

The cost of nickel allergy: a global investigation of coin composition and nickel and cobalt release

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Summary

Background. Nickel is widely used in coins; nickel may cause contact allergy and allergic contact dermatitis in those who handle them.

Objectives. To investigate alloy use, coin composition and nickel and cobalt release for a worldwide selection of currently circulating coins.

Materials and methods. Eight hundred and fifty coins of 361 different denominations or issues from 52 countries were collected and analysed with X-ray fluorescence spectrometry and nickel and cobalt spot tests.

Results. Copper–nickel was the most frequently identified coin alloy, being observed in 100 denominations (28%), followed by aluminium–bronze (62, 17%). In total, 239 denominations released nickel (28%). Coins from Bolivia, Brazil and Costa Rica did not release nickel. Fewer than one-third of the denominations or issues from China, India, the euro area and Indonesia released nickel. In the United States, the Russian Federation, Japan, and Mexico, one-third or more of the denominations released nickel.

Conclusions. This worldwide selection of circulating coins covered countries with 75% of the world population, and shows that the majority of the world population lives in countries where coins release nickel. Pertinently, ~40% of circulating coin denominations do not release nickel.

Key words: alloys; coin allergy; coins; DMG test; hand eczema; nickel allergy; nickel release; risk assessment.

It has often been debated to what extent nickel allergy is a risk factor for hand eczema, as epidemiological studies have given discrepant results. However, it is clear

that, when the hands of nickel-allergic individuals are exposed to nickel daily, hand eczema may develop. Nielsen et al. substantiated this view, as nickel-allergic patients who immersed a finger for 10 min daily into 10–100 ppm nickel in water for 2 weeks experienced significantly increased local vesicle formation and blood flow as compared with a group of nickel-allergic patients who immersed a finger into water without nickel (1). As most coins contain and release nickel, it is often considered that coin handling may cause nickel allergy and dermatitis. Indeed, a recent review article presented evidence from experimental studies and case reports supporting this view (2). The aim of the present study was to investigate alloy use, coin composition and nickel and cobalt release for a worldwide selection of currently circulating coins.

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Conflicts of interest: Carsten Hamann and Dathan Hamann have worked as consultants for SmartPractice (Phoenix, Arizona). Jacob Thyssen sold the cobalt spot test to SmartPractice after its development, and will receive a royalty fee from annual net sales of the spot test. Curtis Hamann owns SmartPractice, which distributes the Reveal & Conceal nickel and cobalt spot tests. Carola Lidén has no conflict to declare. Funding: Partially funded by a grant from SmartPractice.

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Materials and Methods

Collecting strategy

From November 2011 to June 2012, 850 coins of 361 different denominations or issues from 52 countries (the euro zone is counted as one country) were collected. We aimed to collect three copies of each denomination of each currency. Coins were not obtained directly from banks; they were collected from circulating currency. No discrimination was made as to the year of each coin. Most coins were collected by the authors' international colleagues according to the above selection method, and sent by mail to our laboratory for analysis.

X-ray fluorescence spectrometry

Each coin was analysed with a portable Bruker S1 X-Ray Fluorescence Spectrometer Sorter (Bruker Elemental, Billerica, MA, USA). The analyser was interfaced with a Hewlett-Packard iPAQ PDA (Hewlett-Packard, Palo Alto, CA, USA). The X-ray fluorescence (XRF) spectrometer was set to Auto configuration, which allows the instrument to switch from fundamental parameters to empirical analysis modes if, within 10 seconds, the detected spectra cannot be matched to data from a library with > 175 common alloys. It is able to detect titanium and any metals heavier than titanium. Metals with a smaller atomic mass than titanium, for example aluminium, are not detected. Each coin was set in the X-ray field and tested for 30 seconds. Both sides of each coin were tested. When the composition of the three replicates of the same denomination differed significantly, they were reported separately, as different issues of the same denomination. Otherwise, the reported compositions reflect the average of both sides of all coins of the same denomination. For those coins that were made of an inner core and an outer ring of differing compositions, the core and ring were analysed and reported separately. In the fundamental

parameters mode, the relative error of the spectrometer is 0.7% for each element. In the empirical mode, the relative error is ~ 10% for each element.

Spot test analysis

Each coin was tested with a nickel spot test and a cobalt spot test (Reveal & Conceal™, SmartPractice, Phoenix, AZ, USA). The nickel spot test is a dimethylglyoxime (DMG) test containing water, ethanol, ammonium hydroxide, and DMG. The cobalt spot test contains water, sodium acetate, oxalic acid, and 1-nitroso naphthol 3,6-disulfonic acid disodium salt (nitroso R salt). The tests are delivered in single-dose sealed tubes with a cotton tip applicator. All test tubes were manufactured in 2012, and the expiration dates were all February 2014. Testing was performed by rubbing the surface with the moist applicator for 30–60 seconds, according to the manufacturer's recommendations. The cobalt spot test was performed before the nickel spot test, and was performed on another part of the coin. For the nickel spot test, a positive reaction was indicated by pink coloration of the cotton tip. A negative test result was indicated by no colour change of the cotton tip. For the cobalt spot test, a positive reaction was indicated by red or orange coloration of the cotton tip (3). A negative test result was indicated by no colour change of the cotton tip. Coins with doubtful reactions, defined by an applicator with discoloration that was not pink, red, or orange, were cleaned with water and retested. If doubtful reactions persisted, the coin was considered to be negative. Examples of positive DMG test results are shown in Fig. 1.

Determining the composition of coins

The composition of all coins was determined with judgement based on official information on websites of the respective central banks and mints, and information from coin collector catalogues (5, 6), together with the results



Fig. 1. Coins tested with the dimethylglyoxime test from the six major geographical regions according to the UN (4): a 0.25 US dollar coin, a 100 Japanese yen coin, a 1 Argentinian dollar coin, a 2 South African rand coin, a 0.50 Australian dollar coin, and a 0.10 UK pound sterling coin. The pink colour indicates nickel release.

Table 1. Summary of terminology, and results on composition and nickel release from coins

Coin alloy ^a	Typical composition (metal %) ^a	No. of positive DMG test results/no. tested
Aluminium	Al 100	0/17
Aluminium–bronze and aluminium–brass ^b	Cu 92; Al 6; Ni 2	35/62
Brass and bronze ^b	Cu 97; Zn 2.5; Sn 0.5	0/29
Copper	Plated or clad coins only – see below	—
Copper–nickel (cupro-nickel, CuNi)	Cu 75; Ni 25; alternatively, Cu 84; Ni 16	100/100
Nickel	Ni 100	8/8
Nickel–brass	Cu 75; Zn 20; Ni 5	39/39
Nordic gold	Cu 89; Al 5; Zn 5; Sn 1	0/5
Stainless steel	Fe 82; Cr 18	0/28
Steel	Plated or clad coins only—see below	—
All alloys		182/288
Plated and three-layer (clad) coins ^{b,c}	Coating (plating or clad) on different base alloys (no.)	
	Brass or bronze: Ni (1); steel (27)	0/28
	Cu: Al (1); steel (18); Zn (5)	0/24
	Copper–nickel: Cu (1); Ni (1); steel (9)	11/11
	Ni: Cu (3); steel (43)	46/46
All coatings		57/109
Combination coins (bi-colour, bi-metallic) ^d	Colour and alloy (no. of denominations or issues)	
	White: copper–nickel (23); nickel (1); nickel plated steel (2); stainless steel (6)	74 parts tested in 37 denominations—results included above
	Yellow: aluminium–bronze (25); brass (4); bronze-plated steel (2); nickel–brass (11)	
All parts in 361 denominations or issues		239/397

DMG, dimethylglyoxime.

Determination of the composition of assessed coins by judgement based on official information on websites of central banks and mints, and information from coin collector catalogues (5, 6), together with the results of X-ray fluorescence (XRF) analysis for metal content and the DMG test for nickel release.

^aComposition of typical alloys according to (2, 7).

^bGroups merged in this article, owing to inconsistent or incorrect terminology in different sources of information on the composition of coins.

^cThree-layer coins have a core of alloy or pure metal, and a layer (clad, thicker than a plating) of other alloy or pure metal on each surface.

^dCombination coins have a centre core and outer ring of different alloys (typically, but not always, of different colours). Every combination coin was tested twice, which explains why the number of tests is larger than the number of denominations.

Eight hundred and fifty coins of 361 denominations or issues were collected from the circulation in 52 countries, November 2011 to June 2012. Metal content was assessed by XRF spectrometry; nickel release was assessed with the DMG test. Numbers in the table refer to all parts in the denominations or issues assessed.

from XRF analyses and nickel spot tests. Terminology and the typical compositions of alloys, platings, combinations, etc. are shown in Table 1.

Data analysis

Population data were retrieved from the United Nations World Population Prospects report (4). The organization of countries into major areas was performed according to the same report. Table 2 shows the number of denominations in the study, together with population data by country.

Results

A summary of the results on composition (alloys, platings, combination coins, etc.) and nickel release in

850 coins of 361 denominations or issues is shown in Table 1. Copper–nickel was the most frequently identified coin alloy (in 100 denominations), followed by aluminium–bronze (in 62).

Tables 3 and 4 show the nickel-containing coins, the compositions, the number of denominations, and their distribution. Table 3 shows those with nickel release (positive DMG test result), totalling 239. Table 4 shows the nickel-containing denominations with negative or doubtful DMG test results, totalling 29. Aluminium–bronze coins had either positive DMG test results (57%) or negative or doubtful DMG test results (43%). Nickel-plated steel and nickel–brass were frequently identified nickel-releasing denominations.

Table 2. Coins in the study

Major area and population size (million) ^a	Country or area in the study	Number of denominations or issues assessed by country or area ^b	Population size (million) by major area and country or area in the study ^a
Africa 1022	Botswana; Ethiopia; Kenya; Morocco; Namibia; South Africa; Sudan; Uganda	8; 7; 10; 6; 2; 14; 5; 7	2; 83; 41; 32; 2; 50; 44; 33 Total: 287
Asia 4164	China; Hong Kong; India; Indonesia; Iran; Israel; Japan; Lebanon; Malaysia; Philippines; Saudi Arabia; Singapore; South Korea; Sri Lanka; Taiwan; Thailand; Vietnam	4; 9; 18; 7; 4; 10; 6; 3; 7; 8; 6; 6; 6; 11; 4; 7; 5	1341; 7; 1225; 240; 74; 7; 127; 4; 28; 93; 28; 5; 48; 21; 23; 69; 88 Total: 3428
Europe 738	Denmark; euro zone ^b ; Norway; Poland; Russian Federation ^c ; Sweden; Switzerland; United Kingdom	5; 8; 4; 5; 9; 3; 7; 12	6; 329; 5; 38; 143; 9; 8; 62 Total: 600
Latin America and the Caribbean 590	Argentina; Belize; Bolivia; Brazil; Chile; Colombia; Costa Rica; Cuba; Ecuador; Guatemala; Honduras; Mexico; Nicaragua; Panama; Peru; Venezuela	9; 3; 8; 6; 8; 5; 12; 6; 5; 9; 5; 10; 4; 7; 4; 5	40; 0.3; 10; 195; 17; 46; 5; 11; 15; 14; 8; 113; 6; 4; 29; 29 Total: 542
North America 345	Canada; United States	11; 5	34; 310 Total: 345
Oceania 37	Australia	6	22 Total: 22
Total world population: 6895	Number of countries: 52	361	Population: 5224

^aMajor areas and population sizes according to UN statistics.

^bEuro zone in 2011: Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Portugal, Slovakia, Slovenia, Spain, The Netherlands.

^cThe Russian Federation included in Europe.

Eight hundred and fifty coins of 361 denominations or issues collected from the circulation in 52 countries or areas November 2011 to June 2012. Countries and major areas, number of denominations or issues, and population size.

Table 3. Nickel-releasing coins [dimethylglyoxime (DMG) test-positive] and their compositions, identified among circulating coins in 52 countries from November 2011 to June 2012

Composition (alloy, coating by plating or clad)	Number of nickel-releasing denominations or issues						Total
	Africa	Asia	Europe	Latin America	North America	Oceania	
Aluminium–bronze and aluminium–brass	4	13	3	15	—	—	35
Copper–nickel	18	40	24	10	4	4	100
Nickel	1	—	—	3	4	—	8
Nickel–brass	5	11	8	15	—	—	39
Copper–nickel-plated/clad Cu; Ni; steel	4	—	4	—	3	—	11
Nickel-plated/clad Cu; steel	12	15	2	17	—	—	46
Combination coin alloys—results included above	14	12	8	12	1	—	47
All with positive DMG test result	44	79	41	60	11	4	239

Composition determined by judgement based on official information on websites of central banks and mints, and information from coin collector catalogues (5, 6), together with X-ray fluorescence analysis.

Major areas according to UN statistics (4).

Composition and number of denominations or issues by major area.

Table 5 shows the nickel-free compositions, the number of denominations, and their distribution. In total, 129 denominations were identified as being nickel-free. They were made of six alloys and some coatings (plating or clad). Besides the large proportion of aluminium–bronze coins, brass, bronze, stainless steel, brass or copper-plated

steel and aluminium were also nickel-free or not shown to release nickel.

The proportions of nickel-releasing denominations in different countries are shown in Fig. 2. No coins from three countries (Bolivia, Brazil, and Costa Rica) released nickel. Fewer than one-third of the denominations or

Table 4. Nickel-containing coins with negative or doubtful dimethylglyoxime (DMG) test results, identified among circulating coins in 52 countries from November 2011 to June 2012

Composition (alloy, coating by plating or clad)	Number of nickel-containing denominations or issues with negative or doubtful DMG test results						Total
	Africa	Asia	Europe	Latin America	North America	Oceania	
Aluminium–bronze	6	6	1	6	1	2	22
Brass and bronze	1	—	—	1	—	—	2
Stainless steel	—	—	—	1	—	—	1
Bronze-plated/clad Ni	—	—	—	—	1	—	1
Copper-plated/clad steel; Zn	—	—	—	3	—	—	3
Combination coin alloys—results included above	6	5	1	2	1	—	15
All nickel-containing with negative or doubtful DMG test results	7	6	1	11	2	2	29

Nickel-containing coins according to X-ray fluorescence (XRF) analysis.

Composition determined by judgement based on official information on websites of central banks and mints, and information from coin collector catalogues (5, 6), together with XRF analysis.

Major areas according to UN statistics (4).

Composition and number of denominations or issues by major area.

Table 5. Nickel-free coins identified among circulating coins in 52 countries from November 2011 to June 2012

Composition (alloy, coating by plating or clad)	No. of nickel-free denominations or issues						Total
	Africa	Asia	Europe	Latin America	North America	Oceania	
Aluminium	1	12	—	4	—	—	17
Aluminium–bronze	—	2	—	3	—	—	5
Brass and bronze	8	5	5	7	2	—	27
Nordic gold	—	1	4	—	—	—	5
Stainless steel	1	10	—	16	—	—	27
Brass and bronze-plated/clad steel	4	8	2	13	—	—	27
Copper-plated/clad Al; steel; Zn	5	7	5	2	2	—	21
Combination coin alloys – results included above	3	1	1	7	—	—	12
All nickel free	19	45	16	45	4	0	129

Nickel-free according to X-ray fluorescence (XRF) analysis and absence of positive dimethylglyoxime test result.

Composition determined by judgement based on official information on websites of central banks and mints, and information from coin collector catalogues (5, 6), together with XRF analysis.

Major areas according to UN statistics (4).

Composition and number of denominations or issues by major area.

issues were DMG test-positive in China, India, the euro zone, and Indonesia, four of the five most populated countries or areas. In the United States, the Russian Federation, Japan, and Mexico, other countries with a population of more than 100 million each, one-third or more of the denominations were DMG test-positive. Table 6 lists the number and values of DMG test-positive circulating coins from some selected countries. More detailed results from the DMG test and XRF analysis, by denomination and country, are given in Table S1.

Discussion

Our study shows that the majority of the world's population live in countries where coins release nickel. It

is considered new knowledge that ~40% of circulating coin denominations do not release nickel, and that some countries only use coins from which no nickel is released, as assessed with the DMG test. The proportion of nickel-releasing coins differs greatly between countries, as shown in the map (Fig. 2).

Our worldwide selection of circulating coins covers countries containing 75% of the world's population. We managed to find coins of all denominations in the majority of countries; the ambition was not to cover issues of different composition. When estimating the proportion of nickel-releasing coins, we did not consider that the share of denominations or issues vary.

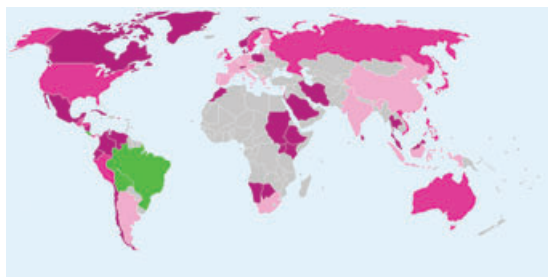


Fig. 2. World map showing the proportions of coin denominations by country with positive DMG test results. Dark pink indicates more than 2/3 DMG positive; pink indicates more than 1/3 but less than or equal to 2/3 DMG positive; light pink indicates less than or equal to 1/3 DMG positive; green indicates no DMG positive; grey indicates unknown.

Table 6. Number and values of dimethylglyoxime (DMG) test-positive circulating coins from selected countries

Countries by population size (ISO code)	No. of DMG test-positive denominations or issues/no. tested	DMG test-positive denominations
China (CNY)	1/4	1 yuan
India (INR)	4/18 ^a	2, 5 ^a , 10 rupee
Euro area (EUR)	2/8	1, 2 euro
United States (USD)	3/5	5, 10, 25 cent
Brazil (BRL)	0/6	—
Russian Federation (RUB)	6/9 ^a	1, 5 kopek; 1, 2, 5, 10 rouble
Japan (JPY)	3/6	50, 100, 500 yen
United Kingdom (GBP)	12/18 ^a	5 ^a , 10 ^a , 20 ^a , 50 ^a penny; 1 ^a , 2 ^a pound
Canada (CAD)	8/11 ^a	5 ^a , 10 ^a , 25 ^a cent; 2 dollar

^aMore than one issue per denomination with different appearance.

Cupro-nickel, or copper–nickel, is the most well-known coin alloy with recognized high nickel release, and it was the most frequently identified coin alloy. Aluminium–bronze, which is less well known among dermatologists, was the second most common coin alloy. Aluminium–bronze coins were either DMG-test positive, or had negative or doubtful DMG test results. A large number of other nickel-releasing compositions were identified, as well as many that had negative or doubtful DMG test results. This proves that there are many widely used alternatives to the nickel-releasing coin materials.

The DMG test offers a qualitative indication of nickel release. It has been used in surveys of nickel release from tools, jewellery, buttons, belts, mobile phones, and other items on the market (8–16). The DMG test has, to the best of our knowledge, not previously been used to assess nickel release from coinage on a national basis; however, it is often used on coins by dermatologists to demonstrate the DMG test to patients. Quantitative assessments

of nickel release from coins in artificial sweat have been performed in other studies, and also assessments of skin exposure through coin handling, as recently reviewed (2, 7, 17–20).

A positive DMG test result strongly indicates that nickel release is higher than 0.5 µg/cm/week, the EU limit for nickel release from items that come into prolonged contact with the skin (21–23). The DMG test was recently validated, and has a high specificity (98%) but a moderate sensitivity (59%) (22). Hence, false-negative reactions may have occurred in this study, whereas, in the vast majority of cases, positive DMG test reactions indicate nickel release at concentrations that may cause allergic nickel dermatitis. Some metals may produce other colours than the pink produced by nickel, which may mask a weak positive DMG test result (11). Examples are aluminium, copper, iron, and zinc, which are all frequently used in coins. This may have resulted in a slight underestimation of nickel release in the present study, particularly from aluminium–bronze coins.

It was sometimes difficult to determine the composition of coins. Official information on websites of central banks and mints was often inaccurate or not given, as was also the case in coin collector catalogues. The XRF analysis provided useful information; however, there are known methodological limitations. The proportions of elements, except for aluminium, close to the surface are given; the instrument cannot discriminate between plating, clad, and alloy; and it does not assess metal release. Single denominations and issues may thus have been misclassified.

Cobalt is not used in coins, but dermatologists often suggest that nickel may contain clinically relevant traces of cobalt. However, cobalt or cobalt release was not detected in any of the coins. We therefore conclude that coins are unlikely to cause cobalt exposure or cobalt dermatitis.

In a review on coins and nickel dermatitis, it was concluded that nickel-releasing coins can indeed pose a risk for those who handle them (2). The conclusion was based on numerous publications on nickel release from different coin alloys, experimental studies showing deposition of nickel on the hands following coin handling, and clinical studies. With up to 30% of middle-aged European women being nickel-sensitized, nickel exposure from coins may not only cause dermatitis in occupational groups such as cashiers, but also add to the burden of daily overall nickel exposure in individuals with nickel-allergic contact dermatitis on the hands (24). Hence, nickel-releasing coins may add to morbidity in many individuals in our societies. It is difficult to estimate the

magnitude of nickel allergy specifically precipitated by exposure to nickel in coins, because it depends heavily on baseline nickel allergy prevalence rates, which are affected by other consumer exposures (e.g. earrings), legislation, and the threshold level of patch testing.

Globally, central banks and mints struggle to bring down the cost of coin manufacturing. We suggest that regulators and other decision-makers deciding on the composition of future coins need to also consider the health risks caused by nickel in coins. This was done when the composition of the euro coins was decided, and recently when it was decided that all Swedish coins from 2015 should be nickel-free (2, 25).

Dermatologists, general practitioners and occupational health services cannot change the composition of coins. It is important that they recognize the nickel allergy risk with coins, to enable more efficient management and prevention of hand eczema.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Detailed X-ray fluorescence (XRF) and spot test results for all coins tested.

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