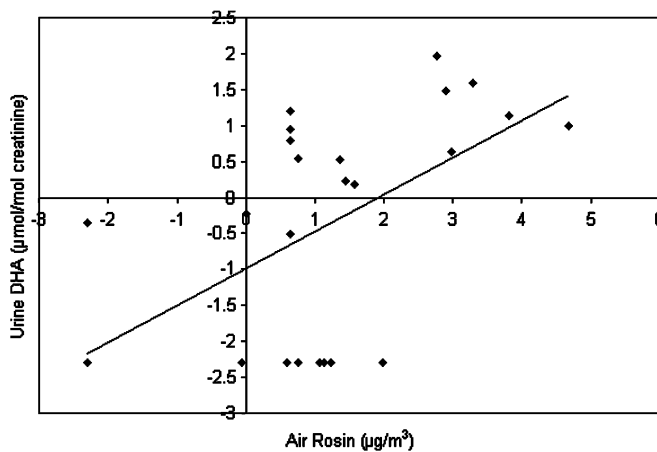


Figure 1. Correlation between airborne rosin levels ($\mu\text{g}/\text{m}^3$, 8-h TWA) and post-shift urinary DHA levels ($\mu\text{mol}/\text{mol}$ creatinine), $r = 0.66$ ($n = 30$). Both scales are natural logarithms.

exposure to RBSFF. The use of suitable personal or respiratory protective equipment was limited to maintenance work, e.g. changing filters and cleaning flow solder machines.

A positive linear correlation ($r = 0.66$) was determined between airborne rosin exposure and urinary DHA levels, expressed on natural logarithm scales. Using this correlation, an 8-h exposure at the WEL ($50 \mu\text{g}/\text{m}^3$) would be expected to give rise to a post-shift urinary DHA result of $2.8 \mu\text{mol}/\text{mol}$ creatinine (95% CI 2.2 – $3.4 \mu\text{mol}/\text{mol}$ creatinine).

RBSFF can cause sensitization. Hence, there is a requirement in the UK for exposures to be controlled as low as reasonably practicable and any biological monitoring guidance value would be based on a 90th percentile 'benchmark' value. From this study—if all the data were included—the 90th percentile value would be $3.4 \mu\text{mol}/\text{mol}$ creatinine. As this figure does not reflect exclusively those companies using 'best practice', urine values should be as far below this value as practicable.

There may be a number of factors influencing the correlation including the fact that the biological monitoring is based on measuring DHA in urine whereas the airborne exposure is expressed as total resin acid (the proportion of DHA in the solder wires used in this survey ranged from 9 to 62% of the total resin acid present). However, comparing airborne DHA with urinary DHA does not dramatically alter the correlation coefficient ($r = 0.72$) indicating that urinary DHA is a valid marker of total resin acid exposure. There may be differences between the measured air exposure and the actual exposure. There are some instances of positive urinary DHA levels with no detectable airborne exposure indicating that there may be some skin absorption of DHA through handling of solder wire (very few workers wore gloves). In cases of close work where the fume is very localized, perhaps the worker is exposed by inhalation which is not reflected by the air sampling de-

spite the use of glasses-mounted sampling as recommended in MDHS 83. There are also a number of data points where there is a positive airborne exposure but no detectable urinary DHA—it has been shown that the sampling position described in MDHS 83 may overestimate the actual exposure by a factor of 1.56 [6]. Alternatively, the different sampling times of the airborne and urinary samples may also play a part; at present, very little is known about the excretion of DHA in urine. There is limited data indicating that the half-life may be in the region of 4 h (HSE, unpublished data).

The urinary DHA levels measured in this study were significantly lower than those found in the Jones *et al.* [3] South African study. In that study, the urinary DHA levels were measured between 3 and $283 \mu\text{mol}/\text{mol}$ creatinine with a 90th percentile level of $73 \mu\text{mol}/\text{mol}$ creatinine. In UK workers, the urinary DHA levels measured were between 0 and $7.2 \mu\text{mol}/\text{mol}$ creatinine with a 90th percentile of $3.4 \mu\text{mol}/\text{mol}$ creatinine. The 20-fold difference in 90th percentile levels between these studies probably reflects the inadequate control measures in the South African factory where there was no LEV installed and the general ventilation of the factory was insufficient to dilute the airborne contaminants (carbon dioxide levels rose markedly during the work shift). It is also possible that differences in work practices and the rosin content of the fluxes used contributed to greater exposures in the South African population. Metabolic or kinetic differences between the two populations are possible although both studies showed some correlation with exposure (only qualitative in Jones *et al.* [3]).

This present study was quite small (six companies, 30 workers) and further studies in the UK to measure urinary DHA levels during hand soldering including touch-up, during the use of flow soldering machines including maintenance, etc., in factories using good control practice would be beneficial. It would also be useful to compare these results with those measured at companies where the controls used are less effective and exposures are therefore expected to be higher—for example, at factories where bench fume absorbers are used as the main control measure. Further work to elucidate excretion kinetics of urinary DHA is also required although, as demonstrated by this study, an end of shift sample can be used to monitor exposure.

This study has shown that there is a linear relationship between exposure to airborne RBSFF and urinary DHA and that biological monitoring may therefore be a useful means of measuring exposure. The study indicates that a biological monitoring guidance value of $3 \mu\text{mol}/\text{mol}$ creatinine would be indicative of controlling RBSFF to within the WEL although exposures should be controlled as far as reasonably practicable. As health surveillance is required for colophony-exposed workers, incorporating a biological monitoring programme into health surveillance

might allow detection and addressing of exposures before ill-health becomes apparent.

Acknowledgements

The authors would like to thank Ian Pengelly, Health & Safety Laboratory, for the analysis of the air and solder wire samples. This work was funded by the HSE.

Conflicts of interest

None declared.

References

1. Health & Safety Executive. *Asthmagen: Critical Assessments of the Evidence for Agents Implicated in Occupational Asthma*. Suffolk: HSE Books, 1997.
2. Health & Safety Executive. *Control of Substances Hazardous to Health Regulations 2002 (as Amended). Approved Code of Practice and Guidance L5*, 5th edn. Suffolk: HSE Books, 2005.
3. Jones K, Garfitt SJ, Calverley A, Channa K, Cocker J. Identification of possible biomarkers for colophony exposure. *Occup Med (Lond)* 2001;**51**:507–509.
4. Health & Safety Laboratory. *MDHS 83/2 Resin Acids in Rosin (Colophony) Solder Flux Fume*. <http://www.hse.gov.uk/PUBNS/mdhs/pdfs/mdhs83-2.pdf> (9 May 2007, date last accessed).
5. Dowker KP. *Effectiveness of a Solder Fume Tip Extraction System: Effects of Tube Diameter, Airflow Rate and Air Flow Velocity*. http://www.hse.gov.uk/research/hsl_pdf/2005/hsl0519.pdf (9 May 2007, date last accessed).
6. Simpson AP. Comparison of sampling positions when measuring personal exposure to solder fume. *Ann Occup Hyg* 2005;**49**:439–442.