

Deposition of nickel, chromium, and cobalt on the skin in some occupations – assessment by acid wipe sampling

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Background: Nickel, chromium, and cobalt are important skin sensitizers. Better knowledge about skin exposure is needed for more efficient prevention. We have previously developed acid wipe sampling for assessment of skin exposure to metals.

Objectives: To apply the acid wipe sampling technique in some occupations where intense contact with metallic items occurs and to gather experience for the design of future workplace studies.

Methods: 18 volunteers (carpenters, locksmiths, cashiers, and secretaries as controls) participated. They performed their normal tasks during a job session for exposure. Samples were taken from fingers and palms by acid wipe sampling, and analysis of metals was performed by inductively coupled plasma mass spectrometer.

Results: The metals were detected in all samples, and the amount of nickel was larger than that of chromium and cobalt. Fingers were more exposed than palms. 8-h exposure to nickel was calculated and was highest in locksmiths (mean 3.784 µg/cm², range 1.846–5.028 µg/cm²) followed by carpenters, cashiers, and secretaries.

Conclusions: The acid wipe sampling technique is suitable for studies of skin exposure to nickel, chromium, and cobalt in the workplace. The sampling efficiency of acid wipe sampling is high. The amounts of nickel deposited on skin in carpenters, locksmiths, and cashiers are judged capable of eliciting allergic contact dermatitis.

Key words: acid wipe sampling; allergic contact dermatitis; chemical analysis; chromium; cobalt; ICP-MS; nickel; occupational exposure; skin exposure assessment. © Blackwell Munksgaard, 2008.

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Nickel is still the most frequent cause of contact allergy in the general population and in dermatitis patients. Chromium and cobalt are also frequent causes of skin sensitization. It is well established that consumer items such as jewellery, buttons, zippers, etc. have been major causes of sensitization to nickel and allergic contact dermatitis and that nickel-sensitive individuals often develop hand eczema. The significance of skin exposure to nickel in the occupational setting has, however, been less well explored. As to occupational skin exposure to other metals, chromium (Cr 6+) in cement has been the major cause of sensitization

to chromium, affecting mainly male construction workers, but little is known about the major sources of sensitization to cobalt, other than in the hard metal and ceramics industries. Cobalt may be present at low level in nickel alloys, consumer products, and cement, but much remains to be known to explain why cobalt is a relatively frequent skin sensitizer in dermatitis patients and the general population. The regulations by EU directives of nickel release from consumer items and of chromium in cement will alter the scene. It is obvious, however, that other sources of exposure remain, causing sensitization and allergic

contact dermatitis to nickel, chromium, and cobalt. For reviews, see refs. (1–4).

Knowledge is increasing concerning dose–response relationships in contact allergy to metals and metal content in, or release from, jewellery, coins, tools, cosmetics, and detergents (1, 5–12). Little is known, however, about the amount of nickel, chromium, and cobalt deposited on the skin in workers and consumers. Better knowledge about skin exposure conditions is needed for more efficient prevention of contact dermatitis.

Methods for assessment of exposure to chemicals and particles by inhalation are applied in occupational and environmental medicine, while assessment of exposure to skin sensitizers, irritants, particles, and toxic substances by skin contact is a new field of research gaining increasing interest (13–21). We have developed a method for assessment of skin exposure to nickel, chromium, and cobalt by acid wipe sampling and analysis by inductively coupled plasma mass spectrometer (ICP-MS) (22). The sampling efficiency by acid wipe sampling is high, and the analytical result is expressed in terms of mass per unit area ($\mu\text{g}/\text{cm}^2$), which is the most relevant in studies of exposure to contact allergens.

The aim of the present study was to apply the acid wipe sampling technique in some occupations where intense contact with metallic items occurs and to gather experience for the design of future workplace studies, characterization of occupational exposure, risk assessment, and follow-up of risk management for harm reduction.

Materials and Methods

A method for assessment of skin exposure to nickel, chromium, and cobalt by acid wipe sampling, which we have developed and described in detail (22), was used. Sampling recovery by the acid wipe sampling method had been shown to be 93% for nickel, chromium, and cobalt. An overview of the method and selected details applied in the present study are given below.

Subjects

18 volunteers (10 females and 8 males) participated in the study (Table 1). They were employed as carpenter ($n = 4$), locksmith ($n = 3$), cashier ($n = 7$), and secretary ($n = 4$). These occupations were chosen as workers are known to have frequent or

Table 1. Description of workers and their activities during the job session for assessment of skin exposure to nickel, chromium, and cobalt by acid wipe sampling and analysis by inductively coupled plasma mass spectrometer

Subject	Sex (M/F)	Job title	Branch	Activities during job session for exposure				
				Handling metallic objects		No obvious metal handling		All tasks
				Activity; contact	Duration (min)	Activity	Duration (min)	
A	M	Carpenter	Real estate maintenance	Maintenance; tools	30	Office work	120	150
B	M	Carpenter	Real estate maintenance	Joinery work; tools	15	Mixed tasks	135	150
C	M	Carpenter	Real estate maintenance	Joinery work; tools	80	Mixed tasks	85	165
D	M	Carpenter	Real estate maintenance	Upholstering chairs; tools	180	—	0	180
E	F	Locksmith	Real estate maintenance	Turning keys	60	Mixed tasks and break	60	120
F	M	Locksmith	Real estate maintenance	Mounting locks; locks, keys, and tools	120	—	0	120
G	M	Locksmith	Hardware retailing	Mounting locks; locks, keys, and tools	110	—	0	110
H	F	Cashier	Restaurants	Cash-desk work; coins	175	Mixed tasks	5	180
I	F	Cashier	Retail trade	Cash-desk work; coins	65	Unpacking goods and break	55	120
J	M	Cashier	Retail trade	Cash-desk work; coins	60	Unpacking goods	60	120
K	F	Cashier	Retail trade	Cash-desk work; coins	120	Unpacking goods, wearing gloves, and break	65	185
L	M	Cashier	Retail trade	Counting cash; coins	10	—	0	10
M	F	Cashier	Retail trade	Cash-desk work; coins	90	Unpacking goods	30	120
N	F	Cashier	Retail trade	Cash-desk work; coins	105	Office work	15	120
O	F	Secretary	Medical health service	—	0	Office work	60	60
P	F	Secretary	Medical health service	—	0	Office work	60	60
Q	F	Secretary	Medical health service	—	0	Office work	60	60
R	F	Secretary	Medical health service	—	0	Office work	60	60
All					1220		870	2090

intense contact with metallic items, of which some are made of materials with high nickel release (2, 8, 11, 23); carpenters' handling tools, locksmiths' tooling and mounting keys and locks, and cashiers' handling coins. Secretaries with office work were included as control group. The participants had no history suggesting contact allergy to metals and no ongoing dermatitis or other skin lesion on their hands or forearms. They were all right handed and regarded their rate of hand sweating as normal.

Chemicals

Nickel, chromium, cobalt, rhodium, and lutetium were used as reference chemicals in the analytical procedure, described in detail separately (22).

Nitric acid 65% (p.a., max. 0.020 ng/ml Ni, 0.020 ng/ml Cr, and 0.010 ng/ml Co, respectively; Merck KGaA, Darmstadt, Germany) was diluted to 1% with deionized water. The 1% nitric acid was used for all further dilutions and also for cleaning and sampling and in the analytical procedure.

Equipment

The analytical instrument was an ICP-MS (ELEMENT 1, Thermo Finnigan; Finnigan MAT, Bremen, Germany) equipped with ASX 500 Autosampler (CETAC Technologies Inc., Omaha, NE, USA).

Acid-cleaned polypropylene test-tubes and containers (Sarstedt, Landskrona, Sweden), checked to be metal free, were used for all reagents, diluents, and samples. Cellulose wipes (injection wipes by Paper-Pak Sweden AB, Sundbyberg, Sweden) were used for acid wipe sampling. To obtain a handy size (16–22 cm² each), the wipes were divided into 2 parts by tearing them apart before use and in the following, such a part is referred to as 'a wipe'. A marking pen with red ink (Lumocolor[®] permanent universal pen F 318-2; Mars GmbH & Co. KG, Nürnberg, Germany) was used to indicate the corners of the sampling area as shown by plastic foil template apertures. Vinyl protective gloves were used by the operator during sampling and preparatory work. The materials used for sampling from the skin surface were analysed for potential release of nickel, chromium, and cobalt by extracting with 1% nitric acid overnight. Measurement of the solution showed 2.2 ng/ml nickel, 0.29 ng/ml chromium, and 0.14 ng/ml cobalt, which is well below the concentrations obtained in the samples from the skin surface.

Washing skin prior to exposure

Before the job session for skin exposure started, the subjects washed their hands with soap and

water and dried them with paper towels. The hands were then wiped carefully with wipes soaked with 1% nitric acid, followed by rinsing with deionized water and drying with paper towels by the operator. One finger (little finger on right hand) was then covered by a cut-off cotton-glove finger and protected by a cut-off vinyl-glove finger and fixed with tape to serve as non-exposed control area at sampling and for quality control of the cleansing before exposure.

Exposure by regular work

The subjects performed their normal tasks during the job session for exposure (Table 1), such as handling of metal items typical for their respective occupation (e.g. tools, screws, and nails by carpenters; keys, locks, handles, and tools by locksmiths; coins by cashiers; and office equipment by secretaries). The items and surfaces handled by the subjects were not pre-washed with nitric acid or other solvent before exposure.

We did not interfere with the work performed by the subjects, other than by the washing before and sampling after the job session for exposure. The operator observed the subjects during the session and recorded tasks performed and the time for each task. The duration of the job session varied depending on what was possible or convenient for each worker.

Sampling from skin surface

The sampling procedure for skin exposure was initiated immediately after each job session. Areas for sampling (2 cm² on volar finger tips and 7.5 cm² on palms) were marked by indicating the corners of a template. In all, 9 areas were marked for each subject: the thumb, index finger, middle finger, and palm of each hand and the little finger of the right hand.

Wipes, moistened by 0.5 ml 1% nitric acid, were used for sampling of metals deposited on the skin. Each demarcated area was wiped applying gentle pressure by 3 passes over the surface per wipe and using 3 consecutive wipes. The wipes from each area were pooled in the same container, and 23.5 ml 1% nitric acid was added for extraction of metals.

To extract the metals from the wipes, the containers with the wipes in nitric acid were shaken for 30 min. The sample solutions were then transferred from their containers to separate test-tubes for analysis of metal content. The samples were stored at approximately 8° C for up to 14 days, which, according to our previous experience, does not affect the analytical result.

Chemical analysis by ICP-MS

Quantitative analysis of nickel, chromium, and cobalt in the acid extracts of wipes was performed by ICP-MS as previously described in detail (22). The work was carried out in clean room facilities in our laboratory at the Institute of Environmental Medicine, Karolinska Institutet. Sample extracts and standard solutions were prepared and analysed as described.

Ethics

The study was approved by the ethical committee (KI Nord at Karolinska Hospital, Stockholm, Sweden). All subjects gave their informed consent.

Results

The tasks performed by the subjects during the job sessions and the duration are shown in Table 1. The job sessions lasted from 10 min up to 180 min (mean 116 min) depending on what was convenient in each case. The tasks were characterized roughly as job-specific tasks with handling of metallic objects and as other tasks with no obvious handling of metallic objects. The group of secretaries was included in the study as a low-exposed control group, and their job sessions were classified as 'no obvious handling of metallic objects', which was confirmed also by observation.

A total of 162 samples were collected by the acid wipe sampling technique from the hands of 18 subjects and analysed by ICP-MS. The results are shown in Tables 2–4 and Fig. 1.

Nickel, chromium, and cobalt were detected in all samples. In all samples, the amounts of nickel were substantially larger than those of chromium and cobalt. The amount of nickel deposits ($\mu\text{g}/\text{cm}^2$) in all subjects and all areas is shown in Table 2. The largest amounts of nickel were found on fingers of both hands of the locksmiths, with the highest value from the left thumb in subject F ($1.257 \mu\text{g}/\text{cm}^2$). The mean value and range of nickel, chromium, and cobalt deposited in each occupational group are shown in Table 3, and values are adjusted for duration of work. The locksmiths had the largest amount of both nickel and chromium on their hands as shown by the mean values of all samples (nickel $0.358 \mu\text{g}/\text{cm}^2/\text{h}$ and chromium $0.045 \mu\text{g}/\text{cm}^2/\text{h}$). The amount of cobalt was much smaller in all groups; mean value in the carpenters, locksmiths, and cashiers is $0.002 \mu\text{g}/\text{cm}^2/\text{h}$.

Values for potential exposure from 8-h work were calculated to facilitate comparison of deposition of nickel on hands between subjects and between occupational groups. The calculation

was based on the measured values and assuming that the deposited amounts were not reduced by washing off, abrasion, absorption, or evaporation (Table 4; Fig. 1). Nickel was deposited on the hands of locksmiths, carpenters, and cashiers and to a much lower degree in secretaries. The 3 locksmiths had the highest nickel dose on their hands. They were exposed almost equally on fingers of both hands, while the other groups were exposed much more on fingers of the right hand than on the left. Palms were generally exposed to a much lower degree than the fingers. An exception was one of the cashiers (subject L) who had counted the cash by intense handling of coins for 10 min, a task he had not performed during a whole working day.

In 8 of the subjects (44%), the largest amount of nickel was found on the right thumb. Samples from the right thumb, index finger, and middle finger and the left thumb covered together 100% of the samples with the highest concentration in each individual. The calculated amount of nickel deposited in 8 h on these 4 fingers, by occupational group, is shown in Table 4.

Discussion

The present study demonstrates that the acid wipe sampling technique (22) performs well and is suitable for studies in the workplace where contact with metallic items occurs under dry conditions. The method was developed by us for assessment of nickel, chromium, and cobalt deposited on the skin, and this is the first study where it was applied outside the laboratory to gain experience for further application. We have applied the acid wipe sampling technique also in studies under standardized exposure conditions of coin handling and in a workplace where cobalt-containing materials are handled. These studies will be reported separately (C. Lidén, L. Skare and M. Vahter, Karolinska Institutet and Stockholm Centre for Public Health, Stockholm, Sweden, unpublished results; A. Julander, L. Skare, M. Mulder, M. Vahter, C. Lidén, Karolinska Institutet and Stockholm Centre for Public Health, Stockholm, Sweden, unpublished results). It will be of interest to apply the technique also in occupations where wet work is frequent, such as work with cutting fluids and plating.

The amount of nickel, chromium, or cobalt deposited onto the skin in different occupations has not, to the best of our knowledge, been studied previously, with the exception of a few studies of nickel exposure (24, 25). The present study shows that not only nickel but also chromium and cobalt are deposited onto the skin in carpenters, locksmiths, and cashiers and to a much lesser degree

Table 2. Amount of nickel deposited on the skin ($\mu\text{g}/\text{cm}^2$) as shown by acid wipe sampling and analysis by inductively coupled plasma mass spectrometer^a

Job title and subjects	Nickel in sample per area (µg/cm ²)								Non-exposed control area ^b	Duration of work for exposure (min) ^c
	Left hand				Right hand					
	Thumb	Index finger	Middle finger	Palm	Thumb	Index finger	Middle finger	Palm		
Carpenter										
A	0.142	0.200	0.206	0.025	0.211	0.092	0.261	0.074	0.002	150
B	0.143	0.116	0.101	0.031	0.254	0.200	0.115	0.045	−0.003	150
C	0.570	0.228	0.256	0.059	0.548	0.376	0.263	0.075	0.009	165
D	0.186	0.157	0.159	0.057	0.900	0.334	0.213	0.105	0.005	180
Locksmith										
E	1.022	0.877	0.815	0.170	1.208	0.730	1.046	0.320	0.025	120
F	1.257	0.934	0.762	0.116	0.830	0.969	0.840	0.105	0.071	120
G	1.109	0.759	0.593	0.119	0.872	0.759	0.423	0.110	0.180 ^d	110
Cashier										
H	0.076	0.079	0.134	0.031	0.379	0.421	0.399	0.140	0.008	180
I	0.032	0.019	0.017	0.005	0.207	0.090	0.043	0.013	0.024	120
J	0.230	0.236	0.174	0.033	0.236	0.159	0.148	0.025	0.006	120
K	0.324	0.242	0.249	0.027	0.735	0.592	0.825	0.069	0.009	185
L	0.047	0.039	0.036	0.106	0.345	0.242	0.203	0.043	0.052	10
M	0.041	0.062	0.045	0.016	0.177	0.131	0.136	0.021	0.000	120
N	0.111	0.084	0.070	0.041	0.240	0.254	0.321	0.088	0.014	120
Secretary										
O	0.013	0.012	0.011	0.003	0.015	0.012	0.017	0.003	0.008	60
P	0.018	0.017	0.019	0.005	0.043	0.031	0.029	0.008	0.009	60
Q	0.013	0.011	0.012	0.003	0.017	0.021	0.017	0.006	0.008	60
R	0.045	0.037	0.029	0.010	0.029	0.030	0.030	0.016	0.038	60

^aSamples were taken from 8 exposed areas on hands (thumb, index finger, middle finger, and palm of each hand) in 18 workers (carpenters, locksmiths, cashiers, and secretaries) after 10–180 min of work not adjusted for duration of work. Number of samples: total, 162; from exposed areas, 144; from non-exposed control areas, 18. Limit of detection (LOD) of the analytical instrument: nickel 0.15 ppb, chromium 0.07 ppb, and cobalt 0.04 ppb; LOD of the method: nickel 2.77 ppb, chromium 0.15 ppb, and cobalt 0.10 ppb.

^bNon-exposed control areas: covered little finger; mean value: 0.017 $\mu\text{g}/\text{cm}^2$ not including subject G.

^cMean duration of work for exposure: 116 min.

^dThe control area in G had not been adequately cleaned before exposure.

in secretaries doing office work (Tables 2–4; Fig. 1). The amount of cobalt was low compared with that of other metals. Because the recovery by acid wipe sampling is equally high (93%) for nickel, chromium, and cobalt (22), it can be concluded that release of cobalt from items handled in the present study was limited. In another study, we have detected high levels of cobalt on the skin when known cobalt-containing items were handled (A. Julander, L. Skare, M. Mulder, M. Vahter, C. Lidén, Karolinska Institutet and Stockholm

Centre for Public Health, Stockholm, Sweden, unpublished results).

The amounts of nickel, chromium, and cobalt measured should be considered minimum amounts. We do not know to what extent metallic particles of different composition, which may be present on the skin surface, are dissolved in 1% nitric acid at room temperature. The results do not allow for drawing conclusions about exposure levels or risks in the studied occupations because the number of subjects was small. Still, the results

Table 3. Amounts of nickel, chromium, and cobalt deposited on the skin as shown by acid wipe sampling and analysis by inductively coupled plasma mass spectrometer for comparison between occupational groups and metals^a

Number of workers in different occupations (number of samples)	Amount of metals deposited in 1 h ($\mu\text{g}/\text{cm}^2$) (samples from 8 areas on hands)		
	Nickel, mean (range)	Chromium, mean (range)	Cobalt, mean (range)
4 carpenters ($n = 32$)	0.077 (0.010–0.300)	0.007 (0.001–0.018)	0.002 (0.0002–0.004)
3 locksmiths ($n = 24$)	0.358 (0.053–0.629)	0.045 (0.004–0.146)	0.002 (0.0002–0.003)
7 cashiers ($n = 56$)	0.200 (0.005–2.070)	0.003 (0.0002–0.018)	0.002 (0.0000–0.011)
4 secretaries ($n = 32$)	0.018 (0.003–0.045)	0.002 (0.001–0.004)	0.001 (0.0000–0.001)

^aSamples were taken from 8 exposed areas on hands (thumb, index finger, middle finger, and palm of each hand) in 18 workers (carpenters, locksmiths, cashiers, and secretaries) after 10–180 min of work for exposure. Mean value and range of all samples from each occupational group adjusted for duration of work. Limit of detection (LOD) of the analytical instrument: nickel 0.15 ppb, chromium 0.07 ppb, and cobalt 0.04 ppb; LOD of the method: nickel 2.77 ppb, chromium 0.15 ppb, and cobalt 0.10 ppb.

Table 4. Calculated amount of nickel deposited in 8 h in 18 workers (carpenters, locksmiths, cashiers, and secretaries)^a

Number of workers in different occupations (number of samples)	Nickel deposited in 8 h ($\mu\text{g}/\text{cm}^2$)	
	Mean (samples from 4 fingers in each subject)	Range
4 carpenters ($n = 16$)	0.875	0.294–2.401
3 locksmiths ($n = 12$)	3.784	1.846–5.028
7 cashiers ($n = 28$)	2.151	0.128–16.560
6 cashiers ($n = 24$) ^b	0.835	0.128–2.141
4 secretaries ($n = 16$)	0.190	0.096–0.360

^aSamples were taken by acid wipe sampling after 10–180 min of work for exposure. Mean value and range of samples from the 4 most exposed fingers (right thumb, index finger, and middle finger and left thumb) by occupational group adjusted for duration of work. Analysis by inductively coupled plasma mass spectrometer.

^bSubject L excluded, exposure 10 min by cash counting.

indicated by far the highest exposure values among the locksmiths.

It has been assumed by metallurgists that transient contact with allergenic metals in massive form generally is too short to cause ionization and release of the metals and that prolonged

contact is needed to cause allergic contact dermatitis (23). The present study clearly shows that frequently repeated contact of short duration with copper–nickel coins (1 SEK and 5 SEK) in cashiers results in deposition of substantial amounts of nickel on the skin (Tables 2–4; Fig. 1). This has been shown also by others (7, 24, 25).

The duration of contact with metallic items was somewhat longer in carpenters and locksmiths compared with cashiers, and this contact is often under pressure and friction. The present study shows that handling of tools by carpenters results in deposition of nickel and chromium onto the skin (Tables 2–4; Fig. 1). This supports the clinical relevance of our previous finding that 27% of hand-held tools gave a positive dimethylglyoxime test and that tools released nickel and chromium when stored in synthetic sweat (11). Locksmiths had the largest amount of nickel on the skin of both hands (Tables 2–4; Fig. 1) probably because of their intense handling by both hands at turning keys and mounting locks and other items, which often are made of alloys and platings with high

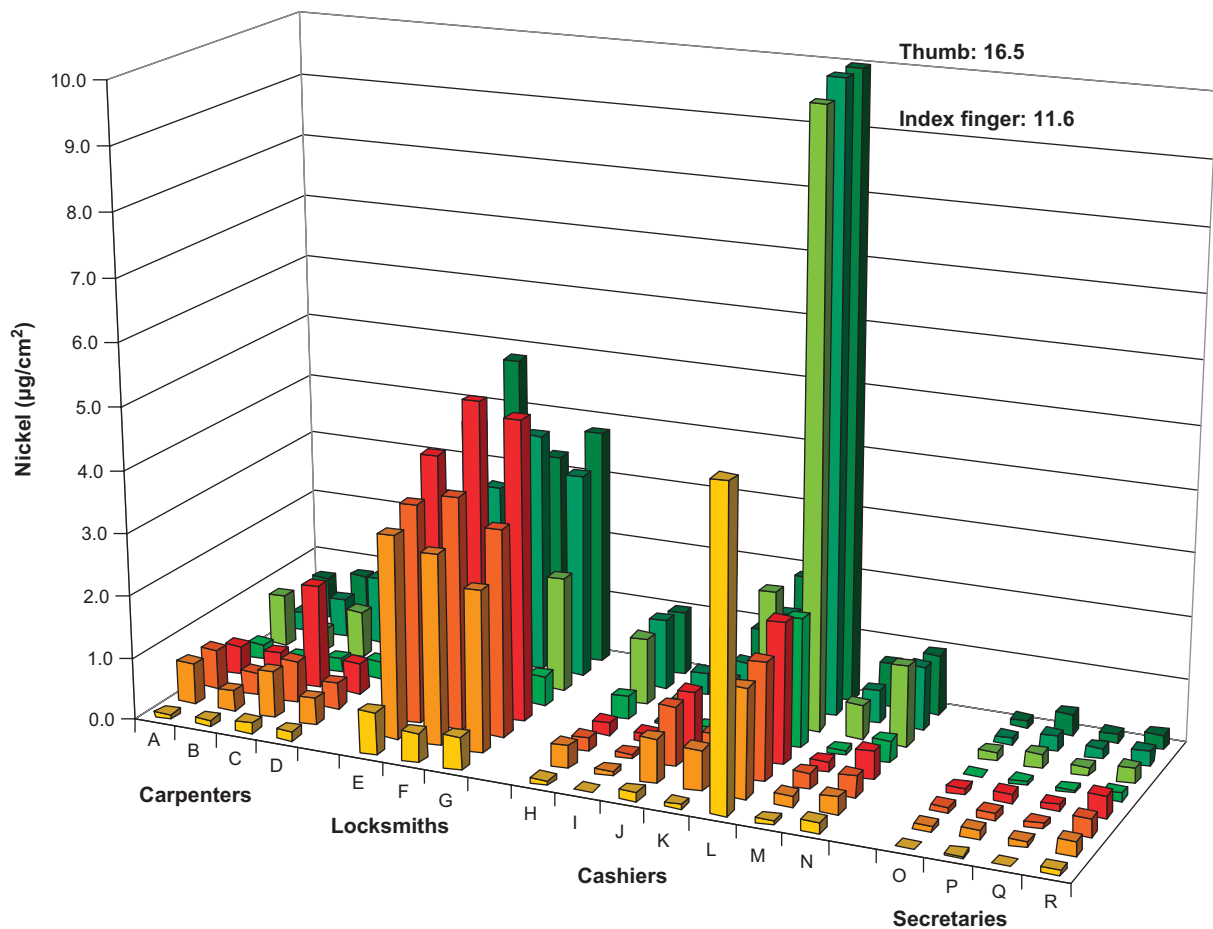


Fig. 1. Calculated amount of nickel deposited on the skin surface in 8 h. Samples were taken by acid wipe sampling from 8 exposed areas on hands in 18 workers after 10–180 min (mean 116 min) of regular work for exposure. Analysis by inductively coupled plasma mass spectrometer. ■ = left palm; ■ = left middle finger; ■ = left index finger; ■ = left thumb; ■ = right palm; ■ = right middle finger; ■ = right index finger; ■ = right thumb.

nickel release (23). Locksmiths constitute a relatively small occupational group to which attention was drawn in a study of occupational dermatology patients in our department (26).

Secretaries had only occasional contact with metallic items such as handles, keys, and office equipment. It can be assumed that nickel exposure in secretaries is much lower today than decades ago when the nickel content of paper clips, typewriters, handles, and other equipment was much higher. Our results show low exposure levels at present.

A method, based on finger immersion in water, has been used to study skin exposure to nickel by coin handling in volunteers and in cashiers, hairdressers, nickel refinery workers, and nickel platers (25). Sampling efficiency by the method, duration of work before sampling, and how the area of the thumb and index finger was assessed were not described. A gross comparison shows that the level of nickel was significantly lower by finger immersion in water (25) than that in the present study by acid wipe sampling, indicating that the sampling efficiency of acid wipe sampling is more than 10 times higher than that by immersion in water.

Examples of measurements of nickel on the skin from Table 2 (mean value of thumb and index finger by immersion in water) in Staton et al. (25) and Table 2 (mean value of right thumb and index finger by acid wipe sampling) in the present study are given for comparison. Cashier 6 in Staton et al. (25) with coin counting continuously for 2–3 h: $0.065 \mu\text{g}/\text{cm}^2$; cashier L in the present study with coin counting continuously for 10 min: $0.294 \mu\text{g}/\text{cm}^2$; shelf stacker in Staton et al. (25) with no coin handling (duration not known): $0.002 \mu\text{g}/\text{cm}^2$; secretaries O–R with office work for 1 h: $0.025 \mu\text{g}/\text{cm}^2$. The probable explanation as to the difference is that sampling was performed by immersing the entire thumb and index finger for 2 min in tubes containing highly purified water, while we used nitric acid (1%) for wipe sampling from demarcated areas of 2 cm^2 each on volar aspects of fingertips. Dilute nitric acid has been shown to be very efficient for extraction of metals from the skin surface (22), while water is not known to be efficient for extraction of metals.

The duration of work for exposure assessments varied in the present study (Tables 1 and 2). The calculated 8-h exposure value for nickel is regarded as realistic in all workers except for subject L with the maximum calculated amount of nickel of $16.5 \mu\text{g}/\text{cm}^2/8 \text{ h}$ on the right thumb (Tables 3 and 4; Fig. 1). This was a cashier who counted cash for 10 min, a task which in this workplace was performed by different employees each morning, and not during a whole workday.

In a review over experimental nickel elicitation thresholds, it was concluded that 5% of a sensitized population will react to a single occluded dose of $0.44 \mu\text{g}/\text{cm}^2$, while 10% will react to $1.04 \mu\text{g}/\text{cm}^2$ and 25% to $3.6 \mu\text{g}/\text{cm}^2$ on normal skin (27). The effect of repeated or continuous open exposure of normal skin to metals is largely unexplored. Highly sensitized individuals and individuals with inflamed skin are known to react to significantly lower levels. In the occupational setting, the sensitizing metals may be deposited onto the skin by accumulated exposure by repeated or prolonged contact with items in everyday work, not only on single occasions. In a recent publication, the relationship between the elicitation threshold to nickel at patch testing and repeated open application testing (ROAT) was studied (6). The threshold for reactivity by ROAT (in $\mu\text{g}/\text{cm}^2$ per application) was significantly lower than the threshold for the patch test, while the dose response for the accumulated ROAT dose at 1, 2, and 3 weeks was very similar to the patch test dose response. These results strongly indicate that the amounts of nickel deposited onto the skin in the present study (calculated 8-h mean level in carpenters $0.875 \mu\text{g}/\text{cm}^2$, locksmiths $3.784 \mu\text{g}/\text{cm}^2$, cashiers 2.151 or $0.835 \mu\text{g}/\text{cm}^2$, and secretaries $0.190 \mu\text{g}/\text{cm}^2$; Table 4) are capable of eliciting allergic contact dermatitis in a substantial proportion of sensitized individuals. It is considered possible also that levels of accumulated deposition of nickel such as in carpenters, locksmiths, and cashiers may cause or contribute to sensitization to nickel.

Conclusions

- The acid wipe sampling technique is suitable for studies of skin exposure to nickel, chromium, and cobalt in the workplace.
- It is essential to observe workers, before sampling is performed, for application of the most efficient sampling strategy. In studies of exposure as in the present study, sampling from 4 fingers (thumb, index finger, and middle finger of the dominant hand and thumb of the non-dominant hand) and pooling samples for analysis could be recommended.
- It is recommended including a non-exposed control area for quality control of the cleaning of sample areas before exposure.
- The amounts of nickel deposited by accumulated exposure on skin in carpenters, locksmiths, cashiers, and secretaries in the present study are judged capable of eliciting allergic contact dermatitis and that they may cause or contribute to sensitization.

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