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Exposures in Nail Salons to Trace Elements in Nail Polish from Impurities or Pigment Ingredients – A Pilot Study

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Abstract

Nail polishes have evolved considerably. Toxic elements, such as lead, have been found in nail polish, and it is unclear if new finishes using metallic effect pigments may be contributing to metals exposure in nail technicians. We characterized concentrations of trace elements in 40 nail polishes, 9 technicians' urine, and 20 technicians' toenail clippings from 8 nail salons in the Boston area in 2017. We also collected 24 salon surface wipes from 3 of the salons. Antimony was not disclosed as a nail polish ingredient, yet concentrations (<15μg/g) were above existing cosmetics guidelines (0.5μg/g) in five (13%) of the samples. Aluminum (<11,450μg/g), barium (<11,250μg/g), iron (<3,270μg/g), and magnesium (<2,375 μg/g) were disclosed as ingredients and were also found on salon surfaces where nail polish was stored or used. Heavy metal impurities in nail polish were not detected for cadmium. Lead and nickel were found at low concentrations (<0.40μg/g lead, <0.67μg/g nickel). Tin (p=0.003) concentrations were higher in nail polish with finishes compared to without. Barium and strontium (both p = 0.0001) concentrations were higher for red nail polishes compared to all other colors. Of those elements in nail polish and salon surfaces, aluminum and iron were detected in toenails, manganese was detected in urine and toenails, and barium was detected in urine at comparable levels to the general population. Besides preventable antimony levels in nail polish, individual metals in nail polish did not appear to be from impurities but mainly from colorants (i.e., pigments) and not major contributors to nail technician exposure. It is unclear if low-level chronic metals mixtures in nail salons are of health concern.

Graphical Abstract

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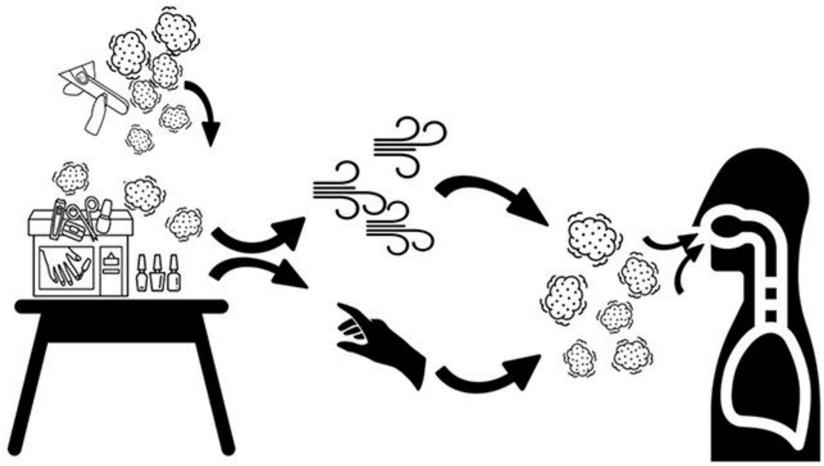
CONFLICT OF INTEREST
The authors declare no conflicts of interest.



Keywords

metals; nail polish; nail salons; nail technicians; biomarker; toenails; urine; surface contamination; trace elements

INTRODUCTION

Lead, cadmium, nickel, manganese, chromium, arsenic, cobalt, and mercury have been found in trace amounts in some nail polish (Ouremi & Ayodele, 2014; Karimi and Parisa, 2015; Iwegbue, 2016; Borowska & Brzóska, 2015; Sipahi et al., 2015; Bocca et al., 2014; Perkin Elmer, 2012). These elements naturally occur in minerals, soil, and water, which can result in trace levels in the manufacturing of pigments and other raw materials used in the making of cosmetics, even if not added intentionally. There are also some instances of colorants (i.e., pigments), used today, that contain metals such as antimony orange (i.e., antimony trisulfide) or manganese violet (i.e., ammonium manganese (III) pyrophosphate) (In-Cosmetics, 2020). Metals such as antimony, arsenic, cadmium, nickel, chromium, cobalt, mercury, and lead are banned as intentional ingredients in cosmetics in the European Union (EU) because of their high neurological and reproductive toxicity, and their inclusion is considered technically avoidable, but this is not the case in the United States (ATSDR, 2012, 2019; Bocca et al., 2014; Bund, 2017; EU Regulations, 2009; FDA, 2020).

Nail polish has been evolving considerably in the last decade, with some nail polish brands adding labels reporting the exclusion of certain toxic ingredients such as lead (Young et al., 2019). New nail polishes, for example, may use metallic effect pigments commonly known as metallic finishes. These new metallic shades in nail polish resemble bronze, copper, gold, and silver, and may contain aluminum, copper, and zinc powders as well as mica and bismuth oxychloride (Eckart, 2020; Koel Colours, 2020; Australian Academy of Science, 2020). Mica is a mineral used as glitter in cosmetics, which may contain iron, aluminum, magnesium, manganese, or barium (Koel Colours, 2020). It is plausible that certain minerals and colorants used in the new finishes could increase metal impurities inadvertently such as lead and cadmium, which are not added as ingredients but can be found in trace amounts in some of the ingredients. Information on metal impurities in nail polish finishes has not been documented in the literature.

In nail salons, dried nail polish from nail filings and chippings likely accumulates on surfaces or indoor dust. There are also new nail products that contain loose fine color powder, commonly used for acrylic nails or gels, which is mixed on-site along with resins right before application. The workers could be exposed to metal-containing dust, from nail polish or color powders, through inhalation, ingestion from hand-to-mouth contact, dermal contact, or contaminated water and food (ATSDR, 2019, 2020). Although metal levels in the blood is an ideal biomarker of exposure, such as blood lead levels (ACGIH, 2019), urine and toenails are often preferred media as they are less invasive and easier to collect, with toenails easily stored at room temperature (Keil, 2011; Grashow, 2014). Urine samples tend to reflec tmore recent exposures (the past few days) compared to toenails (the previous 6–12 months) (Goyer and Clarkson, 2001; Slotnick, 2006; van Dael et al., 2001). The use of metal levels in toenails as a biomarker of exposure for nail technicians has not been documented in the literature.

Nail technicians are exposed to a variety of chemicals from the nail care products used including solvents, acrylics, and plasticizers (Ceballos et al., 2019; Craig et al., 2019). Maternal complications (Quach et al. 2015), respiratory symptoms, neurological, and other adverse health effects (Roelofs et al. 2008) have been a concern to this worker population. It is important then to understand levels of metal impurities present in nail polish that could be contaminating nail salons, exposing nail technicians, and contributing to the burden of exposure and health. Although different, other occupations using paints have presented issues with metal exposures, such as artists Spandorfer et al. 2001), autobody painters (Vitayavirasuk et al. 2005), and other spray painters (Lin et al. 2019).

The specific objectives of this study were to: 1) measure the metal composition of commonly used nail polishes including different types of colors and finishes, 2) assess surface contamination of metals in nail salons, and 3) assess concentrations of metals in the urine and toenail clippings of nail salon technicians.

METHODS

Study Design

We conducted an exposure assessment pilot study to characterize potential metal exposures in nail technicians from nail products. We recruited participants from nail salons in the Greater Boston area, Massachusetts, USA, with the assistance of a regional volunteer stakeholder group (Massachusetts Healthy Cosmetology Committee). The convenient sample of participants were female full-time (i.e., 35 hours/week or more) nail salon technicians who performed primarily nail services, were older than 18 years old, and were non-smokers. All participants read and signed a consent form in their preferred language. One technician opted out of her urine metal analysis. During our visits to their salons, scheduled ideally towards the end of their workweek, we observed nail products used in the salon and administered a short questionnaire in participants' preferred language about occupational factors (such as job tasks and personal protective equipment use) and nonoccupational factors (such as demographics and personal use of nail polish) that might contribute to their body burden. Study protocols were approved by the Institutional Review Boards of the Harvard T.H. Chan School of Public Health and Boston University School of Public Health.

This study included 20 participants and was conducted in two phases in 2017. During Phase I, we recruited and assessed metal exposures from 10 nail technicians from seven nail salons. We collected toenail clippings and pre- and post-shift urine samples for metal analysis. During Phase II, we recruited and collected toenail clippings from 10 different nail technicians from three nail salons (including two of the salons in Phase I). We also performed surface sampling in the three nail salons studied in Phase II.

Nail Polish Sample Selection

Forty nail polishes were chosen from information collected during the salon visits (i.e., reported by the nail salon managers as the most commonly used brands). Nail polish safety data sheets (SDSs) were also obtained from the nail product distributor or manufacturer to understand disclosed ingredients potentially related to metal content. We chose four brands in a variety of colors and finishes as reported by the manufacturer, and only included regular nail polish rather than long-lasting gels. None of the nail polishes selected had labels that reported the exclusion of metals. Details of selected nail polish by color or finish are in supplementary materials (SM) Table S1.

Color in nail polishes has been suggested as a key determinant of metal impurity levels (Karimi and Parisa, 2015); therefore, per brand, the following samples were chosen: a top or base coat, one random red, three other random colors. Reds were chosen as it was reportedly one of the most popular colors used by nail salons. Within the random colors, we made sure to include pinks, as it was the second most commonly used color as reported by the nail salons. Top or base coats were considered as a “no color” category.

Five finishes per brand were also randomly chosen across different types of finishes when available. The finishes included were: glitter, shimmer, metallic, pearl, and neon (definitions for the finish terms are included in the SM). If a nail polish used a different finish term unique to that brand, we renamed the finish term to the closest name of the five types of generic finishes chosen to avoid creating categories with only one finish.

Nail Polish Samples and Analysis

Forty nail polishes were purchased at a Boston local beauty supply distributor and shipped to the University of Washington, Seattle, WA, USA, Environmental Health Laboratory for metal analysis. Each sample of nail polish, between 80 to 750 mg depending on the viscosity of the polish, was weighed in duplicate in the laboratory as‘wet weight’(duplicate average weights listed in SM Table S1). The solvent was left to evaporate at room temperature for a week before digestion in a microwave with a HCl-HNO_3 solution. Duplicate samples were then diluted and analyzed by inductively coupled plasma mass spectrometry (ICP-MS) following the US Environmental Protection Agency (EPA) method 6020a Rev.1 2007 (Restek, 2019). The 27 metals analyzed and minimum detectable limits (MDLs) reported by the laboratory are listed in Table 1.

Nail Salon Surface Wipe Sampling and Analysis

Eight surfaces were wiped from each of the three nail salons in Phase II, for a total of 24 surfaces. Surfaces in the salons were selected from areas in the nail salons identified as in or not in direct contact with nail polish. Direct contact was defined as areas in the salon where nail polish was either stored or used (i.e., manicure and pedicure stations). Areas not in direct contact were where nail polishes were not usually located such as the waiting room or hallways.

Ghost™ wipes (Cat. No. 225–2401A, SKC ltd, Eighty Four, PA) were used to sample surfaces of the nail salons for metal contamination, using a disposable 10 cm by 10 cm paper template and following the US National Institute for Occupational Safety and Health (NIOSH) 9102 wipe method instructions (NIOSH, 2020). The wipes were placed in plastic bags and sent to the University of Washington, Environmental Health Laboratory for ICP-MS analysis following EPA method 6020a Rev.1 2007 (Restek, 2020). Wipe media and 2 field blanks were submitted for analysis from each of the nail salons visited. The 27 metals analyzed in wipe samples are listed in Table 2. The wipe minimum detectable limits (MDLs) reported by the laboratory are listed in SM Table S2.

Nail Technician Urine Sampling and Analysis

Full void urine samples were collected pre- and post-shift in sterile polypropylene specimen containers at the salon. For most metals, one urine sample is usually sufficient (ACGIH 2019), however, we decided to collect at least two samples during the work shift considering the many elements being studied and to obtain some idea of the variability of a spot sample for future studies. Further, for a few metals with short half-lives a post- and pre-shift comparison would suggest changes during the shift – for example, chromium has a half-life of 7hrs (Aitio et al., 1988) and arsenic has a first half-life of 10hrs (ATSDR, 2007a).

Samples were aliquoted and stored on ice during transport. Samples were stored at −80°C until shipped to the U.S. Centers for Disease Control and Prevention's (CDC), Division of Laboratory Sciences, Atlanta, GA, USA, for analysis of creatinine and various metals using an inductively coupled plasma dynamic reaction cell mass spectrometry (ICP-DRC-MS), following published procedures (Caldwell et al., 2005; Jarret et al., 2008). The 15 metals analyzed in urine are listed in Table 2. The urine MDLs reported by the laboratory are listed in SM Table S3.

Nail Technician Toenail Sampling and Analysis

The participants were asked to remove nail polish on their toes at least 72 hours before sampling. For a few of the nail technicians that forgot to remove the nail polish, we removed it with acetone before clipping nails. During the visit to the nail salons, we requested the participants to clip their 10 toenails using a new toenail clipper we provided. Toenail clippings were collected on a paper and placed inside a paper envelope to be shipped for analysis to the Trace Element Analysis (TEA) Core Laboratory, Dartmouth College, Hanover, NH, USA.

Toenail clipping samples were prepared (cleaning and digesting procedure details in SM) and analyzed for 17 trace elements (listed in Table 2) using a standard ICP-MS procedure (Punshon et al., 2016; Specht et al., submitted). The toenail MDLs reported by the laboratory were dependent on the instrument sensitivity and the clipping sample weights (listed in SM Table S4). If clippings weighed below 25 mg, MDLs and concentrations were considered only estimates; this occurred for one of our participants.

Data Analysis

For statistical analyses, we used American Industrial Hygiene Association (AIHA) IHstats V229, SPSS (Version 17.0.2, IBM Corporation), and R (version 3.3.1); statistical significance was evaluated at $p<0.05$. Metal concentrations from the duplicate samples of nail polish were averaged before descriptive statistics. Nail polish concentrations were compared to any existing guidelines in cosmetics (Listed in Table 1). We compared surface contamination to any existing guidelines for surface contamination (Listed in SM Table S2). Observations on work practices and the nail salon environment were not included in the statistical analysis because of the limited number of samples but considered as qualitative information to inform the interpretation of the results. No blank correction was performed on surface wipe samples, as field and media blanks were below MDLs. We substituted all non-detect measured concentrations with MDL/√2, which were presented as “<MDL” in tables.

Considering the high variability of half-lives of metals in urine, ranging from several hours to years in different metals, we explored differences between pre-, post-, and the average of the pre-and post-shift urine median levels against those of the general population, but we did not do statistical comparisons because of the weighed nature of our comparison data from the National Health and Nutrition Examination Survey (NHANES) female data set (CDC, 2020a,b). However, we compared the medians of toenail biomarker levels to those of other studies with U.S. females.

We used Spearman correlation coefficients to examine correlations between variables; for contrasts between paired variables (e.g., pre- and post-shift urine) we used Wilcoxon signed-rank tests; and for contrasts between two independent variables (e.g., finish and no finish nail polish, red and no red nail polish, color and no color nail polish) we used Mann-Whitney U tests.

RESULTS

Nail Salon and Nail Technician Characteristics

Nail technician characteristics in the study are listed in SM Table S5. Participants were 75% Asian, 25% White, and a median of 42 years of age and had worked a median of 5 years full time and 5 years part-time as nail technicians, with a median of 40 hours workweek. During the day of sampling, technicians worked a median of 8 hours. Phase I and II participants had similar characteristics, although Phase I had worked longer full time as nail technicians (median of 10 years) compared to Phase II participants (median of 4.5 years). Fifteen of the 20 participants self-reported as frequently painting their nails with nail polish. All but one technician reported the use of personal protective gloves. However, thirteen of the 20 technicians took gloves off and used their bare fingers and nails to clean customers' nail polish. All salons provided latex gloves and one salon provided nitrile gloves. Eleven nail technicians reported using surgical masks, while only two technicians used disposable N95 respirators with charcoal filters.

Elements in Nail Polish

Table 1 presents medians and ranges of the trace element concentrations measured in nail polish compared to existent cosmetics guidelines. All elements' medians were below guidelines on nail polish from various countries. Specifically, lead in nail polish (up to 0.40 µg/g) was lower than guidelines on lead impurities in cosmetics set by the U.S. Food and Drug Administration (FDA) (10–20 µg/g), Germany Federal Office for Consumer Protection and Food Safety (2 µg/g, also adopted by the EU), and Health Canada (1 µg/g) (FDA, 2020; Health Canada, 2020; German Agency, 2009). Cadmium was not detected (<0.05µg/g) in our nail polishes, so it complied with Germany's and EU's guidelines of 0.1 µg/g and Canada's guideline of 3 µg/g (Health Canada, 2019). The allergenic metals chromium, cobalt, and nickel were also below the suggested 1 µg/g guideline (Basketter et al., 2003). However, antimony concentrations, when detected, severely exceeded Germany's cosmetics' guideline of 0.5 mg/g (German Agency, 2009). Specifically, antimony concentration in five of the nail polishes tested were in the range of 7 to 15 µg/g and above guideline, while antimony in the other nail polishes tested was not detected. The United States has no guidelines for antimony. Table 1 also lists ingredients from the nail polish safety data sheets (SDSs) related to metal content, specifically any disclosed colorants (i.e., pigments), shimmer, or glitter ingredients explicitly containing the measured trace elements. Of the four brands of nail polishes studied, only two of them disclosed any of these ingredients, and none disclosed ingredients explicitly mentioning antimony.

Nail polishes with a finish had a significantly higher median of tin impurities (2.79 µg/g) compared to nail polishes without a finish (0.0859 µg/g, $p = 0.003$). The nail polish with the highest level of aluminum (11,500 µg/g) was a metallic finish; while the product's SDS disclosed mica as an ingredient, which is known to contain aluminum (Koel Colours, 2020). The nail polish with the highest level of magnesium (2,375 µg/g) was the neon finish; while the nail polish's SDS did not disclose any magnesium-containing ingredients.

Colored nail polish had significantly elevated concentration of aluminum, barium, copper, iron, lead, lithium, magnesium, manganese, nickel, and strontium compared to non-colored nail polishes, such as bases and topcoats. Compared to all other polishes, red nail polishes had significantly higher median concentrations of barium and strontium (both $p = 0.0001$). Levels of lead in reds (up to 0.27) were similar to non-reds (not detected to up to 0.40) and levels were lower than the cosmetics' guidelines listed in Table 1. Details of elements in nail polish by finish, color, and red groups are in SM Table S6. Correlations among the elements measured in the 40 nail polishes are in Table S7.

Elements in Nail Salon Surfaces

Table 2 presents the summary results from the 24 surface wipes. Elements on surfaces in nail salons in direct contact with nail polish were not statistically different to those on surfaces without direct contact with nail polish. Details on element levels on surface samples grouped by contact to nail polish and compared to surface reference guidelines are in SM Table S2. Specifically, lead surface levels (not detected in 50% of samples and up to 2.94 μg/100cm^2) were below existing surface contamination guidelines (27 μg/100cm^2 by BNL, 2017; or 93 μg/100cm^2 by EPA, 2019).

Elements in Nail Technician's Biomarkers

Figure 1 shows median creatinine-corrected urinary element concentrations from the nail salon technicians compared to urine samples from US females from the 2015–2016 NHANES (CDC, 2020b). Medians of the pre- and post-shift average element concentrations in urine were not statistically different to the medians from urine samples from NHANES. Element concentrations and percent detected measured in urine are in SM Table S3. Elements in urine did not have concentrations post-shift that were significantly higher than pre-shift suggesting no uptake of metals with short half-lives. Interestingly, cadmium levels in urine post-shift were significantly lower than pre-shift ($p = 0.008$).

Not many studies characterizing toenail concentrations of metals in US female adults have been published. Figure 2 presents a comparison of the median element concentrations in toenail samples from nail salon technicians to toenail samples from four other studies of US females including: Kentucky study (residents of the Appalachian region, Johnson et al., 2011); the Arsenic Mercury Intake Biometric Study (AMIBS, Japanese community in the northwest of the US, Hinners et al., 2012); Health Professionals Follow-up Study (nationwide nurses and other health practitioners, Mozaffarian et al., 2011); and Sister study (nationwide adult females, Obrien et al., 2018). The element medians measured in the toenails of nail technicians were sometimes slightly higher but comparable to those reported in other studies in US females. The most noticeable differences in metals of concern included arsenic, chromium, mercury, and nickel. Element concentrations and percent detected measured in toenails are in SM Table S4.

DISCUSSION

Besides levels of antimony in nail polish exceeding cosmetics guidelines, we did not find other toxic metals in exceedance of current guidelines in our sample of nail polishes. We also did not find levels on nail salon surfaces or in urine biospecimens from the nail technicians studied to be above existing health and safety guidelines.

Nail polish with finishes had significantly higher concentrations of tin compared to nail polishes without finishes. The elements found in highest concentrations in nail polishes were aluminum, barium, bismuth, iron, and magnesium. Surfaces in the nail salons also contained dust with aluminum, barium, iron, and magnesium. No significant differences on surfaces where nail polishes were stored or used with other surfaces may point at the small workplaces where dust may distribute throughout.

A review of the SDSs for the nail polishes disclosed ingredients containing highest elements (except bismuth). For example, barium sulfate, aluminum powder, iron oxides, and mica (known to contain magnesium) were disclosed in nail polish SDSs (listed in Table 1). Of those elements in nail polish and nail salon surfaces, aluminum and iron were also detected in toenails, and manganese was detected in both urine and toenails. Also, barium was detected in urine at comparable levels to those of the general population. Although implications for worker health are unclear, these elements are ubiquitous and occupational exposure limits are often set at extremely high levels (ATSDR, 2007b, 2008) that are unlikely in nail salons. In the context of women's health, these exposures contribute to the overall burden of exposure and should not be ignored.

Our study found traces of 21 of the 27 elements tested in nail polishes. Of the 40 nail polishes analyzed, the antimony guideline of 0.5 μg/g was exceeded in all five samples that detected this element. Our polishes had concentrations up to 15 μg/g of antimony, which is high enough to suggest that antimony was added intentionally as an ingredient. Antimony is a heavy metal, commonly used as a pigment (In-Cosmetics, 2020); although not listed in any of the SDS's reviewed. Although the German guideline was not based on health risks of antimony but technical feasibility (i.e., that presence is avoidable in the product by not adding ingredients composed of antimony), the European Union classifies antimony as an element that must be eliminated from cosmetics because of its toxicity (In-Cosmetics, 2020). In occupational settings, chronic exposures to antimony may cause respiratory irritation, pneumoconiosis, antimony spots on the skin, and gastrointestinal symptoms but only at extremely high concentrations in air (in the mg/m3, Sundar and Chakravarty, 2010), which are not likely to occur in nail salons. However, is important to note that nail polish guidelines were developed thinking of consumers that have lower exposures than nail technicians.

The presence of antimony along with cobalt, lead, manganese, and tin, in all of the types of sample matrices tested in the present study, suggests that these elements are common in small amounts. Specifically, cobalt and manganese are essential trace metals or metalloids that are important for vital functions in humans and possibly found in food (Gutierrez-Gonzalez et al., 2019). Lead was heavily used in paints and gasoline before the 1970s and is still found in soil and dust, especially in old buildings (ATSDR, 2019a). Tin is a low toxicity metal heavily used in metal alloys as a component of furniture and everyday items including cosmetics (Toxnet, 2020; Johnson et al., 2014). However, guidelines are often set based on single metal toxicity, but since they appear together in cosmetics, we don't know their potential collective impact on toxicity or health. Specifically, many elements were found simultaneously in the nail polish samples, like in the case for example of manganese and tin (i.e., elements were significantly correlated, Table S7).

We found the highest nail polish concentrations Pre for aluminum, iron, and magnesium. Aluminum, in particular, is an extremely abundant element found in soil and rocks, and important if added as an ingredient or found as an impurity given its neurotoxicity at very high concentrations (ATSDR, 2008). Other studies on nail polish had not measured those elements. However, Karimi and Parisa (2015) found that nail polish in Iran had lead levels up to 24 μg/g, with reds at up to 6 μg/g, while the present study had lead levels only up to

0.4 µg/g of lead with reds at up to 0.027 µg/g. In general, trace elements found in the nail polishes in our study would not be considered a high-risk exposure source in occupational health. However, it is important to acknowledge that the results from the nail polish analysis may be useful for understanding exposures to personal care products in the general population.

Lead and cadmium are important impurities in cosmetics to study given their neurotoxic and carcinogenic qualities to humans (lead IARC group 2A, cadmium IARC group 1, IARC, 2020; ATSDR, 2019). Although our sample of nail polishes did not detect cadmium, we did not sample the universe of all nail polishes used in the salons and it may still be present in other polishes. Median levels of urinary lead and cadmium in the nail technicians studied were comparable to those of the general female US population. As a contrast, lead and cadmium levels in the nail technicians' toenails were comparable to other studies. However, toenail levels had a wider variability in the results compared to urine samples. There is no data for toenails in the general population for NHANES, so no comparisons to the general public were made.

Toenail levels of lead and cadmium depend on sulfide bonds in toenails for accumulation. The majority of cadmium accumulates in the kidneys and is very slowly eliminated from the body (in decades) compared to a shorter half-life of months in toenails (Keil, 2011). Similarly, the bones are a major storage depot for lead, where it has a half-life of approximately 32 years, and leaves the body very slowly due primarily to lead's ability to mimic calcium. With the sulfide bonds in toenails, less lead will accumulate in total than in bone (Keil, 2011). Levels of lead in toenails may reflect the reduction of environmental lead pollutants and body stores in the past decade, including the use of nail polishes without lead.

The nail technicians in this study had toenail median levels of arsenic of 0.13 µg/g, which was higher than the level (0.04 µg/g) found in the Kentucky study (Johnson et al., 2011) and the Health Professionals Follow-up Study (0.048 µg/g) (Mozaffarian et al., 2011). The higher toenail arsenic in our population may be of concern as Mordukhovich et al. (2012) had found an association between higher toenail arsenic and higher systolic blood pressure and pulse pressure in adults without arsenic-related occupational exposures. Arsenic is also an important impurity given its carcinogenic qualities (IARC group 1, IARC, 2020). Although arsenic was not measured in urine in this study for comparison, toenails can capture months of exposure to arsenic.

Other metals in toenails that were slightly higher in nail technicians compared to other studies included chromium, nickel, and mercury. Toenail chromium (median of 0.38 µg/g) in this study was also slightly elevated compared to that reported by the Sisters study (0.21 µg/g, Obrien et al., 2018). Nickel in toenails was 0.31 µg/g in this study, compared to 0.16 µg/g in the Kentucky study. Nickel in particular is an important impurity given its carcinogenic potential in humans (IARC group 1, IARC, 2020). Nail technicians' toenail mercury of 0.90 µg/g was higher than the reported levels in the Sisters study (0.097 µg/g), the Health Professionals Follow-up Study (0.31 µg/g), and the AMBIS study (0.5 µg/g, Hinners et al., 2012). Some of the mercury differences between these groups could be attributable to cultural differences in fish consumption in the Asian nail technicians, which was 75% of our participants with a higher level in mercury (median of 0.90 μg/g) compared to other participants (median of 0.24 μg/g)although not statistically significant ($p = 0.168$). The Hinners et al. (2012) study included Japanese residents near Puget Sound in Washington with heavy fish diets and suggested a potential link with diet, although they still had lower values than those of our study participants.

There are several limitations to our study. First, this was a pilot study using a convenient and limited number of samples and without urine samples from all participants, which hindered the possibility to do a more in-depth data analysis to be considered as representative of the industry. Another disadvantage of our pilot study was that we asked limited questions about other potential sources of exposure for nail technicians in their environments at home and at work (e.g., diet, hobbies, home, and other jobs). Another limitation of the study is that most nail technicians used nail polish, so any exposures to components of the nail polish would be from both personal and occupational uses. Surfaces are often also made with many of the elements measured, such as aluminum or iron among others, so it is impossible to discern the contribution of surface materials versus nail polish related dust towards our sampling results. To discriminate the different sources of nail polish exposures, a control population may be needed in future health studies including nail technicians. Future studies could include laboratory analysis of other nail products such as colored acrylic nail powder and long-lasting nail polish, which were not analyzed in our study. Further, understanding of the bioavailability of trace elements in nail products will be important in follow up studies.

As discussed above, several studies have analyzed samples of nail polishes for trace heavy metals. However, to our knowledge, this is the first study to characterize potential nail technicians' exposures to trace elements found in nail polish. Important in particular is the evaluation of sources from disclosed pigment ingredients in the nail polishes. Further, this is the first study to analyze different types of nail polishes characterizing the novel generation of finishes new to the industry beyond color. It is important to understand the role that certain metals may play in the health of nail technicians given the many health concerns in this worker population. This study provides preliminary information for future health studies in populations that may include nail technicians.

CONCLUSION

Nail polishes studied did not contain traces of toxic metals above cosmetics' guidelines, except for antimony. Further, we found trace elements in nail polish samples that were not always listed as ingredients in the product information. Our findings suggest that antimony concentrations in nail polish may not be an immediate health hazard but are avoidable and should be disclosed since the existing international guideline was not based on specific health risks of antimony but technical feasibility.

Color in nail polishes contributes to presence of trace elements and finishes in nail polish seem to be contributing specifically to the levels of tin found in nail polishes. The surface wipe data suggests that dust generated in salons from the use of nail polish may be depositing on surfaces and potentially contributing to nail technician's overall exposure. Potential contributions to exposure to nail technicians from nail polish use may include aluminum, barium, iron, magnesium, and tin. Although these would only be toxic individually at very high levels not present in nail salons, it is unclear if low-level metals mixtures are of health concern. Regardless, these results provide further evidence of the importance of ventilation and general housekeeping to keep dust levels low in salons and protect the health of nail technicians.

Results from biomarkers of exposure in nail technicians suggest that this vulnerable population may have levels of certain metals including arsenic and mercury that could be related to other factors rather than their work. Toenails may be a useful non-invasive biomarker to understand exposure to trace elements in this worker population.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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ABBREVIATIONS

Ag	Silver
AIHA	American Industrial Hygiene Association
Al	Aluminum
AMIBS	Arsenic Mercury Intake Biometric Study
As	Arsenic
ATSDR	The Agency for Toxic Substances and Disease Registry
Au	Gold
Ba	Barium

Be	Beryllium
Bi	Bismuth
BNL	Brookhaven National Laboratory
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
DRC	Dynamic Reaction Cell
EPA	U.S. Environmental Protection Agency
EU	European Union
FDA	U.S. Food and Drug Administration
Fe	Iron
GSD	Geometric Standard Deviation
IARC	International Agency for Research on Cancer
ICP	Inductively Coupled Plasma
In	Indium
Li	Lithium
MDL	Minimum Detectable Limits
MS	Mass Spectrometry
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Number
Ni	Nickel
NIOSH	U.S. National Institute for Occupational Safety and Health
NHANES	National Health and Nutrition Examination Survey
Pb	Lead
Sb	Antimony
SDS	Safety Data Sheets

Se	Selenium
SM	Supplementary Material
Sn	Tin
Sr	Strontium
TEA	Trace Element Analysis
Ti	Titanium
Tl	Thallium
V	Vanadium
Zn	Zinc

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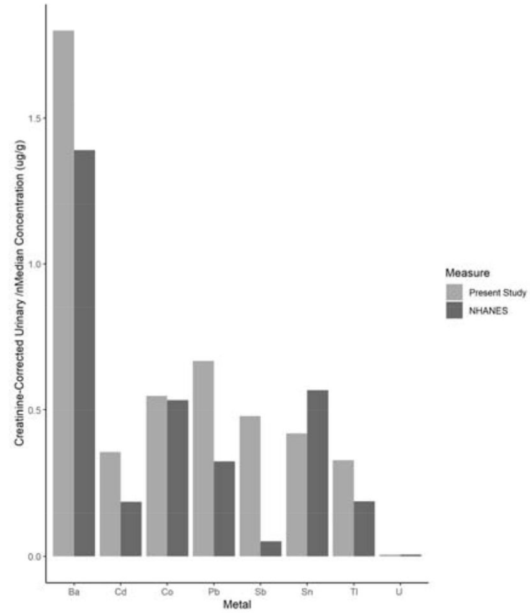
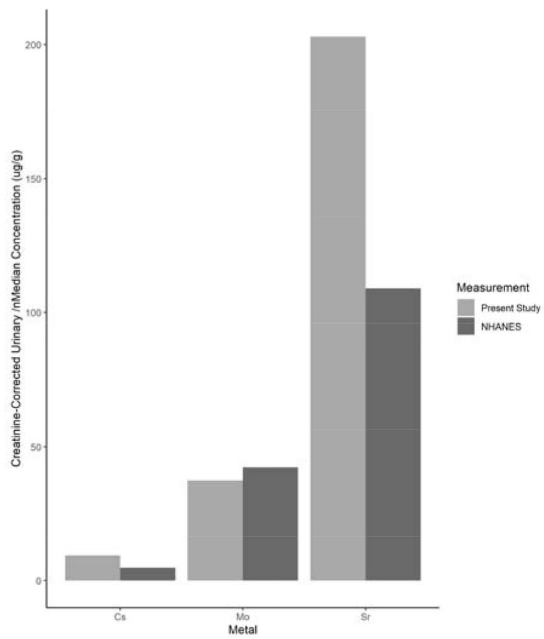
HIGHLIGHTS

- Antimony was measured at levels higher than nail polish guidelines but not disclosed as ingredient in product information.
- Antimony is an avoidable ingredient and should be disclosed as a nail polish ingredient.
- Concentrations of elements in nail polish were related to the presence of pigments.
- Elements from nail polish seem to contribute to some of the nail salon technicians' exposure.



A: Elements in the lowest concentration range



B: Elements in the highest concentration range

Figure 1.

Comparison of creatinine-corrected median and 95th percentile (μg/g) urinary element concentrations in pre- and post-shift average samples from nail salon technicians in the Greater Boston Area (2016–2017) to urine samples from U.S. females from the 2015–2016 NHANES. Elements included were > 50% minimum detectable limit (MDL) and measured by NHANES as follows: top (Figure 1A) showing Ba = Barium, Cd = Cadmium, Co = Cobalt, Pb = Lead, Sb = Antimony, Sn = Tin, Tl = Thallium, and U = Uranium; bottom (Figure 1B) showing Cs = Cesium, Mo = Molybdenum, and Sr = Strontium.

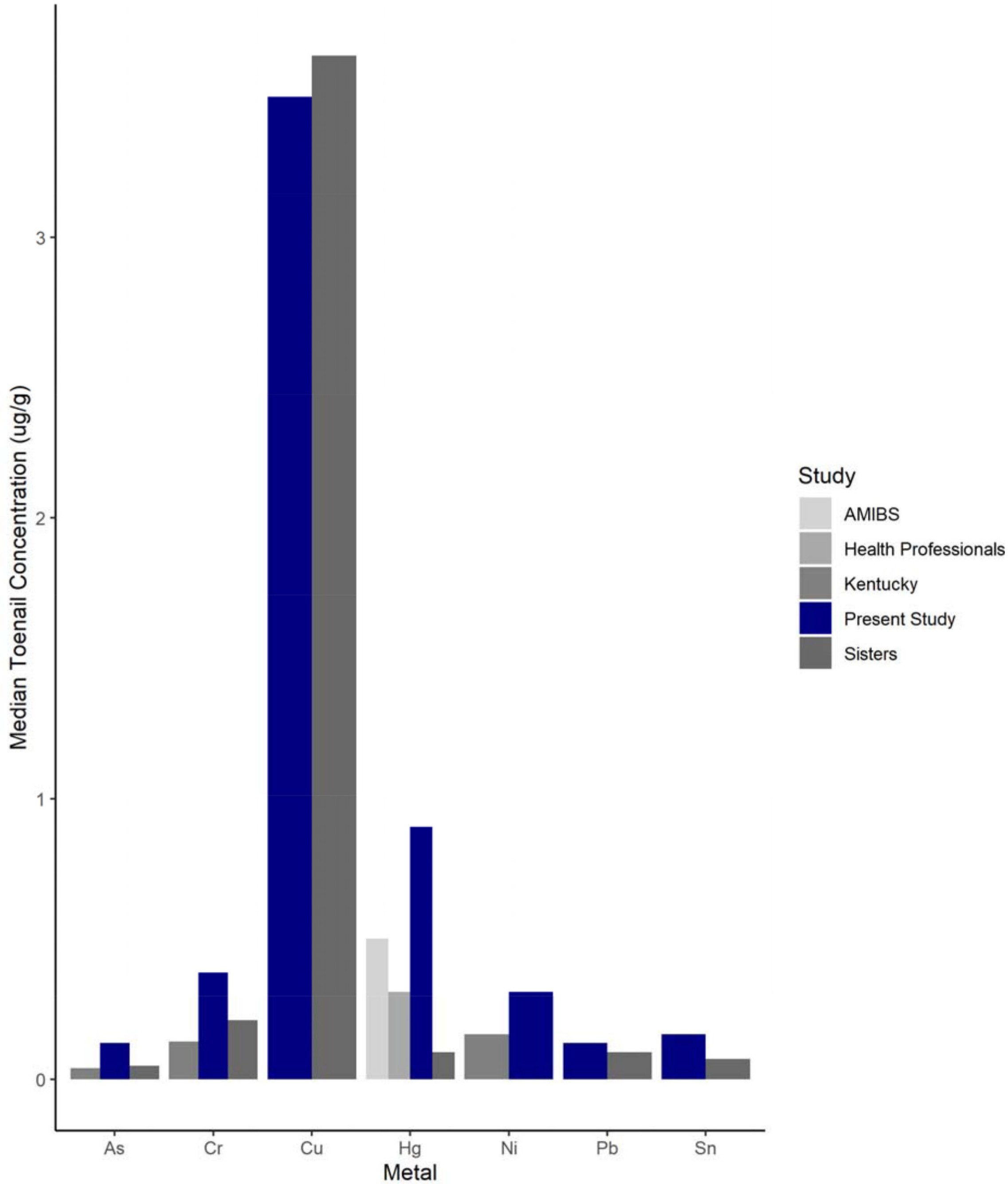


Figure 2.

Comparison of median (µg/g) element concentrations in toenail samples from nail salon technicians in the Greater Boston Area (2016–2017) to toenail samples from other studies with US females: AMIBS (Hinners et al. 2012); Health Professionals Follow-Up Study (Mozaffarian et al 2011); Kentucky (Johnson et al 2011); and Sister Study (Obrien et al 2018)). In the graph, we included Mercury mean (instead of median) from the Health Professionals Follow-Up Study as Mozaffarian et al., 2011 only published mean and median was not possibly deduced from the data presented in the paper. Elements listed left to right include: As = Arsenic, Cr = Chromium, Cu = Copper, Hg = Mercury, Ni = Nickel, Pb = Lead, Sn = Tin. Cadmium, cobalt, and molybdenum were excluded from the graph because of the low and comparable levels of the present study with other studies.

Table 1.

Elements detected in 40 nail polishes selected by brand, color, and finish in order from highest to lowest of percent detected

Element	Ingredient[a]	Nail Polish Concentration, µg/g				Guideline
		MDL	% > MDL	Median	Range	
Mg	Mica[b]	0.25	100	459	0.78–2,375	
Zn	Zink sulfide	0.50	100	1.48	<MDL–13	
Ba	Barium sulfate, mica	0.05	100	6.81	0.095–11,250	
Mn	Manganese violet, mica	0.05	98	0.99	<MDL–9.9	
Fe	Iron powder, iron oxide, mica	2.5	95	51	<MDL–3,270	
Sn	Tin oxide	0.05	95	0.94	<MDL–5.4	
Al	Aluminum powder, alumina (i.e., aluminum oxide), mica	2.5	93	274	<MDL–11,500	
Ni		0.05	93	0.16	<MDL–0.67	1 µg/g (Basketter et al. 2003), skin[c]
Cu	Copper powder	0.05	93	0.17	<MDL–31	1 µg/g (Health Canada 2020),
Pb		0.05	93	0.21	<MDL–0.40	2 µg/g (Germany Agency 2009; EU 2009), 10–20 µg/g (FDA 2020)
Ti	Titanium dioxide	0.25	85	19	<MDL–143	
Sr		0.05	83	3.26	<MDL–99	
Bi		0.05	70	0.08	<MDL–6,355	
Li		0.05	65	13	<MDL–84.2	
Cr		0.25	38	<MDL	<MDL–0.97	1 µg/g (Basketter et al. 2003), skin[c]
As		0.05	20	<MDL	<MDL–0.091	0.5 µg/g (Germany Agency 2009; EU 2009)
Be		0.05	18	<MDL	<MDL–0.093	
V		0.25	13	<MDL	<MDL–0.66	
Mo		0.05	13	<MDL	<MDL–0.18	
Sb		0.05	13	<MDL	<MDL–**15**	0.5 µg/g (Germany Agency 2009; EU 2009)
Co		0.05	10	<MDL	<MDL–0.31	1 µg/g (Basketter et al. 2003), skin[c]
Se		0.25	0	<MDL	<MDL	
Ag		0.05	0	<MDL	<MDL	
Cd		0.05	0	<MDL	<MDL	0.1 µg/g (Germany Agency 2009; EU 2009), 3 µg/g (Health Canada 2020)
In		0.05	0	<MDL	<MDL	
Au		0.05	0	<MDL	<MDL	
T1		0.05	0	<MDL	<MDL	

Mg = Magnesium, Zn = Zinc, Ba = Barium, Mn = Manganese, Fe = Iron, Sn = Tin, Al = Aluminum, Ni = Nickel, Cu = Copper, Pb = Lead, Ti = Titanium, Sr = Strontium, Bi = Bismuth, Li = Lithium, Cr = Chromium, As = Arsenic, Be = Beryllium, V = Vanadium, Mo = Molybdenum, Sb = Antimony, Co = Cobalt, Se = Selenium, Ag = Silver, Cd = Cadmium, In = Indium, Au = Gold, Tl = Thallium. MDL = minimum detection limit.’

[a]Ingredients disclosed in nail polish safety data sheets explicitly containing the element.

[b]Mica is a mineral that might contain iron, aluminum, magnesium, manganese, or barium (Koel Colours 2020).

[c]Skin sensitizer or allergen.

Table 2.

Median and range concentrations of different elements in different matrices measured in nail salons in the Greater Boston Area (2016 – 2017)

Element	Abbreviation	Surface Wipes N samples = 24 N salons = 3 µg/100 cm^2 Median (Range)	Urine N samples* = 9 N salons = 7 µg/g creatinine Median (Range)	Toenail N samples = 20 N salons = 8 µg/g Median (Range)
Aluminum	Al	5 (<MDL–360)	--	9.1 (2.62–21)
Antimony	Sb	<MDL (<MDL–0.2)	0.48 (0.16–1.9)	0.035 (0.0063–0.11)
Arsenic	As	<MDL	--	0.13 (0.057–0.47)
Barium	Ba	0.45 (<MDL–26.4)	1.8 (1.2–5.6)	--
Beryllium	Be	<MDL	<MDL	--
Bismuth	Bi	<MDL (<MDL–0.1)	--	--
Cadmium	Cd	<MDL	0.36 (0.17–1.6)	0.0067 (<MDL–0.09)
Cesium	Cs	--	9.4 (4.4–13)	--
Chromium	Cr	<MDL (<MDL–7.6)	--	0.38 (0.064–21)
Cobalt	Co	<MDL (<MDL–1.8)	0.55 (0.24–2.9)	0.0071 (0.0035–0.089)
Copper	Cu	<MDL (<MDL–5.7)	--	3.5 (2.76–7.0)
Gold	Au	<MDL	--	--
Indium	In	<MDL	--	--
Iron	Fe	(<MDL–184)	--	39 (8.41–179)
Lead	Pb	0.043 (<MDL–2.9)	0.67 (0.26–1.9)	0.13 (0.052–1.1)
Lithium	Li	<MDL (<MDL–0.2)	--	--
Magnesium	Mg	7 (<MDL–859)	--	--
Manganese	Mn	<MDL (<MDL–6.1)	0.29 (<MDL–0.82)	0.22 (0.05–4.1)
Mercury	Hg	--	--	0.90 (0.0272–2.5)
Molybdenum	Mo	<MDL	38 (17–67)	0.0084 (0.00526–0.14)
Nickel	Ni	<MDL (<MDL–4.1)	--	0.31 (0.052–113)
Platinum	Pt	--	0.03 (<MDL–0.07)	--
Selenium	Se	<MDL	--	0.75 (0.59–1.1)
Silver	Ag	<MDL	--	--
Strontium	Sr	<MDL (<MDL–4.7)	203 (59–1,017)	--
Thallium	Tl	<MDL	0.30 (0.11–0.76)	--
Tin	Sn	<MDL (<MDL–9.7)	0.41 (0.17–3.3)	0.16 (0.036–3.3)
Titanium	Ti	<MDL (<MDL–2.5)	--	
Tungsten	W	--	0.08 (<MDL–0.19)	--
Uranium	U	--	0.0059 (<MDL–0.01)	--
Vanadium	V	<MDL (<MDL–0.2)	--	0.016 (0.0057–0.037)
Zinc	Zn	<MDL (<MDL–50)	--	89 (63–122)

*Average of pre- and post-shift urine samples. N = Number. MDL = Minimum detectable limit. – Notes that this element was not measured in the specific sample matrix.