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Harmful Element Content and Migration from Metal Accessories That May Be Accidentally Swallowed by Infants and Young Children

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Recent reports from various countries have indicated that metal accessories may contain high levels of harmful elements. Although this is primarily a concern because of the risk of accidental swallowing by infants and young children, information on this issue in Japan remains limited. Therefore, this study aimed to investigate the contents of eight harmful elements (Sb, As, Ba, Cd, Cr, Pb, Hg, and Se) in 47 metal accessories available in Japan that infants and young children might accidentally swallow, and determine the migration of these elements from the accessories. Pb (80–2,600 mg/kg) and Cd (50–660,000 mg/kg) were detected in metal accessories, with some products exceeding the European Union regulatory limits for jewelry articles (Pb: 500 mg/kg; Cd: 100 mg/kg). Cd migration was detected from eight metal accessories with concentrations ranging from 0.99 to 1,100 mg/kg. Two products exceeded the maximum acceptable migration limit of 75 mg/kg specified in ISO 8124-3:2020 "Safety of toys-Part 3: Migration of certain elements." In contrast, Pb migration was detected in only one product and was less than 10% of the maximum acceptable migration limit. Notably, two products exhibited high Cd migration (390 and 1,100 mg/kg), whereas some products contained high levels of Pb (up to 2,600 mg/kg) and Cd (up to 660,000 mg/kg). These findings highlight the need for continued monitoring of harmful element content and migration from metal accessories, considering not only accidental swallowing but also other exposure routes, such as mouthing behavior.

Key words harmful element, metal accessory, accidental swallowing

INTRODUCTION

Pb and Cd are metals of toxicological concern, as exposure to Pb in infancy is known to affect the development of the central nervous system,[1] whereas Cd is carcinogenic and highly bioaccumulative.[2] Therefore, exposure to these metals through various sources, including food,[3] house dust,[4] and consumer products,[5] is of particular concern for infants and young children. In the early to mid-2000s, multiple cases of Pb poisoning occurred in the United States, including child deaths caused by the swallowing of accessories containing high concentrations of Pb.[6-8] Additionally, high concentrations of Cd have been detected in children's metal accessories, leading to product recalls.[9] In response to these concerns, some countries have established standards for Pb and Cd content and migration levels and tightened regulations for toys and accessories.[10] However, in recent years, elevated concentrations of Pb and Cd have been detected in commercially available metal accessories in various countries.[11,12] Thus, products containing harmful metals remain on the market, highlighting the need for continuous monitoring. In Japan, studies conducted in the 2000s investigated the Pb and Cd content in metal products, including accessories, and the migration of these elements from these products. These products contained high levels of Pb and Cd and exhibited high migration levels of these elements.[13-15] However, more than a decade has passed since these investigations were conducted, and recent knowledge in this field in Japan remains limited. Therefore, in this study, we aimed to evaluate the total content and migration concentrations of eight harmful elements listed in the international standard ISO 8124-3:2020 "Safety of toys-Part 3: Migration of certain elements" (Table 1)[16] in metal accessories available in Japan.

Table 1. Maximum Acceptable Element Migration from Toy Materials Specified in ISO 8124-3:2020

Toy material	Element (mg/kg)							
	Sb	As	Ba	Cd	Cr	Pb	Hg	Se
Any toy material, except modelling clay and finger paint	60	25	1,000	75	60	90	60	500

MATERIALS AND METHODS

Samples Metal accessories of sizes that could be accidentally swallowed by infants and young children were select-

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Table 2. Number of Products and Specimens by the Product Classification

Product classification	Number of products	Number of specimens
Straps	9	17
Necklaces	3	10
Earrings	5	5
Body piercing jewelry	2	2
Rings	4	4
Garment accessories	6	6
Accessory components	6	6
Nail decorations	3	3
Hair accessories	6	6
Others	3	3
Total	47	62

Table 3. Measurement Conditions for Energy Dispersive X-ray Spectroscopy

Composite channel	Excitation voltage (kV)	Tube current (μA)	Range (keV)	Time (s)
Al–U	50	Auto	0–40	100
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	100
Cr–Fe	50	Auto	5.2–6.6	100
S–K	15	Auto	2.1–3.4	100

Table 4. Measurement Conditions for Inductively Coupled Plasma-Mass Spectrometry

Parameter	Value
Forward power	1,550 W
Nebulizer gas (Ar)	0.94 L min^{-1}
Auxiliary gas (Ar)	0.8 L min^{-1}
Cool gas flow (Ar)	14 L min^{-1}
CCT gas flow (He)	4.7 mL min^{-1}
CCT gas flow (H_2)	4.0 mL min^{-1}
Sample uptake/wash time (s)	80/30
Integration time (s)	0.1 (Hg and Se, 0.3)
Number of readings per sample	3 main runs
Peristaltic pump speed	40 rpm

ed. This size was defined as being able to fit without compression inside the test fixture specified in the toy standards of the Specifications and Standards for Foods, Food Additives, under the Food Sanitation Act.[17] We purchased 47 inexpensive metal accessories commercially available in Japan from online shops between April and June 2025 (Table 2). Multicomponent products were separated into individual components, each of which was analyzed independently (n = 62).

Reagents An XSTC-622 multi-element standard solution (SPEX CertiPrep; Metuchen, NJ, USA) was used for calibration. Internal standard solutions (Be, Bi, Ir, Rh, and Te), Hg and Au standard solutions, and reagent-grade hydrochloric acid were purchased from Fujifilm Wako Pure Chemical Co. (Osaka, Japan). Ultrapure nitric acid was obtained from Kanto Chemical Co. (Tokyo, Japan). Ultrapure water was prepared using a Milli-Q® Advantage A10 water purification system (Merck Millipore, Tokyo, Japan). Before use, all plasticware was soaked in diluted nitric acid and then rinsed with ultrapure water.

Preparation of Solutions The internal standard mixture was prepared to contain Be (0.5 μg/mL), Bi (0.2 μg/mL), Ir (0.005 μg/mL), Rh (0.005 μg/mL), and Te (5 μg/mL). An online internal standard addition system was used to automatically introduce internal standards during the analysis. Standard solutions were prepared with concentrations of 0.1–100 ng/mL for Sb, As, Ba, Cd, Cr, Pb, and Se and 0.001–1 ng/mL for Hg. The calibration standards were prepared by diluting a multi-element standard solution (XSTC-622; 10 μg/mL for each of the 35 elements) and Hg standard solution (1 mg/mL) with 10% nitric acid containing 200 ng/mL Au.

Analysis of Hazardous Elements Using X-Ray Fluorescence (XRF) The contents of the eight elements in the products were analyzed using an energy-dispersive XRF spectrometer (EDX-7000; Shimadzu Corporation, Kyoto, Japan). The samples were analyzed under atmospheric conditions using a 5 μm-thick polypropylene film (Cole-Parmer, Vernon Hills, IL, USA) under the analytical conditions shown in Table 3. The elemental contents were quantified using a fundamental parameter method. The limit of detection (LOD) for each element was calculated for each sample as three times the theoretical standard deviation of the background intensity of the continuous scattered X-rays.

Metal Migration Test Metal accessories were placed in a container with an inner diameter of approximately 40 mm, and 0.07 mol/L hydrochloric acid preheated to 37°C was added until the samples were completely immersed. The mixture was then incubated at 37°C for 2 h in the dark. Subsequently, the solution was filtered through a membrane filter with a pore size of 0.20 μm (Merck Millipore, Tokyo, Japan) to obtain the test solution. Hydrochloric acid was added to the test solution to adjust the concentration to 1 mol/L for sample stabilization. The solution was diluted 10–10,000 times with 10% nitric acid containing 200 ng/mL Au to fall within the calibration range. The concentration of the target element in the test solution was measured using an inductively coupled plasma mass spectrometer (ICP-MS).

Analysis of Hazardous Elements Using ICP-MS ICP-MS analysis was performed using an iCAP RQ (Thermo Fisher Scientific Inc., Waltham, MA, USA). The optimal ICP-MS operating parameters are listed in Table 4, and the analytical parameters for each target element are summarized in Table 5. Se was measured in the H_2 reaction mode to minimize spectral interference; all other elements were analyzed in the He kinetic energy discrimination (He-KED) mode. The instrument detection concentration was calculated as 1.645 times the standard deviation of 10 replicate measurements of the calibration blank solution.[18] The concentration of each element in the test solution was determined from the calibration curve, and element migration (mg/kg) per 1 kg of the sample used in the test was calculated using the following formula:

$$\text{Element migration (mg/kg)} = \frac{\text{Concentration in test solution (mg/L)} \times \text{Volume of test solution (L)}}{\text{Sample mass (kg)}}$$

As the purpose of this study was not to determine compliance with ISO 8124-3:2020, analytical correction values were not considered. In this study, 1% of the element migration specified in ISO 8124-3:2020[16] was used as the reporting limit.

Table 5. List of Elements, Internal Elements, Mass, Calibration Range, R^2, and Instrument Detection Level (IDL)

Element	*m/z*	Internal element	*m/z*	Calibration range (ng/mL)	R^2	IDL* (ng/L)
Sb	121	Te	125	0.1–100	1.0000	1.1
As	75	Rh	103	0.1–100	0.9999	3.1
Ba	137	Te	125	0.1–100	1.0000	12
Cd	111	Te	125	0.1–100	0.9999	0.49
Cr	52	Be	9	0.1–100	1.0000	3.1
Pb	208	Ir	193	0.1–100	1.0000	3.8
Hg	201	Bi	209	0.001–1	0.9999	0.53
Se	78	Rh	103	0.1–100	0.9999	7.7

*IDL was calculated as 1.645 times the standard deviation of ten replicate measurements of the calibration blank solution.

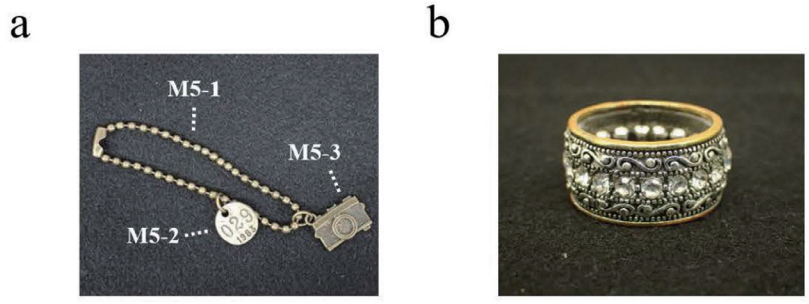


Fig. 1. Products That Showed Cd Migration Exceeding The Maximum Acceptable Migration Limit Specified in ISO 8124-3:2020. a, M5-2 (Cd: 1,100 mg/kg); b, M29 (Cd: 390 mg/kg).

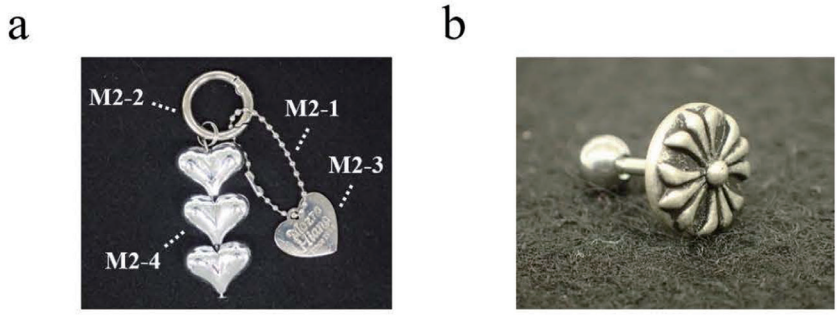


Fig. 2. Products That Contained Pb at Levels Exceeding The European Union Regulatory Limit. a, M2-4 (Pb: 2,600 mg/kg); b, M37 (Pb: 1,100 mg/kg).

RESULTS AND DISCUSSION

XRF analysis detected Pb content in six products (80–2,600 mg/kg), Cd content in 12 products (50–660,000 mg/kg), Sb content in one product (71,000 mg/kg), Ba content in one product (13,000 mg/kg), Cr content in 13 products (14 samples; 120–200,000 mg/kg), and Se content in 12 products (16 samples; 70–13,000 mg/kg) (Table 6). In contrast, As and Hg concentrations were below the LOD for all the samples.

ICP-MS analysis of the test solutions detected Pb from one product (2.1 mg/kg), Cd from eight products (0.99–1,100 mg/kg), and Cr from eight products (0.81–8.9 mg/kg) (Table 6). The migration concentrations of As, Sb, Ba, Hg, and Se were below the reporting limits for all samples. Cd was the only element that exceeded the maximum acceptable element migration limit specifies in ISO 8124-3:2020, with migration concentrations of 1,100 mg/kg and 390 mg/kg from the two products (M5-2, Fig. 1a and M29, Fig. 1b).

Regarding reports on Pb content, Jurowski *et al.*[11] investigated inexpensive accessories intended for adults sold on Chinese e-commerce platforms and detected Pb in 23 out of 106 products (22%), with contents ranging from 95.21 to 3,450.25 mg/kg. In contrast, Pb was detected in 6 out of 47 products (13%), with contents ranging from 80 to 2,600 mg/kg (Table 6). Most products analyzed in this study were manufactured in China, and the Pb content and detection frequency were comparable to those reported by Jurowski *et al.* Furthermore, the Pb content in two out of 47 products (M2-4, Fig. 2a and M37, Fig. 2b) exceeded the EU limit (500 mg/kg),[19] indicating the continued presence of products with elevated Pb content in the marketplace. In a previous report on metal accessories in Japan, Isama *et al.*[20] investigated the migration of elements in

Table 6. Harmful Element Content in Metal Accessories and Migration from Them (40/62 Samples)

No.	Product	Specimen	Pb		Cd		Sb		Ba		Cr		Se	
			Content	Migration amount	Content	Migration amount	Content	Migration amount	Content	Migration amount	Content	Migration amount	Content	Migration amount
			(mg/kg)		(mg/kg)		(mg/kg)		(mg/kg)		(mg/kg)		(mg/kg)	
M1-2	Strap	Decoration	n.d.[a]	–[b]	270	0.99	n.d.	–	n.d.	–	n.d.	–	80	–
M2-3	Strap	Decoration	n.d.	–	50	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M2-4		Decoration	2.6×10^3	–	n.d.	–	7.1×10^4	–	n.d.	–	2.0×10^3	–	n.d.	–
M3	Strap	Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	710	–	1.3×10^4	–
M5-2	Strap	Decoration	120	–	6.6×10^5	**1.1×10^3** [c]	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M7	Phone strap	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	0.81	n.d.	–
M9-1	Lanyard	Fitting	n.d.	–	n.d.	–	n.d.	–	n.d.	–	720	–	n.d.	–
M9-2		Fitting	n.d.	–	n.d.	–	n.d.	–	n.d.	–	630	–	n.d.	–
M10	Necklace components	Fitting	n.d.	–	n.d.	–	n.d.	–	n.d.	–	2.0×10^5	–	n.d.	–
M12	Filigree components	Decoration	80	–	n.d.	–	n.d.	–	n.d.	–	280	5.5	6.0×10^3	–
M13-1	Necklace	Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	250	–
M13-2		Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	160	–
M13-3		Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	420	–
M14	Necklace components	Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	190	–	2.7×10^3	–
M15	Button	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	1.2	4.2×10^3	–
M16	Button	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	860	–
M17	Stud setting	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	1.0	n.d.	–
M18	Pyramid studs	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	1.7	n.d.	–
M19	Zipper pull	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	320	–
M23	Beads	Whole	n.d.	–	330	3.1	n.d.	–	n.d.	–	n.d.	–	70	–
M25	Nail decorations	Whole	n.d.	–	6.4×10^4	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M26	Nail decorations	Whole	n.d.	–	3.5×10^5	2.1	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M27	Ring	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	150	–	n.d.	–
M28	Ring	Whole	n.d.	–	220	–	n.d.	–	n.d.	–	4.7×10^4	–	n.d.	–
M29	Ring	Whole	n.d.	–	2.5×10^5	**390**	n.d.	–	1.3×10^4	–	n.d.	–	n.d.	–
M30	Ring	Whole	n.d.	–	1.5×10^5	22	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M31	Earrings	Whole	140	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	1.1×10^4	–
M32	Earrings	Whole	n.d.	–	1.5×10^5	3.5	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M37	Body jewelry	Whole	1.1×10^3	2.1	740	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M38-2	Necklace	Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	180	–
M38-4		Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	70	–
M38-5		Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	70	–
M39-1	Necklace	Fitting	n.d.	–	n.d.	–	n.d.	–	n.d.	–	1.4×10^5	5.7	n.d.	–
M39-2		Decoration	n.d.	–	2.4×10^5	45	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M41	Bracelet components	Decoration	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	160	–
M42	Hair clip	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	980	8.9	n.d.	–
M43	Hair clip	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	1.1×10^3	5.3	n.d.	–
M44	Bobby pin	Whole	440	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–	n.d.	–
M45	Bobby pin	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	540	–	n.d.	–
M46	Bobby pin	Whole	n.d.	–	n.d.	–	n.d.	–	n.d.	–	120	–	n.d.	–

[a] Less than detection limit.
[b] Less than 1% of migration limits of ISO 8124-3:2020.
[c] Bold values indicate exceedance of the ISO 8124-3:2020 migration limits.

accordance with ISO 8124-3:2010 and reported that 28 out of 117 products (24%) exceeded the maximum acceptable level of Pb migration (90 mg/kg). In contrast, no product exceeded the maximum acceptable level of Pb migration in this study, and for one product with Pb migration, the concentration was less than 10% of the maximum acceptable level of Pb migration. Therefore, within the scope of this study, the prevalence of Pb migration in metal accessories may have decreased substantially compared to that in previous reports.

Jurowski *et al.* reported that Cd was detected in 60 out of 106 inexpensive accessory products (57%), with contents ranging from 100.85 to 6,542.12 mg/kg.[11] In addition, Kern *et al*. reported that Cd was detected in 32 out of 80 inexpensive accessory products (40%) at concentrations ranging from 20 to 459,000 mg/kg.[12] In this study, Cd was detected in 12 of the 47 products (26%) at concentrations ranging from 50 to 660,000 mg/kg, and 11 products exceeded the EU limit (100 mg/kg).[21] Similar to recent reports from other countries, high Cd content has been detected in commercially available metal accessories in Japan.

In contrast, with respect to migration, Isama *et al*.[20] reported that one out of 117 products (0.85%) exhibited Cd migration of 160 mg/kg, exceeding the maximum acceptable level of 75 mg/kg. In this study, 2 out of 47 products (4.3%) exceed-

ed the maximum acceptable level for Cd, with high migration concentrations of 390 and 1,100 mg/kg. The migration concentration and detection frequency of Cd in this study were higher than those reported in previous domestic studies. Additionally, differences in Cd migration were observed even among products with high Cd contents in this study, a similar trend has been reported in previous studies.[12,22] This may be due to differences in product surface conditions, such as surface damage and variations in surface plating.

Because the maximum acceptable level of Cd migration is derived from exposure-based assumptions regarding bioavailability and toy material ingestion scenarios,[16] it remains difficult to evaluate the health risks associated with accidental swallowing of metal accessories that exhibit high concentrations of Cd migration based solely on the results of the present study. Nevertheless, the presence of products containing exceptionally high levels of Cd and exhibiting markedly elevated Cd migration levels indicates the need for further consideration of high Cd exposure in infants and young children through accidental swallowing and mouthing behavior.

In conclusion, this study investigated the contents of harmful elements in metal accessories and their migration from products available in Japan. Some products contained high levels of Pb and Cd, and high Cd migration was detected from several products. These findings suggest that certain metal accessories may be potential sources of harmful-element exposure in infants and young children. Therefore, continued monitoring of both the total content and migration of harmful elements is necessary, considering not only accidental swallowing by infants and young children but also other exposure routes, such as mouthing behavior.

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Conflict of interest The authors declare no conflict of interest.

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