Chromium and Cobalt Concentrations in Textile Products and the Amounts Eluted into Artificial Sweat

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Summary

Metal allergy due to accessories, dental implants, and other metal-based household products is one of the most common causes of contact dermatitis. Meanwhile, nylon, wool, and silk textile products are often dyed with mordant dyes and metal complex acid dyes that contain chromium and cobalt, which are recognized as allergenic metals. In this study, elements present in 78 textile products (106 samples) made of nylon, wool, and silk were analyzed by X-ray fluorescence using a fundamental parameter method. Twenty elements were detected in one or more samples, and Cr and Co were detected in 66 and 40 samples, respectively. The Cr concentration was found to be high, and exceeded 1,000 μg/g in 49 samples, among which, five samples showed >10,000 μg/g of Cr. On the other hand, the Co concentration exceeded 1,000 μg/g in three samples, and no sample showed >10,000 μg/g of Co. Both Cr and Co were detected in dark-toned samples (black, gray, and navy blue), and were hardly detected in light-toned samples (pink and red). Elution tests using seven samples which contained Cr and Co at high concentrations (>10,000 and >1,000 μg/g, respectively) were performed using artificial sweat. The Cr concentrations in acidic sweat (pH 5.5) and alkaline sweat (pH 8.0) were found to be 0.17–170 and 0.36–82 ng/mL, respectively, while the Co concentrations were found to be 0.042–130 and 0.028–130 ng/mL, respectively. The differences in the elution tendencies observed from each textile might be due to differences in the chemical structures of dyes containing Cr or Co. In the case of samples investigated in this study, it is deemed that Cr and Co are not likely to cause contact dermatitis at concentrations eluted into the artificial sweat.

Key words: allergic contact dermatitis, dye, textile, chromium, cobalt

INTRODUCTION

Contact dermatitis caused by household products are often attributed to metals. Allergic metals present in accessories (like earrings), metallic household products (like belt buckle and wristwatch belt), and dental implants. Meanwhile, in patients who suffered allergic contact dermatitis due to sports stocking, chromium was detected in the stocking, and positive reactions to Cr in patch tests have been reported. In such cases, a Cr-containing dye was considered to be present in the stocking. Mordant dyes and metal complex acid dyes are the main dye candidates that contain metals such as Cr in their chemical structure, and they have been used in nylon, wool, and silk. Various kinds of these type dyes have been developed and used for textile products. Some examples of these dyes are shown in Fig. 1. Although these metal-containing dyes have been used since a long time, the use of such dyes, which are prepared by treatment with potassium dichromate or chemicals containing Cr and Co, in textile products are restricted by Eco-Label in the European Union. In Japan, the use of these dyes is decreasing because of their toxicity, adverse environmental effects, etc. However, there is a lack of adequate information about these dyes and metals in textile products distributed in the Japanese market. Metal allergies are often suspected to be caused by products such as jewelries, belts, and leather products, and not textiles. Therefore, it is important to clarify the actual condition of metal-containing dyes in textile products to aid clinical studies on contact dermatitis caused by allergic metals.

Although various methods are used for the qualitative and quantitative analyses of metals in household products, X-ray fluorescence analysis (XRF) is considered to be a simple, effective, and non-destructive screening method that does not require extraction. In
this study, XRF analysis was used to analyze metals including allergic metals in textile products, and the elution of Cr and Co into artificial sweat was investigated.

**MATERIALS AND METHODS**

**Samples**

Commercial textile products made of nylon, wool, and silk were purchased from various online and retail stores in Japan. The parts with different textures such as lace and lining were separated and were analyzed as different samples. Thus, a total of 78 textile products (106 samples) were analyzed (Table 1) in this study.

**Reagents**

Sodium chloride and sodium hydroxide were obtained from Sigma-Aldrich Japan (Tokyo, Japan). L-histidine chloride monohydrate, sodium dihydrogenphosphate dihydrate, and disodium hydrogenphosphate dodecahydrate were purchased from Kanto Chemical Co., Inc. (Tokyo, Japan). Heavy metal analysis-grade nitric acid and Ultrapure water was obtained using a Milli-Q® Advantage A purification system (Merck Millipore, Tokyo, Japan). A volumetric analysis-grade aqueous sodium hydroxide solution (0.1 mol/L) was purchased from Wako Pure Chemical Industries (Osaka, Japan). L-histidine chloride monohydrate, sodium dihydrogenphosphate dihydrate, and disodium hydrogenphosphate dodecahydrate were purchased from Wako Pure Chemical Industries (Osaka, Japan). An yttrium solution used as the internal standard was purchased from Fluka (Sigma-Aldrich Japan). Ultrapure water was obtained using a Milli-Q® Advantage A10 water purification system (Merck Millipore, Tokyo, Japan). A volumetric analysis-grade aqueous sodium hydroxide solution (0.1 mol/L) was purchased from Wako Pure Chemical Industries (Osaka, Japan).

Acidic and alkaline artificial sweats described in JIS L1848 were used for elution tests. The acidic artificial sweat was prepared by dissolving 0.5 g of L-histidine chloride monohydrate, 5 g of sodium chloride, and 2.2 g of sodium dihydrogenphosphate dihydrate in water, and then adjusting the pH of the solution to 5.5 with 0.1 mol/L sodium hydroxide solution. Finally, the volume of this artificial sweat was made up to 1 L. Alkaline artificial sweat was prepared similarly by dissolving 0.5 g of L-histidine hydrochloride monohydrate, 5 g of sodium chloride, and 5 g of disodium hydrogenphosphate dodecahydrate in water, and adjusting the pH to 8.0 with 0.1 mol/L sodium hydroxide solution. After that, the volume was made up to 1 L. These artificial sweat solutions were prepared before use.

**XRF analysis**

Elemental analysis was conducted by energy diffraction XRF using EDX-7000 (Shimadzu, Kyoto Japan). The textile sample was cut to an appropriate size, and the sample was placed with a 5-μm-thick polypropylene film to the sample container. Qualitative and quantitative analyses of the elements were performed by the fundamental parameter method (FP method), and the balance was set to C6H12O assuming nylon. The measurement was performed at the atmospheric pressure, and the collimator was 10 mm diameter. The other measurement conditions are listed in Table 2. The lower limit of detection was three times the standard deviation of noise.

**Elution test of Cr and Co using artificial sweat**

Elution test using the artificial sweat was performed on a sample containing high concentrations of Cr and Co, as confirmed by XRF analysis. The sample (0.1-0.2 g) was weighed and placed in a 15 mL polypropylene tube with a screw cap, and artificial sweat was added at 50 times the sample weight (bath ratio 1:50). After manually shaking the tube several times until the fiber sample was totally wet, it was left at 37°C for 6 h. After that, the solution was filtered through a 0.45-μm PTFE filter (DISMIC®-25HP, ADVANTEC). Then, 1 mL of the filtrate was weighed and mixed with 1 mL of a 5% nitric acid aqueous solution, and then the metal concentration was determined using an inductively coupled plasma-mass spectrometer (ICP-MS).

**ICP-MS analysis**

The concentrations of Cr and Co eluted into the artificial sweat were determined by ICP-MS (Agilent 7500ce, Agilent Technologies, Santa Clara, CA) using an octopole reaction system. Helium was used as the collision gas. The operation condition of the ICP-MS are as follows: RF power, 1500 W; argon plasma gas, 15 L/min; nebulizer gas, 0.7 L/min; make-up gas, 0.33 L/min; collision gas, 5 mL/min; spray chamber temperature, 2°C; integration time, 0.1 s/element. Three replicate samples were analyzed. Yttrium was used as an internal standard (2 ng/mL in a 5% nitric acid solution). The standard solutions of Cr and Co were prepared using a 5% nitric acid solution. The Cr, Co, and Y ions were monitored at [m/z] of 53, 59, 89, respectively. Background equivalent concentrations of Cr and Co were 0.042 and 0.0088 ng/mL, respectively.

| Materials | Usage | Products | Samples |
|-----------|-------|----------|---------|
| **Nylon** | Underwear | 39 | 66 |
| | Supporter | 1 | 1 |
| | Stocking | 10 | 11 |
| | Medical stocking | 8 | 8 |
| **Wool** | Glove | 9 | 9 |
| | Cap | 1 | 1 |
| **Silk** | Scarf | 8 | 8 |
| | Socks | 2 | 2 |

Table 1 List of products and samples studied

| Channels | Excitation voltage (kV) | Tube current (μA) | Measurement range (keV) | Measurement time (s) |
|----------|------------------------|-------------------|-------------------------|---------------------|
| Al-U     | 50                     | Auto              | 0-40                    | 50                  |
| Na-Sc    | 15                     | Auto              | 0-4.4                   | 100                 |
| Rh-Cd    | 50                     | Auto              | 19.5-23.5               | 100                 |
| Zn-As, Pb| 50                     | Auto              | 8.5-13.0                | 100                 |
| Cr-Fe    | 50                     | Auto              | 5.2-6.6                 | 100                 |
| S-K      | 15                     | Auto              | 2.1-3.4                 | 100                 |

Table 2 The conditions used for XRF measurements using the fundamental parameter method
RESULTS AND DISCUSSION

Concentrations and detection frequencies of Cr and Co in textile products determined by XRF

The concentration range, detection number, and detection frequency of the elements detected in each sample are shown in Table 3. Twenty elements were detected in one or more samples. Detection frequencies of silicon, sulfur, calcium, titanium, iron, copper, and zinc are as high as 80% or more. Further, the detection frequencies of chlorine, potassium, and Cr are 60 to 70%, and it is ~40% for Co and bromine. The detection frequencies of other elements are low at 10% or less. Elements that were detected at a high frequency are elements expected to be present in large amounts in the background environment (such as silicon and calcium) or elements used in catalysts (such as copper and zinc). Detection frequencies of Cr and Co are 62% and 38%. Some representative XRF spectra of samples containing Cr and Co are shown in Fig. 2. On the other hand, nickel, which has been reported to cause many allergies\(^1\), was not detected in any sample.

Of the 66 samples in which Cr was detected, 49 samples showed Cr concentrations exceeding 1,000 \(\mu\text{g}/\text{g}\) (0.1%), among which five samples showed Cr concentrations exceeding 10,000 \(\mu\text{g}/\text{g}\) (1%). On the other hand, the Co concentration exceeded 1,000 \(\mu\text{g}/\text{g}\) in three out of 40 samples, and it exceeded 10,000 \(\mu\text{g}/\text{g}\) in none of the samples. The frequency and concentration range according to the color of the analyzed samples in which Cr and Co were detected are shown in Table 4. Both Cr and Co were detected in dark-toned samples that were black, gray and navy blue, and hardly detected in light-toned samples that were pink and red. This tendency is consistent with the characteristics of metal complex hydrochloric acid dyes and the acid mordant dyes\(^3\), and therefore, these types of dyes were speculated to be present in the analyzed samples. Although Cr and Co were also detected in textile products made of polyamide (nylon) with mainly dark colors (such as black, blue, and green) in previous studies, their concentrations were reported to be lower by one order of magnitude or more than those found in this study\(^6\). These differences might be due to the difference in the quantification method used, XRF in this study and ICP-MS with nitric acid extraction in previous studies.

Elution of Cr and Co

Elution test was performed using artificial sweat on seven samples (N2-2, N21-1, N29-1, N35, N45, W9, and S9) that contained Cr and Co at concentrations between 10,000 and 1,000 \(\mu\text{g}/\text{g}\) of the textile (Table 5). The soaking time was set to 6 h, because the studied textiles might be in contact with the skin for a long duration. The Cr and Co concentrations in acidic (pH 5.5) and alkaline (pH 8.0) artificial sweats after each textile sample was soaked in them for 6 h are shown in Table 6. Both Cr and Co were confirmed to elute into artificial sweats from all the tested samples. The concentrations of Cr in acidic and alkaline sweats were found to be 0.17–170 and 0.36–82 ng/mL, respectively, while the concentrations of Co in acidic and alkaline sweats were found to be 0.042–130 ng/mL and 0.028–130 ng/mL, respectively.

The amount of Cr eluted from the samples made from nylon and wool into the alkaline sweat was higher than that eluted into the acidic sweat. However, the amount of Cr eluted from sample S5 made from silk into the acidic sweat was higher (170 ng/mL) than that eluted into the alkaline sweat (14 ng/mL). Moreover, although the Cr concentration in sample S5 did not exceed 10,000 \(\mu\text{g}/\text{g}\), the acidic artificial sweat showed the highest eluted concentration of Cr among all samples. Among the five nylon samples (N2-2, N21-1, N29-1, and

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Table 3 Concentration ranges, detected numbers, and detection frequencies of elements in 78 textiles (106 samples) analyzed by XRF

| Range (\(\mu\text{g}/\text{g}\)) | Si | P | S | Cl | K | Ca | Ti | V | Cr | Mn | Fe | Cu | Zn | Ge | Br | Sr | Nb | Sb | Ba |
|-----------------------------|----|---|---|----|---|----|----|---|----|----|----|----|----|----|----|----|----|----|----|
| <100                        | 0  | 0 | 0 | 0  | 1 | 0  | 0  | 0 | 4  | 7  | 61 | 3  | 0  | 69 | 1  | 34 | 1  | 5  | 0  | 0  |
| 100–1,000                   | 0  | 0 | 2 | 29 | 66 | 42 | 2  | 1 | 13 | 1  | 41 | 34 | 104| 13 | 0  | 11 | 0  | 5  | 0  |
| 1,000–10,000                | 89 | 1 | 56| 35 | 2  | 47 | 37 | 0 | 44 | 0  | 3  | 3  | 0  | 7  | 0  | 1  | 0  | 0  | 1  | 0  |
| ≥10,000                     | 13 | 0 | 45| 6  | 0  | 9  | 57 | 0 | 5  | 0  | 0  | 0  | 0  | 0  | 2  | 0  | 0  | 0  | 0  | 0  |
| Detected number             | 102| 1 | 103| 70 | 69 | 98 | 96 | 1 | 66 | 8  | 105| 40 | 104| 91 | 1  | 46 | 1  | 5  | 1  |
| Detection frequency (%)     | 96 | 0.94| 97| 66 | 65 | 92 | 91 | 0.94| 62 | 7.5 | 99 | 38 | 98 | 86 | 0.94| 43 | 0.94| 4.7 | 4.7 | 0.94|

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![Fig. 2 XRF spectra of samples containing Cr and Co](image-url)
Table 4  Concentration ranges of Cr and Co in the textile of each color

| Range (μg/g) | Black | Grey | Beige | Blue | Navy | Pink | Red | Green | Yellow | Brown | Orange | Khaki | Unclassifiable |
|--------------|-------|------|-------|------|------|------|-----|-------|--------|-------|--------|-------|----------------|
| <100         | 0     | 0    | 1     | 3    | 0    | 0    | 0   | 0     | 0      | 0     | 0      | 0     | 0              |
| 100-1,000    | 1     | 3    | 1     | 1    | 2    | 1    | 1   | 2     | 0      | 0     | 1      | 1     | 1              |
| 1,000-10,000 | 25    | 5    | 0     | 0    | 5    | 0    | 0   | 1     | 0      | 2     | 0      | 4     | 1              |
| ≥10,000      | 4     | 1    | 0     | 0    | 0    | 0    | 0   | 0     | 0      | 0     | 0      | 0     | 0              |
| Total        | 30    | 9    | 2     | 4    | 7    | 1    | 1   | 3     | 0      | 2     | 1      | 1     | 5              |
| <100         | 0     | 1    | 0     | 0    | 1    | 0    | 0   | 0     | 0      | 0     | 0      | 0     | 1              |
| 100-1,000    | 11    | 7    | 2     | 0    | 4    | 1    | 1   | 1     | 0      | 0     | 1      | 1     | 5              |
| 1,000-10,000 | 2     | 0    | 0     | 0    | 0    | 0    | 0   | 0     | 0      | 0     | 0      | 0     | 0              |
| ≥10,000      | 0     | 0    | 0     | 0    | 0    | 0    | 0   | 0     | 0      | 0     | 0      | 0     | 0              |
| Total        | 13    | 8    | 2     | 0    | 5    | 1    | 1   | 2     | 0      | 0     | 1      | 1     | 6              |

* The number in the parenthesis indicates the number of samples

b Includes light blue and sax blue

Table 5  Characteristics and Cr and Co concentrations of samples used for elution test

| Materials | Sample No. | Type of products | Cr | Co |
|-----------|------------|------------------|----|----|
| Nylon     | N2-2       | Underwear        | 10,000 | 300 |
|           | N21-1      | Underwear        | 11,000 | 3,400 |
|           | N29-1      | Underwear        | 10,000 | 210 |
|           | N35        | Underwear        | 7,500  | 1,500 |
|           | N45        | Stocking         | 13,000 | ND |
| Wool      | W9         | Globe            | 18,000 | 27 |
| Silk      | S5         | Scarf            | 6,400  | 5,300 |
| ND: not detected |

Table 6  Amounts of Cr and Co eluted into artificial sweat (n = 5) from different textiles

| Sample No. | Acid sweat (pH 5.5) | Alkaline sweat (pH 8.0) | Acid sweat (pH 5.5) | Alkaline sweat (pH 8.0) |
|------------|---------------------|-------------------------|---------------------|-------------------------|
|            | Average | SD | Average | SD | Average | SD | Average | SD |
| N2-2       | 8.8     | 0.29 | 15      | 1.2 | 1.1     | 0.10 | 0.68    | 0.11 |
| Per unit weight (ng/g) | 440    | 14 | 780     | 230 | 56      | 5.0  | 36      | 6.9  |
| Per unit area (ng/cm²) | 4.6    | 0.15 | 8.1     | 2.4 | 0.59    | 0.052 | 0.37    | 0.072 |
| N21-1      | 19      | 3.6  | 24      | 0.91 | 3.4     | 0.50 | 6.1     | 0.73 |
| Per unit weight (ng/g) | 960    | 180 | 1,100   | 30  | 170     | 25   | 270     | 100  |
| Per unit area (ng/cm²) | 19     | 3.5  | 21      | 6.0  | 3.3     | 0.49 | 5.3     | 2.0  |
| N29-1      | 19      | 0.29 | 42      | 6.2  | 0.36    | 0.041 | 9.1     | 2.8  |
| Per unit weight (ng/g) | 970    | 15  | 2,700   | 890 | 18      | 2.1  | 580     | 200  |
| Per unit area (ng/cm²) | 14     | 0.21 | 39      | 13  | 0.25    | 0.029 | 8.3     | 2.9  |
| N35        | 0.36    | 0.037 | 2.3    | 1.6  | 0.74    | 0.043 | 3.5     | 1.9  |
| Per unit weight (ng/g) | 18     | 1.8  | 100     | 76   | 37      | 2.1  | 160     | 130  |
| Per unit area (ng/cm²) | 0.37   | 0.038 | 2.1    | 1.6  | 0.77    | 0.045 | 3.4     | 2.6  |
| N45        | 0.17    | 0.074 | 0.36    | 0.091 | 0.042   | 0.011 | 0.028   | 0.026 |
| Per unit weight (ng/g) | 8.3    | 3.7  | 15      | 3.6  | 2.1     | 0.56 | 1.1     | 1.0  |
| Per unit area (ng/cm²) | 0.26   | 0.12 | 0.46    | 0.11 | 0.065   | 0.018 | 0.036   | 0.033 |
| W9         | 55      | 12   | 82      | 16   | 0.19    | 0.056 | 0.091   | 0.043 |
| Per unit weight (ng/g) | 2,700  | 620  | 4,000   | 780  | 9.3     | 2.8  | 4.6     | 2.4  |
| Per unit area (ng/cm²) | 160    | 35   | 230     | 44   | 0.53    | 0.16 | 0.26    | 0.14 |
| S5         | 170     | 34   | 14      | 1.2  | 130     | 5.4  | 130     | 10   |
| Per unit weight (ng/g) | 8,400  | 1,700 | 680    | 120  | 6,700   | 270  | 6,100   | 1,000 |
| Per unit area (ng/cm²) | 30     | 6.0  | 2.4     | 0.42 | 24      | 0.96 | 22      | 3.7  |

SD: standard deviation

N45 in which the Cr concentration exceeded 10,000 μg/g, the lowest amount of Cr was eluted from N45 into each type of artificial sweat. Therefore, the chemical structures of the dyes used for N45 and S5 were deemed to be largely different.

Among the three samples, N21-1, N29-1, and S5, with Co concentration exceeding 1,000 μg/g, the amounts of Co eluted from the nylon samples (N21-1 and N29-1) into the alkaline artificial sweat were higher than those eluted into the acidic sweat. On the other hand, the amount of Co eluted from S5 made of silk into the acidic and alkaline sweat was the same. Moreover, the concentrations of Co eluted from S5 into both artificial sweats were very high as compared to those eluted from other samples. Therefore, the chemical structure of the dye containing Co in S5 is deemed to be largely different. In
addition, there was no significant difference in the eluted concentration of Co, regardless of the pH of the sweat, in contrast with the observation made with Cr.

The eluted amounts of Cr and Co per unit weight and area of the textile are shown in Table 6. The eluted amounts of Cr and Co per unit weight of the textile are the highest for sample S5. The calculated maximum elution ratio of Cr and Co is 0.13%. The metal complex dyes and the acid mordant dyes are known to have high color fastness owing to the coordination bonding between the fiber and metal\(^{23,24}\), therefore, the elution ratio was considered to be lowered. The eluted amount of Cr per unit area of W9 is larger than that from S5, because of the different weight per unit area of these two samples.

**Safety of the textile products investigated in this study**

EU Ecolabel\(^9\) regulates the amount of Cr and Co eluted into an acidic sweat from textile products targeted for children less than 3 years old. The stipulated limit of Cr in textiles dyed with metal complex acid dyes is 1.0 \(\mu g/g\), and it is 0.5 \(\mu g/g\) in all other textiles. The limit of Co in all textiles is 1.0 \(\mu g/g\). Furthermore, the EU Ecolabel and OEKO-TEX Standard 100\(^{25,26}\) have a maximum Cr elution limit of 2.0 \(\mu g/g\) in an acidic sweat from textiles dyed with metal complex acid dyes, other than those targeted for children less than 3 years old, and the limits for all other textiles is 1.0 \(\mu g/g\). Similarly, the limit of Co for textiles dyed with a metal complex acid dye is 4.0 \(\mu g/g\), and for all other textiles, it is 1.0 \(\mu g/g\). Of the seven textile samples subjected to the elution test, the amounts of Cr eluted from W9 and S5, and Co from S5, exceeded the elution limit of the above regulation for textiles used for children less than 3 years old. Although all the products investigated in this study are not for children less than 3 years old, it is necessary to use the textile products carefully. In this study, the samples were analyzed without washing them; however, it is considered that the amounts of Cr and Co leached will be lower if consumers launder the product before use.

Cr and Co are listed in the Japanese standard allergen series because they are frequently reported as the cause of allergic contact dermatitis\(^25\). As a patch test reagent, Cr is prepared with 0.5% aqueous potassium dichromate solution, and Co is prepared with 1% cobalt chloride in petroleum. This concentration is set to confirm the induced reaction of a patient who has already been sensitized to these metals. Thus, the possibility of sensitization and induced reaction is considered to be low at the Cr and Co concentrations in the artificial sweat detected in this study. However, it is not known if the amounts of these metals eluted from the textile products can cause contact dermatitis. Thus, it is necessary to carry out elution studies on other products that cause contact dermatitis. Furthermore, in patients with contact dermatitis syndrome caused by Cr or Co, skin symptoms may occur throughout the body upon the intake of trace amounts of these metals through oral ingestion or dermal absorption\(^25,26\). Textiles cover a large area of the human body, and the actual dermal exposure to these metals is not small. Therefore, further studies are required to clarify the relationship between the allergic metals in textile products and dermatitis.

**CONCLUSION**

Acid mordant dyes and metal complex dyes that contain Cr and Co, which are recognized as allergic metals are used for dyeing nylon, wool, and silk textile products. Therefore, 78 textile products (106 samples) made of nylon, wool, and silk were purchased and qualitative and quantitative analyses of elements including Cr and Co that they contain were conducted by XRF using the fundamental parameter method. Cr and Co were detected in 66 and 40 samples, respectively. The Cr concentration was higher than that of Co; 49 samples contained Cr at concentrations exceeding 1,000 \(\mu g/g\), among which five samples had more than 10,000 \(\mu g/g\) of Cr. On the other hand, the concentration of Co exceeded 1,000 \(\mu g/g\) in three samples, although none of the samples showed more than 10,000 \(\mu g/g\) of Co. Both Cr and Co were detected in dark-toned samples (black, gray and navy blue), and they were hardly detected in light-toned samples (pink and red). Elution tests using artificial sweat were performed on seven samples that contained high concentrations (10,000 and 1,000 \(\mu g/g\)) of Cr and Co. The eluted Cr and Co concentrations in artificial sweat after the soaking of each sample in acidic and alkaline artificial sweat were determined. The concentrations of Cr in acid sweat and alkaline sweat were found to be 0.17-170 and 0.36-82 ng/mL, respectively. The concentrations of Cr in acidic and alkaline sweats were found to be 0.042-130 and 0.028-130 ng/mL, respectively. The differences in the elution tendencies observed for each type of textile might be due to differences in the chemical structures of dyes containing Cr or Co. In the case of the samples investigated in this study, we speculate that Cr and Co are not likely to cause contact dermatitis at concentrations eluted into the artificial sweat.

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