

## ORIGINAL ARTICLE

## Contamination of skin and surfaces by cobalt in the hard metal industry

Jolinde Kettelarij  | Klara Midander  | Carola Lidén  | Anneli Julander 

Unit of Work Environment Toxicology,  
Institute of Environmental Medicine,  
Karolinska Institutet, Stockholm, Sweden

**Correspondence**

Jolinde Kettelarij, PhD Unit of Work  
Environment Toxicology, Institute of  
Environmental Medicine, Karolinska Institutet,  
Box 210, SE-171 77 Stockholm, Sweden.  
Email: jolinde.kettelarij@ki.se

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**Background:** It is well known that hard metal workers have historically been affected by contact allergy to cobalt. Knowledge is sparse about occupational skin exposure to cobalt, in terms of skin doses and sources of exposure, which could be used to improve protection of workers.

**Objectives:** To improve knowledge about skin doses and sources of skin exposure to cobalt within hard metal production, thereby facilitating better protection of workers.

**Methods:** Forty workers were sampled on the index finger by acid wipe sampling after 2 hours of work. The samples were analysed with inductively coupled plasma mass spectrometry. Cobalt spot testing was performed in the work environment.

**Results:** The highest skin doses were found among raw material workers. Skin doses among other production workers were also significant. Most office workers had low, but measurable, levels of cobalt on the skin. Glove use varied between workers. Cobalt was found on production equipment, on items in the canteen area, and on handles and buttons throughout the company.

**Conclusions:** Cobalt skin doses were prominent, and originated from contact with raw materials, sintered materials, and contaminated surfaces. Cobalt was present on surfaces outside production areas. Companies need to identify and reduce skin exposure for protection of workers.

**KEYWORDS**

cobalt skin dose, cobalt spot test, exposure, hard metal, ICP-MS, prevention

## 1 | INTRODUCTION

Cobalt is a potent skin sensitizer and a frequent cause of contact allergy. Studies have shown that the prevalence of contact allergy to cobalt has been high in workers (not patients) in some occupations, including cement workers (7%), dental technicians (12%), and hard metal workers (5%).<sup>1–3</sup> The prevalence of cobalt allergy is also higher among dermatitis patients with occupational dermatitis (9.3%) than among those with non-occupational dermatitis (6.8%), as shown in a study including 11 European countries.<sup>4</sup> Sources of exposure to cobalt have not been well studied in general, and it is often suggested that cobalt allergy may be explained by cross-reactivity to nickel or concomitant nickel exposure. The proportion of solitary cobalt allergy without nickel or chromate allergy has been approximately 40% to 50% in patch tested dermatitis patients, and approximately 60% in adolescents from the general population.<sup>5–8</sup> This indicates that a focus must be put on finding cobalt exposure sources.

Knowledge about skin doses of cobalt is essential for understanding the link between exposure and allergy. The patch test elicitation dose (ED) in cobalt allergy, tested with cobalt chloride in water, was studied by Fischer et al, and was found to be in the range of 0.067 to 1.95 µg Co/cm<sup>2</sup> for 10% of the patients (ED<sub>10</sub>).<sup>9</sup> In 1 of the studies included by Fischer et al, patch testing was also performed with hard metal discs that contained cobalt.<sup>10</sup> Hard metal discs, releasing various amounts of cobalt, were able to elicit an allergic reaction in cobalt-allergic patients, but not in controls.

Measurements of cobalt on skin, deposited by contact with metallic items and materials, have been performed in various occupational groups,<sup>11–14</sup> and have shown that skin doses frequently exceed the ED<sub>10</sub> value. In these studies, no information is available on how skin comes into contact with cobalt other than by direct handling of cobalt-containing items or materials.

Already in the 1980s, it was evident that contact allergy to cobalt was common among workers in hard metal (cemented tungsten

carbide) production.<sup>1</sup> Wide ranges of cobalt skin doses are still found in the hard metal industry, depending on the work area.<sup>14,15</sup> Assessment of surface contamination has been limited to work surfaces inside production areas of hard metal facilities.<sup>15</sup> Less evident, but potential, sources of skin exposure outside production areas have not been investigated. An applied approach to assess occupational skin exposure to cobalt, combining measurements of actual skin doses and the identification of cobalt exposure sources, would provide valuable information that could be used for prevention.

The aim of this study was to improve knowledge about skin doses and sources of skin exposure to cobalt within hard metal production, thereby facilitating better protection of workers. This was achieved by performing acid wipe sampling on fingers, and cobalt spot tests in the work environment of the participating hard metal workers.

## 2 | MATERIALS AND METHODS

### 2.1 | Study design and participants

Two hard metal production facilities of 1 company were visited for sampling in this study. At the 2 sites, the production areas, process equipment and work tasks were organized in a similar manner, giving comparable work exposure scenarios. After receiving information and giving their signed consent to participate, 40 workers took part in the study. Ethical approval was granted by the regional ethical review board in Stockholm, Sweden (dnr. 2012/1802-31/1).

Skin doses of cobalt were studied by acid wipe sampling, and cobalt contamination was investigated qualitatively by performing spot tests in the work environment of the participating hard metal workers. Sampling was performed for 2 weeks, 1 in May and 1 in August 2013. The workers were assigned to 4 exposure groups, depending on the work tasks performed. These were raw material workers, sintered material workers, final product workers, and office workers. The first 3 groups were considered to be exposed workers, and office workers constituted a non-exposed control group. Descriptive statistics for the study participants are shown in Table 1, and a schematic overview of the study is shown in Figure 1. Each worker answered a questionnaire to provide information about the work tasks performed, and the use of protective equipment on the study day (Table 1).

Statistical calculations of descriptive statistics, and group comparisons for skin doses by the use of Wilcoxon's rank-sum test, were performed with STATA version 14 (StatCorp, College Station, Texas).

**TABLE 1** Variables describing the characteristics of 40 workers, in 4 exposure groups in the hard metal industry

| Variable                       | Office     | Raw material | Sintered material | Final production |
|--------------------------------|------------|--------------|-------------------|------------------|
| Number of workers              | 8          | 14           | 7                 | 11               |
| Sex (male/female)              | 4:4        | 11:3         | 3:4               | 11:0             |
| Age (y), mean (range)          | 43 (31-61) | 38 (22-60)   | 42 (32-49)        | 40 (28-55)       |
| Glove use (Y/S/N) <sup>a</sup> | 0/0/8      | 9/5/0        | 1/4/2             | 2/6/3            |

<sup>a</sup> The question to hard metal workers was as follows: Did you wear gloves when performing the work tasks during the 2-hour period? (Yes/Sometimes/No).

Graphs were created and the Kruskal-Wallis test was performed with GRAPHPAD PRISM version 7.01 (GraphPad Software, La Jolla, California).

### 2.2 | Cobalt skin dose determined with acid wipe sampling

All plastic materials used for skin sampling and analysis were acid-cleaned prior to use, soaked in 10% HNO<sub>3</sub> for 24 hours, rinsed 4 times in deionized water, and dried in ambient air in the laboratory. Nitrile or vinyl gloves were used during all sampling and laboratory work to prevent contamination of samples.

To establish the amount of cobalt deposited on skin after a 2-hour work period, we used the acid wipe sampling technique.<sup>16</sup> In short, workers' hands were first washed with soap and water, then rinsed with 1% HNO<sub>3</sub>, and finally rinsed with deionized water. The little finger on the non-dominant hand was covered with an occlusive and waterproof band aid (6.5 × 5 cm; OPSITE Post-Op; Smith & Nephew, London, UK) to serve as a reference area, and to control the quality of skin cleaning. Immediately after this, workers performed normal work tasks for 2 hours (average 2.05 hours), without washing their hands, if possible. After these 2 hours, a surface of 2 cm<sup>2</sup> on the index finger (volar side, non-dominant hand) and the reference finger was sampled with 3 consecutive wipes moistened with 0.5 mL of 1% HNO<sub>3</sub>. The wipes from each surface were pooled and extracted in 23.5 mL of 1% HNO<sub>3</sub> prior to chemical analysis of the extract. The sampling area on the index finger was selected on the basis of previous observational studies, when sampling strategies were developed for skin exposure assessment.<sup>11,13</sup> Sampling of the non-dominant hand in the present study was chosen because of the observation that the cobalt-containing materials are mainly held with the non-dominant hand by these workers, while the dominant hand holds a tool for processing the material.

The cobalt content in the acid wipe samples was analysed with inductively coupled plasma mass spectrometry (iCAP Q; Thermo Fisher Scientific, Waltham, Massachusetts), according to the procedure described in Kettelarij et al.<sup>12</sup> Cobalt was monitored at mass 59; indium was used as an internal standard (5 µg/L) and monitored at mass 115. The limits of detection (3 times the SD of acid blank samples) for analysis of samples in 2 batches were 0.015 and 0.027 µg/L. All results were above the detection limit, except for 2 samples from office workers and 1 sample from a sintered material worker.

### 2.3 | Cobalt sources determined with spot testing

The main sources of cobalt exposure are the raw material powders and hard metal materials produced from them. To identify less evident cobalt sources for skin exposure, we used the cobalt spot test,<sup>17,18</sup> which is a qualitative test for the presence of cobalt. Each worker or work area (if multiple workers were situated in 1 area) was observed during the study day. Surfaces and items that were likely to come into contact with skin were spot tested. Spot tests were performed on a random selection of surfaces and items that workers came into contact with regularly, or where we, on the basis of our experience, suspected that cobalt might be present. In addition, surfaces and items were spot tested in common areas for all production workers, as well as in common areas for production and office workers, or work areas

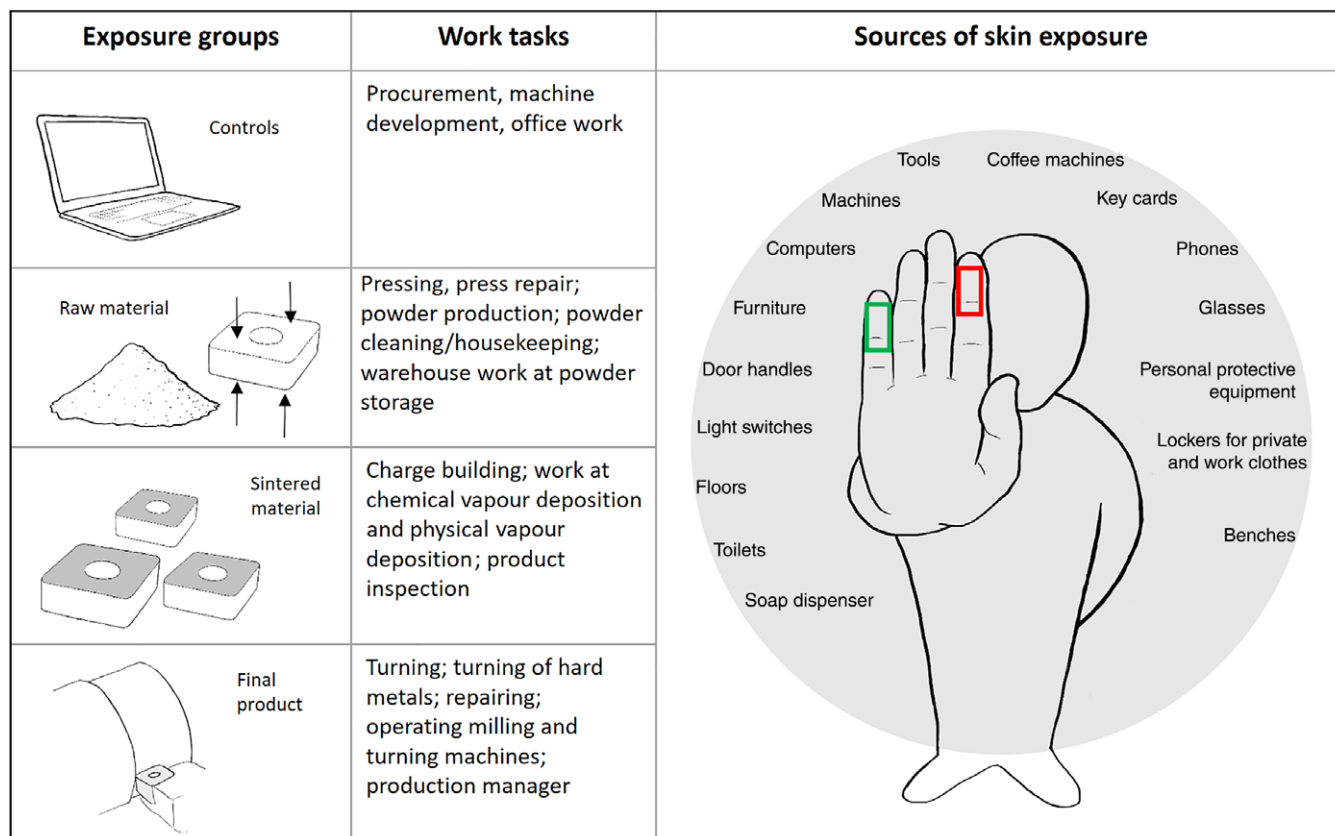


**FIGURE 1** Schematic overview of the study approach. Hard metal workers were divided into 4 exposure groups with different levels of cobalt exposure related to routine work tasks performed and the stage in the production process of hard metal tools. Office workers were used as a non-exposed control group. The skin dose of cobalt was quantified in wipe samples collected after 2 hours of work without hand washing, from the index fingers on the non-dominant hands of 40 workers. (The little finger on the same hand was cleaned and protected accordingly, in order to provide a reference sample.) Sources of skin exposure to cobalt were investigated in the work environment of each worker by the use of cobalt spot tests

of office workers alone. Migration of cobalt through the facility was visualized by spot testing of floors in common areas for production and office workers.

The spot test reagent solution was prepared in our laboratory according to procedures previously published by Midander et al.<sup>17</sup> After preparation, 50 µL of the cobalt spot test solution was pipetted into clean microtubes (1.5 mL; Sarstedt, Nümbrecht, Germany). For testing, a cotton swab (Critical Swab double cotton tip, paper handle, 76.2 mm; VWR International, Radnor, Pennsylvania) was dipped into the tube to absorb the clear yellow spot test solution, after which the swab was rubbed against a selected surface for 30 seconds. A positive test result was defined as an orange-red colour on the swab, a doubtful test result as any colour other than orange-red (possibly masking a colour change resulting from reaction with cobalt), and a negative test result as no colour change.<sup>17</sup>

### 3 | RESULTS

Median skin doses and corresponding ranges are shown in Table 2. Among the exposed groups, the highest skin doses, of up to 28 µg Co/cm<sup>2</sup>, were found in the group of raw material workers ( $n = 14$ ). The median cobalt skin dose was statistically significantly higher ( $P < .001$ ) for raw material workers than for sintered material workers ( $n = 7$ ) and office workers, but not final product workers ( $n = 11$ ). Median cobalt skin

doses on the fingers of office workers ( $n = 8$ ) after 2 hours of performing their normal work tasks were significantly lower ( $P \leq .01$ ) than in all other exposed groups, according to Wilcoxon's rank-sum test.

Cobalt on surfaces (not including main sources of cobalt) in different areas of the hard metal industry production facilities was assessed with the cobalt spot test on a total of 358 surfaces. We divided the tested surfaces and items into 8 categories for presentation of the results (Figure 2). Some categories contained items and surfaces from work areas or common areas in production alone (spot tests categorized as production equipment, personal work equipment, and changing

**TABLE 2** Cobalt skin exposure for 40 hard metal workers, expressed as median skin dose per cm<sup>2</sup>, after 2 hours (average 2.05 hours) of normal work without washing hands

| Exposure group    | <i>n</i> | Skin dose (µg/cm <sup>2</sup> ) <sup>a</sup><br>Median (minimum-maximum) |
|-------------------|----------|--------------------------------------------------------------------------|
| Office            | 8        | 0.011 (0.0019-0.047)*                                                    |
| Raw material      | 14       | 1.51 (0.25-28)**                                                         |
| Sintered material | 7        | 0.12 (0.024-9.0)                                                         |
| Final product     | 11       | 0.42 (0.017-24)                                                          |

<sup>a</sup> Skin doses of 2 office workers and 1 sintered material worker were below the limit of detection, and were not included in this range.

\*Median skin dose significantly lower ( $P \leq .01$ ) than the dose in all other groups (Wilcoxon's rank-sum test). \*\*Median skin dose significantly higher ( $P < .001$ ) than the dose in the office and sintered material group (Wilcoxon's rank-sum test).

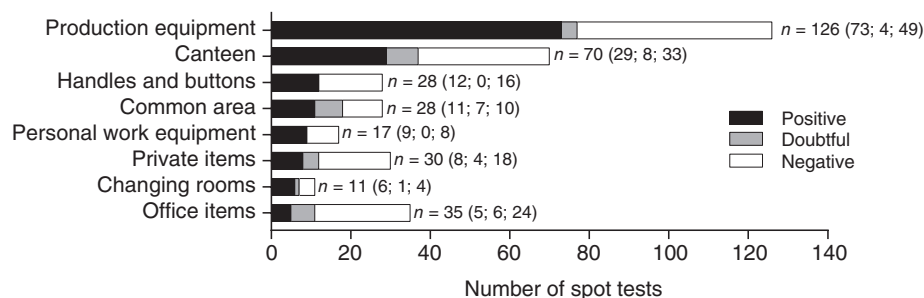


**FIGURE 2** Cobalt spot tests ( $N = 358$ ) to assess contamination with cobalt in different areas of the hard metal industry facilities: total (positive; doubtful; negative). Production equipment: for example, machines, tools, and computers. Canteen: for example, coffee machines and furniture. Handles and buttons: for example, door handles, light switches and soap dispensers in office and production areas. Common area: for example, toilets and floors in production and office areas. Personal work equipment: for example, safety goggles, insides of gloves, and key cards. Private items: for example, private telephones and glasses. Changing rooms: for example, lockers for private and work clothes, and benches. Office items: for example, computers and furniture in the office area

rooms), whereas other categories contained items and surfaces from office areas alone (categorized as office items), or from common areas for production and office workers together (categorized as canteen, handles and buttons, common area, and private items). To visualize migration of cobalt through the facility, spot tests of floors were performed and included in the category common area. Totals of 161 (45%) positive test results, 165 (46%) doubtful test results and 32 (9%) negative test results were found. The highest number of tests ( $n = 126$ ) was performed on production equipment, which also showed the highest proportion of positive test results (58%; Figure 2). The second largest number of tests ( $n = 70$ ) was performed in the canteen area, where both surfaces coming into contact with hands and items handled with hands were tested. In the canteen, 40% of the spot tested machine buttons and furniture were positive. Handles and buttons in other areas of the facilities were positive for cobalt (12 positive test results out of

28 tests performed). The categories with the highest proportions of negative test results were the office areas and private items, where 69% and 60% of all tests gave negative results, respectively.

As can be seen in Table 1, glove use on the study day differed between the groups of workers. Raw material workers used gloves during all or part of the 2-hour study period. Glove use within the groups of sintered material workers and final product workers varied considerably, with some of them not using gloves, and some using gloves all of the time. None of the office workers wore gloves. Figure 3 shows the difference in cobalt skin dose between production workers (excluding office workers) who wore gloves during the study period ("yes"), and those who wore gloves only during part of the 2-hour study period ("sometimes"), or not at all ("no"). The geometric means were  $0.44$ ,  $1.04$  and  $1.06 \mu\text{g}/\text{cm}^2$  for the "yes", "sometimes" and "no" groups, respectively, and did not differ significantly from each other ( $P = .59$ ; Kruskal-Wallis test).

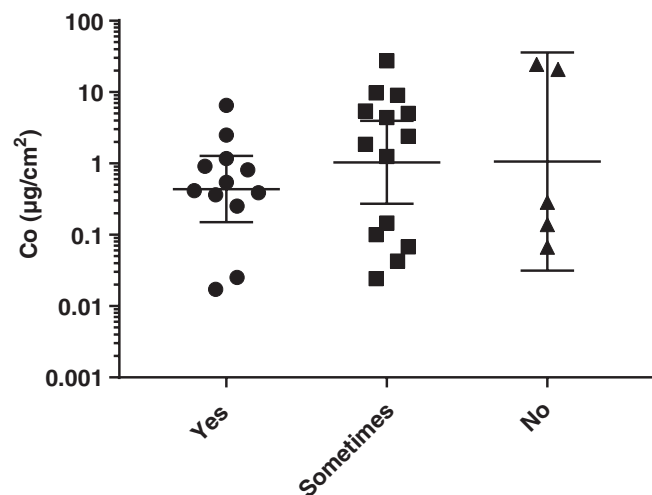


**FIGURE 3** Cobalt skin dose ( $\mu\text{g}/\text{cm}^2$ ) in workers normally wearing gloves (Yes), sometimes wearing gloves (Sometimes) or not wearing gloves (No) when performing the particular work task at 2-hour sampling. Skin dose is presented on a logarithmic scale to facilitate the visualization and interpretation of the result. Bars show the 95% confidence interval of the geometric mean. There is no statistically significant difference between the 3 groups as analysed with the Kruskal-Wallis test ( $P = .59$ ). Note: only production workers are included in this graph

## 4 | DISCUSSION

In this study, we simultaneously quantified skin doses of cobalt in workers and qualitatively assessed cobalt contamination on surfaces, which may be sources for skin exposure to cobalt in the hard metal industry. The results from the cobalt spot test show that cobalt is present in the entire work environment, and that even areas outside the production area are contaminated. In addition, the skin of hard metal production workers is heavily exposed to cobalt. The skin doses are highest among raw material workers, but high skin doses also occur among workers handling sintered material and final products. In addition, office workers show skin doses of cobalt indicative of exposure from diffuse sources of cobalt from contamination of the work environment.

The metal skin dose was measured after 2 hours of normal work tasks without hand washing. This sampling strategy was selected to enable the comparison with skin exposure to metals in other occupational exposure studies. We used a similar protocol to describe cobalt skin exposure in dental technicians, which was 10 times lower on average.<sup>12</sup> The amount of cobalt on skin in the hard metal industry was found to be higher than in the production of space propulsion

components and some other occupations.<sup>11,13</sup> It is not known to what extent our close observation of the workers during sampling and the fact that they did not wash their hands affected their habits and exposure as compared with their normal work habits and exposure.

In a recent study by Klasson et al, a study design similar to that of our study was used, but samples were collected from multiple areas on the hands after 2 hours of work without washing hands. They reported a median skin dose of cobalt based on all areas on the hand of 4.0  $\mu\text{g}/\text{cm}^2/2$  hours (range 0.09–200  $\mu\text{g}/\text{cm}^2$ ) for 62 participants. The highest skin doses were found in powder and pressing departments, with median values of 3 and 46  $\mu\text{g}/\text{cm}^2/2$  hours (range 1.8–22 and 0.88–200  $\mu\text{g}/\text{cm}^2$ ), respectively.<sup>14</sup> These observations are in line with our study of 40 workers, in which raw material workers had the highest skin doses after 2 hours, with a median of 1.51  $\mu\text{g}/\text{cm}^2$  and a range 0.25 to 28  $\mu\text{g}/\text{cm}^2$ . A study by Day et al reported skin exposure and surface contamination in a hard metal production facility, and showed that cobalt was transferred to skin from contaminated surfaces during routine work activities.<sup>15</sup> However, the results are not directly comparable with the results of our study, owing to different sampling methods, differences in glove use, and the fact that the workers were allowed to wash their hands in the study by Day et al.

Taken together, the available studies performed in the hard metal industry show that skin contamination is prevalent among hard metal workers and should be taken into consideration when health effects are discussed. For many workers, the levels found on skin are clearly higher than those shown to elicit allergic contact dermatitis in up to 50% of cobalt-allergic individuals by patch testing with cobalt chloride ( $\text{ED}_{50}$ ).<sup>9</sup> However, such elicitation doses are not directly comparable with the amounts deposited onto the skin by contact with solid materials and cobalt powder, because it is not known how much of the cobalt is available for skin absorption in either situation. However, it has been shown by patch testing that hard metal alloys are able to elicit allergic contact dermatitis.<sup>10</sup>

No study has, to the best of our knowledge, investigated the prevalence of cobalt allergy or hand eczema among hard metal workers since the 1980s.<sup>1</sup> A limitation of the current study is that we did not investigate this prevalence either. This was, however, outside the scope of the study. It should also be mentioned that a healthy worker effect could be expected, owing to the company policy of patch testing workers with suspected cobalt allergy and moving them to different work areas if necessary.

The main strength of this study is that we combined measurement of the skin doses of cobalt with qualitative evaluation of its less evident sources, which required a close interaction with the hard metal workers. Furthermore, this approach created an increased awareness and understanding of cobalt skin exposure among the participating workers, healthcare services, and management.

Skin doses of cobalt turned out to be high for many of the raw material workers, despite the fact that all of these workers declared having worn gloves during the complete 2-hour study period or during parts of it. Similar results were obtained in the study by Day et al.<sup>15</sup> Furthermore, the frequency of glove use among sintered material and final product workers varied widely. In some cases, gloves were used to protect the materials that were worked with, rather than to protect

the skin. Production workers in our study mainly wore reusable leather or textile gloves. Disposable vinyl or nitrile gloves were occasionally used for changing powder drums or performing work tasks involving liquids. Possible contamination of the inside of reusable gloves was not examined. Improved awareness of exposure sources and guidelines on proper glove use could improve the situation.

Day et al showed that contamination of work surfaces inside hard metal production areas is widespread.<sup>15</sup> Those results correspond with the spot test results from our study. Even though the cobalt spot test is indicative, and does not correspond directly to a released surface area concentration in  $\mu\text{g}/\text{cm}^2$ , it showed that cobalt was present on surfaces throughout the facilities. As we were actively looking for cobalt-contaminated surfaces expected to come into contact with skin, the frequency of positive spot test results is probably not representative of all surfaces in the facilities. The cobalt spot test has not previously been used to systematically track sources of cobalt contamination in industrial settings, but rather to investigate cobalt release from jewellery, laptop computers, and toys, and in clinical cases with suspected occupational exposure.<sup>19–23</sup> Our use of the cobalt spot test proved it to be a valuable indicative tool showing that skin may be contaminated from multiple sources, not only the production materials. To what extent contact with the cobalt-contaminated surfaces may contribute to the skin dose of cobalt, and therefore to possible sensitization or elicitation of cobalt allergy, is not known.

Contamination of tools, facilities and skin by skin-sensitizing materials is not always obvious or visible, and has rarely been mapped or quantified. This may be performed by observation or interviews, as was done in studies of epoxy pipe relining.<sup>24,25</sup> Correspondingly, methods to visualize and quantify contamination by skin-sensitizing metals are available. Examining contamination by hazardous substances is essential to identify and reduce exposure, and prevent disease in the workplace.

Our results show that there is a need for improvement, indicating that, to protect workers, routines should be implemented regarding changing of work clothes, improved skin care, including hand-washing routines before entering lunch rooms, and the correct use of gloves that will protect workers' skin and not only the produced items. In a recent publication by the Nordic Expert Group, possibilities are discussed for further legislative actions regarding skin exposure in general and in occupational settings.<sup>26</sup> In the report, it is suggested that regulation should be introduced in order to reduce skin exposure to hazardous chemicals at the workplace, including: biological limit values, skin notations as warnings for skin absorption and sensitization, and restrictions on occupational use.

## 5 | CONCLUSIONS

Skin doses of cobalt in the hard metal industry are prominent, and do not only originate from contact with raw materials. Skin contact with sintered materials, which has so far been considered to be safe by the industry, has been shown to give rise to cobalt on skin at levels that are able to elicit allergic contact dermatitis. It has also been shown, by use of the cobalt spot test, that cobalt is found in many areas even

outside of the production areas. Potential skin exposure resulting from touching such contaminated surfaces should be considered both in preventive work and in clinical practice.

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## Conflict of interest

The authors declare no potential conflict of interests.

## ORCID

Jolinde Kettelarij  <http://orcid.org/0000-0001-5121-9422>

Klara Midander  <http://orcid.org/0000-0002-7160-4640>

Carola Lidén  <http://orcid.org/0000-0001-9951-5896>

Anneli Julander  <http://orcid.org/0000-0003-2131-4896>

## REFERENCES

1. Fischer T, Rystedt I. Cobalt allergy in hard metal workers. *Contact Dermatitis*. 1983;9:115-121.
2. Lee JY, Yoo JM, Cho BK, Kim HO. Contact dermatitis in Korean dental technicians. *Contact Dermatitis*. 2001;45:13-16.
3. Wang BJ, Wu JD, Sheu SC, et al. Occupational hand dermatitis among cement workers in Taiwan. *J Formos Med Assoc*. 2011;110:775-779.
4. Pesonen M, Jolanki R, Larese Filon F, et al. Patch test results of the European baseline series among patients with occupational contact dermatitis across Europe—analyses of the European Surveillance System on Contact Allergy network, 2002–2010. *Contact Dermatitis*. 2015;72:154-163.
5. Hegewald J, Uter W, Pfahlberg A, Geier J, Schnuch A, the IVDK. A multifactorial analysis of concurrent patch-test reactions to nickel, cobalt, and chromate. *Allergy*. 2005;60:372-378.
6. Lidén C, Andersson N, Julander A, Matura M. Cobalt allergy: suitable test concentration, and concomitant reactivity to nickel and chromium. *Contact Dermatitis*. 2016;74:360-367.
7. Lagrelus M, Wahlgren CF, Matura M, Kull I, Lidén C. High prevalence of contact allergy in adolescence: results from the population-based BAMSE birth cohort. *Contact Dermatitis*. 2016;74:44-51.
8. Uter W, Gefeller O, Geier J, Schnuch A. Contact sensitization to cobalt—multifactorial analysis of risk factors based on long-term data of the Information Network of Departments of Dermatology. *Contact Dermatitis*. 2014;71:326-337.
9. Fischer LA, Johansen JD, Voelund A, et al. Elicitation threshold of cobalt chloride: analysis of patch test dose-response studies. *Contact Dermatitis*. 2016;74:105-109.
10. Julander A, Hindsén M, Skare L, Lidén C. Cobalt-containing alloys and their ability to release cobalt and cause dermatitis. *Contact Dermatitis*. 2009;60:165-170.
11. Julander A, Skare L, Mulder M, Grandér M, Vahter M, Lidén C. Skin deposition of nickel, cobalt, and chromium in production of gas turbines and space propulsion components. *Ann Occup Hyg*. 2010;54:340-350.
12. Kettelarij J, Nilsson S, Midander K, Lidén C, Julander A. Snapshot of cobalt, chromium and nickel exposure in dental technicians. *Contact Dermatitis*. 2016;75:370-377.
13. Lidén C, Skare L, Nise G, Vahter M. Deposition of nickel, chromium, and cobalt on the skin in some occupations—assessment by acid wipe sampling. *Contact Dermatitis*. 2008;58:347-354.
14. Klasson M, Lindberg M, Bryngelsson IL, et al. Biological monitoring of dermal and air exposure to cobalt at a Swedish hard metal production plant: does dermal exposure contribute to uptake? *Contact Dermatitis*. 2017;77:201-207.
15. Day GA, Virji MA, Stefaniak AB. Characterization of exposures among cemented tungsten carbide workers. Part II: Assessment of surface contamination and skin exposures to cobalt, chromium and nickel. *J Expo Sci Environ Epidemiol*. 2009;19:423-434.
16. Lidén C, Skare L, Lind B, et al. Assessment of skin exposure to nickel, chromium and cobalt by acid wipe sampling and ICP-MS. *Contact Dermatitis*. 2006;54:233-238.
17. Midander K, Julander A, Skare L, Thyssen JP, Lidén C. The cobalt spot test—further insights into its performance and use. *Contact Dermatitis*. 2013;69:280-287.
18. Thyssen JP, Menné T, Johansen JD, et al. A spot test for detection of cobalt release—early experience and findings. *Contact Dermatitis*. 2010;63:63-69.
19. Thyssen JP, Jellesen MS, Menné T, et al. Cobalt release from inexpensive jewellery: has the use of cobalt replaced nickel following regulatory intervention? *Contact Dermatitis*. 2010;63:70-76.
20. Midander K, Hurtig A, Borg Tornberg A, Julander A. Allergy risks with laptop computers—nickel and cobalt release. *Contact Dermatitis*. 2016;74:353-359.
21. Jensen P, Hamann D, Hamann CR, Jellesen MS, Jacob SE, Thyssen JP. Nickel and cobalt release from children's toys purchased in Denmark and the United States. *Dermatitis*. 2014;25:356-365.
22. Bregnbak D, Zachariae C, Thyssen JP. Occupational exposure to metallic cobalt in a baker. *Contact Dermatitis*. 2015;72:118-119.
23. Thyssen JP, Johansen JD, Jellesen MS, Menné T. Cobalt spot test used for diagnosis of occupationally-related exposure to cobalt-containing powder. *Contact Dermatitis*. 2012;66:228-229.
24. Anveden Berglind I, Lind ML, Lidén C. Epoxy pipe relining—an emerging contact allergy risk for workers. *Contact Dermatitis*. 2012;67:59-65.
25. Fillenham G, Lidén C, Anveden Berglind I. Skin exposure to epoxy in the pipe relining trade—an observational study. *Contact Dermatitis*. 2012;67:66-72.
26. Julander A, Boman A, Johanson G, Lidén C. The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals. 151. Occupational skin exposure to chemicals. With focus on skin exposure assessment, skin sensitisation and prevention by exposure reduction. *Arbete och Hälsa*. 2018;52(3):1-69.

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