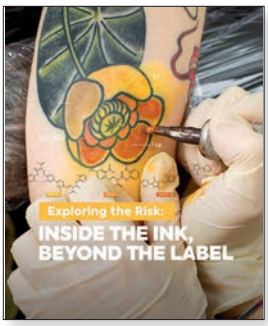

Decoding Tattoo Inks: Multiple Analysis Techniques Reveal Discrepancies in Ingredient Composition and Elemental Content When Compared Against Label Claims

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Abstract

Permanent body art has grown in popularity in recent years, with millions of individuals having black/monochrome or colorful tattoos. With this decision to get a tattoo comes risk: Injecting coloring compounds into the skin has been reported to cause allergies, skin inflammation, and systemic disorders. Despite the growing number of tattooed individuals, there are currently few regulations, laws, and safety criteria for tattoo and permanent cosmetic formulations. The goal of our study was to identify the pigments in a set of commercially available yellow tattoo inks. We examined a set of previously unstudied yellow tattoo inks: lemon yellow (LY), golden yellow (GY), golden rod (GR), and bright orange (BO). We also examined reference pigments: pigment yellow 14 (PY14), pigment yellow 65 (PY65), pigment blue 15 (PB15), and pigment orange 13 (PO13). Both sets of inks were examined using a range of techniques, including Fourier transform infrared (FTIR) spectroscopy, nuclear magnetic resonance (NMR) spectroscopy, X-ray diffraction (XRD), Raman spectroscopy, energy dispersive X-ray (EDX) spectroscopy, and inductively coupled plasma optical emission spectroscopy (ICP-OES).

We report that the combined use of these techniques can provide major insights into ink composition without needing difficult and time-consuming sample preparation. Results of our study indicate that the ink compositions differed from what was described on the labels. Furthermore, we demonstrate that the tattoo inks tested included additional elements that were not listed as ingredients, such as aluminium (Al), sodium (Na), and silicon (Si). These unlabeled ingredients raise concerns about the regulation, health effects, and degradation products of tattoo inks.

Keywords: tattoo ink, pigment yellow, chemical analysis, safety regulations

Introduction

Body decoration by tattooing has increased in popularity in the last 10 years. It has been reported that 40% of young adults in the U.S. and 25% of adults in Australia have at least one tattoo (Chalmers et al., 2019; Heywood et al., 2012; Lichnyi et al., 2021; Niederer et al., 2018). Tattoo ink suspensions can contain various chemical compounds, including 1) vehicles such as water, glycerine, and other alcoholic derivatives; 2) additives such as surfactants, polycyclic aromatic hydrocarbons, nanoparticles, and polymers; and 3) pigments of varying purity (Arl et al., 2019; Bäumler, 2020; Høgsberg et al., 2011; Wang et al., 2021). These chemical compounds can include substances that were designed for use in paints, non-tattoo inks, or plastics.

Throughout history, the composition of tattoo pigments has evolved from natural extracts and metal salts to a mix of inorganic oxides, salts, inorganic pigments, and azo dyes (Barua, 2015). Historically, inorganic compounds such as mercury(II) oxide for red, cobalt(II) aluminate for blue, chromium(III) oxide for green, manganese violet for purple, titanium dioxide for white, and iron oxides for brown tones were used (Bocca et al., 2017; Poon et al., 2008; Riffo et al., 2020). Often, these inorganic compounds were blended with other organic and inorganic components to enhance the vibrancy of the colors (Forte et al., 2009). Now, however, tattoo ink manufacturers use artificial organic and organometallic pigments mixed with inorganic compounds to make tattoo inks (Negi et al., 2023), with metals still present as chromophores, shading additives, or impurities (Arl et al., 2019; Riffo et al., 2020). Further, inorganic pigments based on metal salts are currently used in micropigmentation inks in permanent cosmetics such as permanent eyebrow makeup, eyeliner, and lip color (Riffo et al., 2020) due to their higher durability against light and heat, better setting capacity, and larger size—all of which make their removal more difficult.

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Modern tattoo inks vary greatly in composition and can contain hazardous ingredients not originally intended for this purpose (Negi et al., 2022) and might not have a proven track record of safety in tattooing (Lehner et al., 2011; Vasold et al., 2004). Increasingly, there are concerns about tattoo ink effects on human health, including potential carcinogenicity (Bauer et al., 2022; Desmedt et al., 2022). Additionally, it has been reported that tattoo inks can trigger acute allergic reactions immediately or lead to hypersensitivity after long-term exposure (Senaldi et al., 2016; Renzoni et al., 2018; Wang et al., 2021). For example, Klügl et al. (2010) reported that >70% of 3,411 tattooed persons experienced issues with their skin immediately or within a few weeks after getting their tattoo. Moreover, allergic responses to tattoos, especially with red inks, have been reported to persist for months or years (Serup et al., 2017).

Given the growing popularity of tattoos and the possibility of dangerous ingredients in tattoo products, regulations are needed to reduce the hazards caused by inappropriate tattoo inks (Wang et al., 2021). In Australia, for example, tattoo inks are not considered therapeutic materials and are not regulated by the Therapeutic Goods Administration. Instead, the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) regulates the chemicals found in tattoo inks but typically does not legislate the import of a chemical that is used in tattoo ink if they are listed in the Australian Inventory of Chemical Substances. Little is known about tattoo ink contamination or adulteration (Musgrave, 2014); however, there is evidence of incorrect labeling. In 2016, a NICNAS report about tattoo ink composition advised that specific tattoo inks in Australia were noncompliant with regulations, marketed with incorrect ingredients, or not suitable for use (National Industrial Chemicals Notification and Assessment Scheme, 2018). In addition, according to a survey conducted among tattoo artists in downtown Brisbane and Melbourne Central in Australia, tattoo artists were unaware of the ingredients in their inks or the possible dangers associated with them (Matsika et al., 2016).

In Europe, tattoo inks are regulated by the European Union's General Product Safety Directive. According to this directive, a producer is required to place only safe items on the market, and a comprehensive list of contents must be included on the product label, which is accomplished through classification, labeling, and packaging (Minghetti et al., 2019; Negi et al., 2022).

In 2011, an analysis by Hauri (2011) reported finding 34 prohibited pigments in 30 tattoo ink samples. The pigment green 36 (PG36, C.I. [color index] 74265) was declared in three green inks, but the samples were demonstrated to include the prohibited pigment green 7 (PG7, C.I. 74260). Furthermore, a yellow and a blue pigment were stated for one ink, but the ink was again found to contain PG7, not the stated yellow and blue pigments. The ingredient list on a violet ink was incorrect: The ink included the pigment white (titanium dioxide [TiO_2]) and the pigment blue 15 (PB15, C.I. 74160), which when combined produce a light blue. And the violet color was shown to be created with the prohibited pigment violet 23 (PV23, C.I. 51319).

Concerningly, mislabeling and undeclared ingredients continue to persist in commercial formulations of tattoo ink. A study by Poon et al. (2008) examining 190 tattoo inks indicated that 37% of the inks included prohibited substances and 53% contained >1 of A) excessive levels of nitrosamine, B) unreported material, or C) claimed material that was not found in the ink. More than a decade later, Wang et al. (2021) reported that for 50% of the tattoo inks they tested, labeling inaccurately stated at least one pigment component. Furthermore, a study by Moseman et al. (2024) showed major discrepancies between tattoo ink composition and ingredient labels, especially for the nonpigment components (e.g., carrier, vehicle). Regarding tattoo safety and the possibility of allergic sensitization, it is likely that some pigments have been removed from the ink formulations due to EU regulations banning specific pigments in tattoo inks (Kiszla et al., 2023; Wang et al., 2021).

Identifying pigments in commercial tattoo inks presents a large challenge due to the inks' complex composition, diverse combinations of pigments used to achieve subtle colors, poor solubility of pigments in traditional solvents, and other additives present that enhance pigment dispersion (Bauer et al., 2019). Studies have primarily relied on mass spectrometry (MS) for pigment analysis. Both Hauri (2011) and Wang et al. (2021) used MALDI-TOF MS to identify pigments in tattoo inks; however, this approach has limitations. For example, Wang et al. (2021) showed that some pigments were unable to be detected using MALDI-TOF MS due to poor ionization and or low mass. Furthermore, MS-based techniques often require extensive sample preparation, making the analysis time-consuming and challenging for label compliance assessments.

Given the complex and varied chemical nature of tattoo ink ingredients, our study aimed to develop a novel approach for pigment identification by applying a combination of spectroscopic techniques. Unlike previous studies that primarily analyze tattoo inks after extensive pretreatment, digestion, or extraction, our approach focused on examining inks in their dried, untreated state or with minimal sample preparation. Compared with MS, spectroscopic techniques such as infrared (IR), nuclear magnetic resonance (NMR), X-ray diffraction (XRD), Raman, and energy dispersive X-ray (EDX) enable rapid, minimally destructive analysis of pigment molecular structures, crystallinity, and elemental composition with minimal sample preparation requirements (Bauer et al., 2019, 2020; Moseman et al., 2024). Although most prior research uses these techniques in isolation, our study leveraged the combined information from spectroscopic and elemental analysis techniques of IR, NMR, XRD, Raman, EDX, and inductively coupled plasma optical emission spectroscopy (ICP-OES) to rapidly assess the pigment composition of a set of yellow inks that have not been examined previously.

Methods

Materials and Instruments

INTENZE brand lemon yellow (LY), golden yellow (GY), golden rod (GR), and bright orange (BO) tattoo inks were purchased from Tattoo Direct in Victoria, Australia. Pigment yellow 14 (PY14, C.I. 21095, 97% purity); pigment yellow 65 (PY65, C.I. 11740, 98% purity); pigment white (titanium dioxide [TiO_2], C.I. 77891, 99.5% purity); pigment blue 15 (PB15, C.I. 74160, technical grade); pigment orange 13 (PO13, C.I. 21110, technical grade); and barium sulfate ($BaSO_4$, C.I. 77120, 99% purity) were purchased from AK Scientific in Union City, California. Methy-

TABLE **1**

Reported Ingredients of Tattoo Inks According to Manufacturer's Label and Material Safety Data Sheets (MSDS)

Tattoo Ink	INTENZE: Lemon Yellow					INTENZE: Golden Yellow				
	Declaration of Ingredients*	MSDS			Confirmed in Study	Declaration of Ingredients*	MSDS			Confirmed in Study
		2018	2022	2023			2018	2022	2023	
TiO_2	x	x	x	x	✓	x	x	x	x	✓
$BaSO_4$	x	x	x	x	✓	–	x	x	x	✓
PB15	x	x	x	–	✓	–	–	–	–	–
PY65	x	–	–	–	x	–	–	–	–	–
PY14	–	x	x	x	✓	x	x	x	x	✓
PO13	–	–	–	–	–	x	–	–	x	x
Aqua	x	x	x	x	–	x	–	x	x	–
Glycerine	x	x	x	x	–	x	–	x	x	–
Hamamelis virginiana (witch-hazel) extract	x	x	x	x	–	x	–	x	x	–
Isopropyl alcohol	–	x	x	–	–	–	–	x	x	–

continued

lene chloride (99.9% purity) was purchased from RCI Labscan, Australia.

Except for the tattoo inks, all chemicals used in our study were not purified further. Tattoo inks were pipetted onto microscope slides and dried in open air at ambient temperature for 48 hr prior to characterization. To extract the pigments from the liquid tattoo inks, we added approximately 25 mg of tattoo ink to a 50-ml conical glass tube containing 2 ml of water. The contents were mixed vigorously and extracted 3 times with 15 ml of methylene chloride. The methylene chloride extracts were combined, dried, and analyzed as dry tattoo ink extracts.

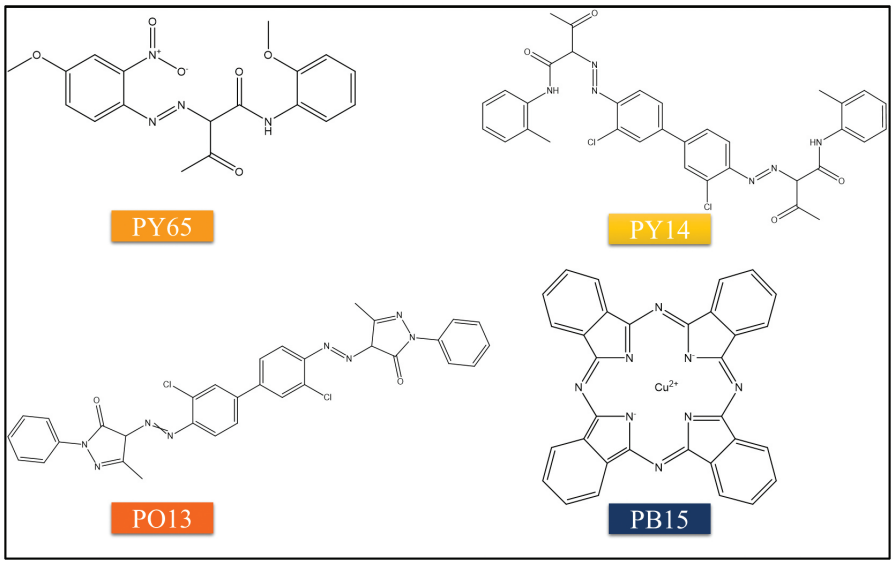
Instrumental Analysis

Fourier transform infrared spectroscopy (FTIR) was used to generate an IR spectrum of the pigments and dried inks using a Perkin Elmer Spectrum 100 FTIR spectrophotometer equipped with an attenuated total reflectance (ATR) diamond crystal in the range of 400–4,000 cm^{-1} with a resolution of 4 cm^{-1}. The energy of electromagnetic radiation is expressed in wavenumbers, and the intensity is expressed as a percentage of transmittance.

Solid state carbon-13 nuclear magnetic resonance (^{13}CNMR) experiments were undertaken using a Bruker Avance III 400 MHz spectrometer operating at 100 MHz for ^{13}C. Chemical shifts are relative to adamantane. Approximately 100 mg of pigment sample/dried ink extract was placed in a Bruker 4-mm rotor and spun at 5 kHz. ^{1}H-^{13}C cross-polarization magic angle spinning spectra were recorded using an acquisition time of 18.4 ms, a recycle delay of 2 s, and a contact time of 4 ms with a 50% ramp and

FIGURE **1**

Schematic Representation of the Reference Pigments Reported to Be Present in the Lemon Yellow (LY), Golden Yellow (GY), Golden Rod (GR), and Bright Orange (BO) Tattoo Inks



Note. PB = pigment blue; PO = pigment orange; PY = pigment yellow.

TABLE **1** continued

Reported Ingredients of Tattoo Inks According to Manufacturer's Label and Material Safety Data Sheets (MSDS)

Tattoo Ink	INTENZE: Golden Rod			INTENZE: Bright Orange				
	Declaration of Ingredients*	MSDS**	Confirmed in Study	Declaration of Ingredients*	MSDS			Confirmed in Study
					2018	2022	2023	
TiO_2	–	–	–	x	x	x	x	✓
$BaSO_4$	–	–	–	–	x	x	x	✓
PB15	–	–	–	–	–	–	–	–
PY65	–	–	–	–	–	–	–	–
PY14	x	x	✓	x	x	x	x	✓
PO13	x	x	x	x	x	x	x	✓
Aqua	x	x	–	x	x	x	x	–
Glycerine	x	x	–	x	x	x	x	–
Hamamelis virginiana (witch-hazel) extract	x	x	–	x	x	x	x	–
Isopropyl alcohol	–	x	–	–	x	x	x	–

* Declaration of ingredients according to the label on the bottles of ink that were purchased in 2019.
** Golden Rod ink has the same composition according to the three MSDS from 2018, 2022, and 2023.
Note. $BaSO_4$ = barium sulfate; PB = pigment blue; PO = pigment orange; PY = pigment yellow; TiO_2 = titanium dioxide.
Source: INTENZE Advanced Tattoo Ink, 2025.

decoupling during acquisition (Spinal 64). Sideband suppression was achieved using the standard total suppression of sideband (TOSSa) sequence.

XRD was recorded for pigment samples and dried tattoo inks. Data were collected using a Bruker Advanced D8 diffractometer with Co Kα (λ = 1.7889 Å, 2θ = 10°–90°, time per step = 0.5 s). All samples were ground to a fine powder with a mortar and pestle before being loaded onto an XRD sample stage.

Raman spectra were collected using a Horiba Scientific Xplora Plus Raman spectrometer at both 786 nm and 532 nm. The analysis was performed at 200 cm^{-1} to 3,000 cm^{-1} wavenumbers, with the laser intensity reduced using 10% and 25% filters. For each sample, 12 scans of 20-s pulses were recorded. In all instances, dried pigment/ink powder was placed onto a glass slide, which was mounted on the Raman spectrometer's sample holder for analysis.

Scanning electron microscopy (SEM) was undertaken with an FEI F50 inspect system equipped with an Octane Pro EDX detection system. Pigment samples were prepared by directly spreading pigment powder onto sticky carbon tabs. The working distance was 10 mm, and the acceleration voltage was 10 kV. The PY14, GR, and GY inks were coated with platinum with a thickness of about 2 nm to increase their electrical conductivity.

ICP-OES was conducted using a Perkin Elmer Optima 8000 ICP-OES. Prior to analysis, approximately 100 mg of the dried ink samples were digested in 5 ml of nitric acid (HNO_3) using a microwave digestor. After digestion, the samples were diluted to 50 ml in Milli-Q water, giving an HNO_3 concentration of 10%, and an aliquot was diluted twice in ultrapure water (18 MΩ), giving a 5% HNO_3 concentration. Finally, the samples were filtered using a 0.45-µm nylon filter prior to analysis. Calibration standards (5 ppb to 1 ppm) were prepared in 5% aqueous HNO_3.

Results and Discussion

Ink Characterization

Reported Ingredients

As prior research has shown that tattoo inks ingredients are sometimes misidentified on the label (Bauer et al., 2019, 2020; Moseman et al., 2024; Wang et al., 2021), our study examined the reported ingredients listed on the manufacturer's label and in the provided material safety data sheet (MSDS) of the four inks we examined. Table 1 shows the MSDS ingredient lists for the inks as of 2018, 2022, and 2023, and the declared ingredients on the label. It is evident there are some differences in reported ingredients on the MSDS over this time.

Inks used in our study were purchased in 2019, so it could be expected that the reported ingredients on the label would match those of the MSDS from 2018. Despite this expectation, there are some discrepancies between each label and the corresponding 2018 MSDS. For example, the label for LY ink indicates that it contains PY65 (Figure 1), but PY65 is not listed in the 2018 MSDS. Similarly, PY14 (Figure 1) is not listed as an ingredient on the label of the LY ink, but PY14 is listed in the 2018 MSDS. The labels for GR and GY inks list that they contain PO13 (Figure 1); however, PO13 is not listed in the 2018 MSDS. And lastly, PB15 (Figure 1) is listed on the label and in the MSDS for LY in 2018 and 2022, but it is no longer listed on the 2023 MSDS. Similarly, there were discrepancies on other ingredients such as $BaSO_4$, which is not listed on the label of GY and BO inks.

Pigment Characterization

Reference pigments, dried inks (D-ink), and ink extracts (E-ink) were compared using FTIR, NMR, XRD, Raman, EDX, and ICP-OES to identify the likely pigments in the inks.

FTIR Spectra

Figure 2 depicts the FTIR spectra of pigments obtained from ink extracts (E-LY, E-GY, E-GR, and E-BO) and reference pigments (PY14, PY65, PB15, and PO13) between 1,900 cm^{-1} to 600 cm^{-1}. The full range of the spectra (4,000 cm^{-1} to 550 cm^{-1}) and assignment of functional groups to the FTIR spectra can be found in Supplemental Figure S1 and Table S1. Moreover, PO13 had characteristic peaks at 1,653, 1,493, 1,371, 1,331, 1,235, 1,144, 1,044, 998, 907, and 682 cm^{-1}. These peaks were not observed in the ink extracts, which indicates that none of the ink extracts contained PO13—or if they did, PO13 presented at levels below the instrumental limit of detection.

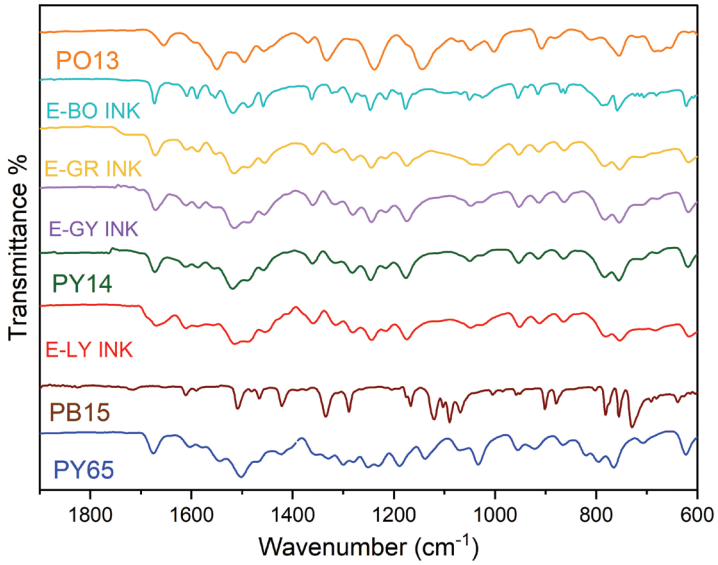
Similarly, PY65 had distinctive absorption peaks at 1,546, 1,302, 1,187, 1,135, 1,030, and 763 cm^{-1} that were not observed in the ink extracts. This finding indicates that PY65 was not present in any of the inks—or if it was, it was present at levels below the instrumental limits of detection. The IR spectral of PB15 shows several peaks at 1,612, 1,464, 1,421, 1,331, 1,287, 1,166, 1,119, 1,087, 901, 877, 778, and 725 cm^{-1}. The absence of these peaks in LY ink indicates that the FTIR spectra could not confirm the existence of this pigment in this ink. Moreover, PY14 had peaks at 1,670, 1,515, 1,360, 1,245, 1,171, 950, 860, 782, 750, and 619 cm^{-1} that were correlated with the presence of C-Cl and N-C=O bonds (Bauer et al., 2020). All four ink-extracts yielded FTIR spectra that appeared very similar to the spectra from PY14, indicating that they likely contained PY14. FTIR spectra from the dried inks (D-LY, D-GY, D-GR, D-BO) were consistent with those of the extracted inks (Supplemental Figure S2).

NMR Analysis

In case the pigments were at concentrations below the limits of detection for the FTIR study, NMR analysis was also undertaken. Figure 3 shows the ^{13}CNMR spectra for PY14, PY65, and PO13 along with dried inks from LY, GR, BO, and GY inks. NMR spectra of

FIGURE **2**

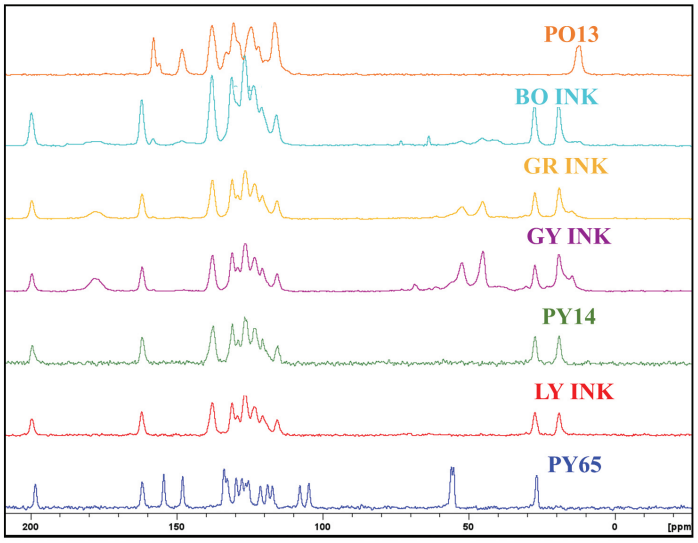
Spectrum of Reference Pigments and Tattoo Inks Using Fourier Transform Infrared (FTIR) Spectroscopy



Note. A magnification of the infrared (IR) spectra is in the 1,900–600 cm^{-1} range with a resolution of 4 cm^{-1} to demonstrate the characteristics more accurately. IR spectra comparison of inks and pigments reveals the presence of PY14 instead of PY65 in the lemon yellow (LY) ink. The golden yellow (GY), golden rod (GR), and bright orange (BO) inks did not have PO13. E-BO = ink extract, bright orange; E-GR = ink extract, golden rod; E-GY = ink extract, golden yellow; E-LY = ink extract, lemon yellow; PB = pigment blue; PO = pigment orange; PY = pigment yellow.

FIGURE **3**

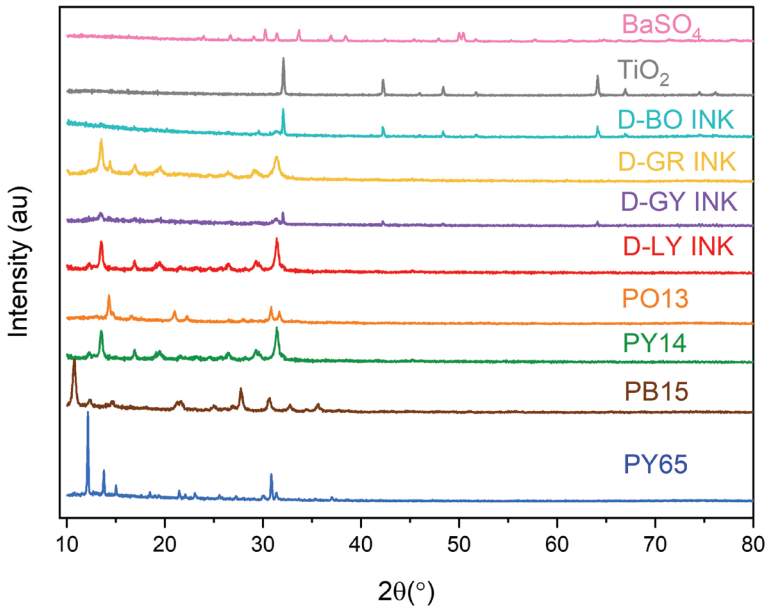
Spectrum of Reference Pigments and Tattoo Inks Using ^{13}C Solid-State Nuclear Magnetic Resonance (NMR) Spectroscopy



Note. Spectral analysis confirms the presence of PY14 in all inks, with PO13 in the bright orange (BO) ink and PO13 absent in golden yellow (GY) and golden rod (GR) inks. NMR spectra also confirmed that the lemon yellow (LY) ink did not have PY65. C = copper; PO = pigment orange; PY = pigment yellow.

FIGURE **4**

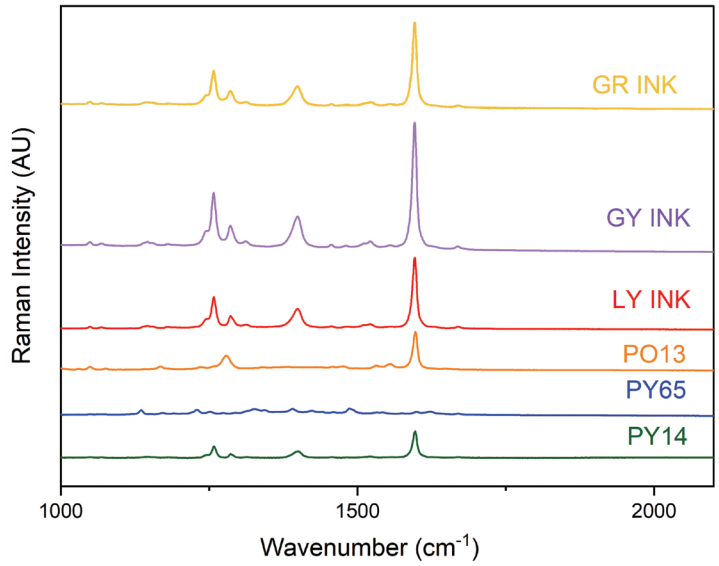
X-Ray Diffraction (XRD) Data Analysis of Organic and Inorganic Pigments



Note. This analysis compared the spectra from the lemon yellow (LY), golden yellow (GY), golden rod (GR), and bright orange (BO) tattoo inks. Titanium dioxide (TiO_2) was identified in the BO and GY inks. $BaSO_4$ = barium sulfate; D-BO = dried ink, bright orange; D-GR = dried ink, golden rod; D-GY = dried ink, golden yellow; D-LY = dried ink, lemon yellow; PB = pigment blue; PO = pigment orange; PY = pigment yellow.

FIGURE **5**

Baseline-Corrected Raman Spectra of Reference Pigments and Tattoo Inks



Note. LY = lemon yellow; GY = golden yellow; GR = golden rod; PO = pigment orange; PY = pigment yellow.

PB15 were not collected due to paramagnetic characteristics of copper (Cu), which generate local magnetic fields that might interfere with the NMR measurements. We did find distinct peaks in PY65 at approximately 38 ppm and 58 ppm, which were associated with the presence of methyl groups (CH_3-O, CH_3-C=O). Peaks at 145 ppm and 155 ppm were correlated to the presence of C-NO_2 and Ar-O groups, which were only found in PY65 (Blau et al., 2008). These peaks were not found in any of the inks, suggesting that none of them contained PY65. Moreover, PY14 had peaks between 130 ppm and 140 ppm and at 20 ppm and 30 ppm that can be attributed to the presence of the C-Cl and methyl group (C-CH_3 and O=C-CH_3).

These peaks were identified in all inks, which confirmed the presence of PY14 in them. In addition, NMR characterization did not confirm the presence of PO13 in the LY, GY, and GR inks, which is because PO13 had distinguishing peaks between 150 ppm and 160 ppm that were not detected in these inks. There was also a slight chemical shift of the peak at 12 ppm, which was assigned to the CH_3 group in PO13. The presence of PO13 in the BO ink was consistent with the manufacturer's ingredients, with small quantities as identified in the NMR spectra. These NMR spectra for the three pigments were consistent with those spectra reported in the literature (Feng et al., 2019).

The presence of PY14 was confirmed by FTIR and NMR analyses in all three inks. The results from FTIR and NMR analyses clearly show that LY ink contains PY14 instead of PY65. This finding contradicts the manufacturer's label claim that LY ink contains PY65 (not PY14), but is consistent with the declaration in the MSDS that indicates PY14. Furthermore, the presence of PO13 in both the GY and GR inks could not be confirmed, as the FTIR and NMR spectra did not contain the characteristic peaks expected from PO13. The absence of PO13 in the GY ink is consistent with the MSDS for the ink (at time of purchase) and indicates that, once again, the ink bottle might have been mislabeled. The absence of PO13 in the GR ink is in contrast with the label and MSDS for this ink. It could be, however, that the amount of PO13 used in these inks was too small for the instrumentation to detect (i.e., <2 mg of PO13 in 100 mg of dried tattoo ink). This threshold was

confirmed by the control experiment to identify the limits of detection of the NMR instrument (Supplemental Figure S3).

XRD Analysis

To confirm the FTIR and NMR results along with verifying the existence of inorganic ingredients, we used XRD analysis. The XRD diffraction pattern of all inks revealed amorphous and crystalline phases (Figure 4). The vehicles and organic pigments are associated with the amorphous phases of the inks. The diffraction pattern of D-LY ink is similar to PY14 but not to PY65 or PB15, which further confirms the presence of PY14 (Figure 4). Furthermore, when comparing the XRD pattern of PO13 with that of GY and GR inks, the peaks differed, which was predicted and corresponded with the FTIR and NMR findings.

Additionally, TiO_2 has been recognized as one of the most common crystalline oxide peaks in both D-BO and D-GY inks. The intensity of TiO_2 peaks, however, was greater in D-BO ink than in D-GY ink, which might be because the quantity of TiO_2 was smaller in the D-GY ink than that in the D-BO ink, as per a November 20, 2018, clarification on the manufacturer's website in the MSDS of these inks (INTENZE Advanced Tattoo Ink, 2025). The absence of the TiO_2 peaks in the D-LY ink, however, suggests that the amount of TiO_2 was smaller than the level detectable by XRD. These results from the XRD data analysis of the pigments and inks were compared with results from the reference (Arl et al., 2019). The possible presence of $BaSO_4$ in the BO ink was evidenced by low-intensity peaks in the XRD analysis; however, this finding could not be confirmed using XRD alone, as some of these low-intensity peaks overlapped with the TiO_2 peaks.

Raman Spectra Analysis

Furthermore, Raman analysis was conducted to confirm the previous instrument examination data and the presence of PY65, PO13, PB15, and the other inorganic ingredients (e.g., $BaSO_4$ and TiO_2), as shown in Figure 5. The full range of the spectra (2,500 cm^{-1} to 200 cm^{-1}) can be found in Supplemental Figure S4.

The Raman spectra analysis of the LY ink revealed that PY14 is a prominent component and that PY65 is not present. The challenge in resolving these separate pigments for this specific shade of ink can be due to the quantity of PY14 versus PB15 (Supplemental Figure S5), primarily, which causes signals from PY14 to overwhelm signals from PB15. Many aspects of the comparatively narrow PY14 spectrum corresponded with and overlapped with the few peaks (e.g., 1,598.5 cm^{-1}) derived from PB15 due to similar structural vibrations.

For example, the normally noticeable 1,332 cm^{-1} C-C bond stretching in PB15 (Scherrer et al., 2009) is hidden by a rather weak feature in PY14 at 1,310 cm^{-1}. Additionally, the allocated peaks from PB15 at 1,414 cm^{-1} and 1,136 cm^{-1} were shifted to 1,456 cm^{-1} and 1,148 cm^{-1}, respectively. At the same time, the BP15 peak of 584 cm^{-1} was masked in the D-LY ink. Therefore, Raman spectra analysis results could not confirm the presence of PB15.

Furthermore, the Raman spectra analysis of the GY and GR inks was consistent with previous characterization (e.g., IR, NMR, and XRD) studies and confirmed the absence of PO13 in these inks. This finding is because PO13 had a peak at 1,588 cm^{-1} and this peak was shifted to 1,600 cm^{-1} in the GY and GR inks. The Raman spectra analysis of TiO_2 and $BaSO_4$ revealed two distinct peaks at 441cm^{-1} and 603cm^{-1} (Supplemental Figure S6), which were not observed on the Raman spectra analysis of the dried inks at the same region. This result could be because the quantity of elements was inadequate to be detected by Raman analysis. As a next step, therefore, we conducted an EDX analysis.

EDX Analysis

The pigments and dried inks were analyzed using EDX analysis to identify the element composition (Table 2 and Supplemental Figures S7–S11). As expected, the pigment reference samples contained carbon (C), nitrogen (N), oxygen (O), copper (Cu), barium (Ba), sulfur (S), and chlorine (Cl). The presence of Cl in the D-LY ink spectrum is further proof that PY14 is present in this ink. It was expected that Cu (from PB15) and Ba (from

TABLE **2**

Element Composition Analysis of Pigments and Inks Using EDX (Energy Dispersive X-Ray) Spectroscopy

Pigment/Ink	Element (%)										
	C	N	O	Cl	Cu	Ti	Ba	S	Si	Na	Al
PY14	66	19	14	2	–	–	–	–	–	–	–
PY65	62	20	14	–	–	–	–	–	–	–	–
PB15	76	18	6	–	2	–	–	–	–	–	–
PO13	70	21	5	2	–	–	–	–	–	–	–
$BaSO_4$	–	–	48	–	–	–	30	19	–	–	–
TiO_2	4	3	70	–	–	23	–	–	–	–	–
D-LY	76	11	7	3	–	3	–	–	–	3	–
E-LY	70	16	8	2	–	–	–	–	–	–	–
D-GY	65	9	18	2	–	4	–	–	–	–	–
E-GY	65	21	10	2	–	–	–	–	–	–	–
D-GR	67	20	10	2	–	–	–	–	1.0	–	–
E-GR	69	16	11	2	–	–	–	–	–	–	–
D-BO	60	5	20	2	–	10	–	–	0.7	-	0.8
E-BO	63	5	18	3	–	–	–	–	–	–	–

Note. EDX spectroscopy provides supportive evidence of the presence of certain pigments in inks and establishes a match between LY ink and PY14 pigment. The elemental percentage represents the average atomic percentages from surface analysis of three spots on a sample. Al = aluminum; Ba = barium; $BaSO_4$ = barium sulfate; C = carbon; Cl = chlorine; CU = copper; D-BO = dried ink, bright orange; D-GR = dried ink, golden rod; D-GY = dried ink, golden yellow; D-LY = dried ink, lemon yellow; E-BO = ink extract, bright orange; E-GR = ink extract, golden rod; E-GY = ink extract, golden yellow; E-LY = ink extract, lemon yellow; N = nitrogen; Na = sodium; O = oxygen; PB = pigment blue; PO = pigment orange; PY = pigment yellow; S = sulfur; Si = silicon; Ti = titanium; TiO_2 = titanium dioxide.

TABLE **3**

ICP-OES Data of Tattoo Inks to Confirm the Presence of $BaSO_4$, Cu, and TiO_2

Sample Identification	Ba 455.403 (mg/g)	Cu 327.393 (mg/g)	Ti 334.940 (mg/g)
Golden Yellow	Trace	–	0.0565
Golden Rod	–	–	–
Lemon Yellow	0.0062	0.0035	0.0525
Bright Orange	0.0058	–	High quantity

Note. Ba = barium; $BaSO_4$ = barium sulfate; Cu = copper; ICP-OES = inductively coupled plasma optical emission spectroscopy; Ti = titanium; TiO_2 = titanium dioxide.

$BaSO_4$) would have been observed in the LY and GY inks. The EDX analysis, however, did not show elemental Cu and Ba in the case of either ink. Interestingly, the EDX data indicated that the stated inks contained impurities not listed on the product label. For example, the D-GY ink had excessive levels of Na, and the D-BO ink had a small amount of Al and Si. Moreover, the EDX analysis was consistent with the XRD data and revealed that the D-BO ink contained a higher concentration of Ti than did the D-GY inks, which have the same ingredients according to the label on the ink's bottle. Overall, C, O, and N concentrations were all high in all the inks analyzed. The carbon tape holder, which was not entirely covered by the inks or pigments, is responsible for the high-intensity peaks of C in the spectra. The existence of components revealed in the SEM and EDX examinations was confirmed by XRD analysis but in different quantities.

ICP-OES Analysis

Analyses by XRD and EDX exhibited limited sensitivity when detecting small amounts of Ti, Cu, and Ba. Consequently, ICP-OES proved valuable in verifying the existence of these elements (Table 3). ICP-OES analysis was conducted to assess tattoo inks, with ink samples subjected to acid digestion (using HNO_3 and hydrogen peroxide [H_2O_2]) in an ETHOS UP microwave digester. It should be noted that Ti cannot be digested in HNO_3 (it requires hydrofluoric acid [HF]), so our results are not accurate for quantitative analysis. The ICP-OES analysis, however, clearly showed that the GY, LY, and BO inks contained Ti, and this finding was consistent with the data from the EDX and XRD analyses. We found that only the LY ink contained concentrations of Cu that could be properly measured by ICP-OES. And this technique confirmed the presence of Ba in the LY and BO inks. A closer look at the spectra, however, showed that the GY ink also contained Ba, although below the limit of quantification. The detection of Ba could be a match to only the MSDS of the GY and BO inks and not to the labels.

Health Implications Related to Tattoo Ink

The inconsistency between the ingredients reported on the MSDS and the experimental data highlights a major issue, namely that the manufacturer-provided MSDS cannot be relied on for a comprehensive and accurate characterization of tattoo ink components. The MSDS also falls short in accurately reporting the quantities of each ingredient present. From both consumer and medical perspectives, ingredient mislabeling is a critical concern due to its potential health implications.

Our study found PY14, PY65, PB15, and PO13 in tattoo inks—these inks are prohibited under European Union Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulations since 2015 (Food and Drug Administration, 2015; Hauri, 2011; Serup et al., 2020; Wang et al., 2021). These pigments have been banned because they contain substances such as polycyclic aromatic hydrocarbons (PAHs), metals, and primary aromatic amines (PAAs), all of which pose toxicological risks to human health (Moseman et al., 2024). PO13 was detected in a subset of skin biopsies with allergic reactions (12%), but the most commonly identified pigments were red varieties, specifically pigment red 170/210 (36%) and pigment red 22 (35%). PB15 was also observed in imaging studies of adverse tattoo reactions. Chronic allergic reactions were the most common type of adverse response observed in skin samples (Brungs et al., 2022; Serup et al., 2020).

Additionally, PY14 contains an azo functional group, raising particular concerns due to its potential to release PAAs. Research by Lachenmeier et al. (2023) found that red and yellow tattoo pigments emitted significant levels of PAAs (Fels et al., 2023). Furthermore, there has been a documented case where a patient experienced an allergic reaction to tattoo inks containing PY65 (INTENZE brand), that affected all tattooed areas (González-Villanueva et al., 2018).

Research on the metabolic breakdown of tattoo inks beneath the skin remains limited, resulting in a substantial knowledge gap in this area (Serup et al., 2020). The pigments that we identified in our study are known to degrade under sunlight or during laser irradiation (such as that used in tattoo removal), raising additional health concerns due to the potential formation of toxic by-products.

For example, o-toluidine, a known human carcinogen, has been identified as a decomposition product of various organic pigments (Foerster et al., 2020; Serup et al., 2020). Compounds derived from commonly used pigments, such as PO13, are classified as sensitizers by both manufacturers and the European Chemical Agency; notable examples include the carcinogens aniline and 3,3'-dichlorobenzidine, which are degradation products of various pigments (Engel et al., 2007; Hauri & Hohl, 2015; Serup et al., 2020). The disazopyrazolone pigment PO13 has also been shown to affect cytokine release in reconstructed human skin from punch biopsies of tattooed skin (Kurz et al., 2023). Another pigment, PB15, is listed in Annex 1 of Germany's cosmetics code, which restricts its use in tattoo inks (Schreiver et al., 2016). The use of PB15 is prohibited because pyrolysis (i.e., the chemical decomposition of a material through the application of heat in the absence of O) can produce hazardous substances such as hydrogen cyanide, benzene, and 1,2-benzenedicarbonitrile (Schreiver et al., 2016).

Concerns also extend to TiO_2, a potential human carcinogen, possibly due to the for-

mation of reactive oxygen species that can lead to lung cancer (Baan et al., 2006). Ba, which is present in tattoo inks as $BaSO_4$ to brighten dark colors (Schmitz et al., 2016) and act as a stabilizer, might not pose a major issue in itself, but soluble impurities can induce severe effects, including respiratory paralysis, cardiac arrest, or death (Oskarsson & Reeves, 2007; Wang et al., 2021).

Conclusion

In summary, the pigment composition of a set of previously unstudied yellow tattoo inks were investigated in this study. Characterization using IR, NMR, XRD, Raman, EDX, and ICP-OES analyses showed that the pigments in commercially available tattoo inks that we tested differed from the chemical components described on the ingredient labels. The ink characterization indicates the existence of PY14 in the LY ink, which differs from the PY65 mentioned on the bottle label. According to both the label and MSDS, PO13 was listed as being present in the GY and GR inks, but no PO13 was detected in either ink. Additionally, Na, Si, and Al were found in the inks we analyzed, but none of these elements had been listed either on the label or in the MSDS.

The large discrepancies between the actual ingredients and the ingredients listed in tattoo inks raise serious health concerns and underscore the need for stricter regulations and more accurate labeling to ensure consumer safety. Moreover, the integration of different techniques for analysis provides a broader understanding of ink composition, while removing the necessity for intricate and time-consuming sample preparation.

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References

Arl, M., Nogueira, D.J., Köerich, J.S., Justino, N.M., Vicentini, D.S., & Matias, W.G. (2019). Tattoo inks: Characterization and in vivo and in vitro toxicological evaluation. *Journal of Hazardous Materials*, *364*, 548–561. https://doi.org/10.1016/j.jhazmat.2018.10.072

Baan, R.A., Straif, K., Grosse, Y., Secretan, B., El Ghissassi, F.E., & Cogliano, V. (2006). Carcinogenicity of carbon black, titanium dioxide, and talc. *The Lancet Oncology*, 7(4), 295–296. https://doi.org/10.1016/s1470-2045(06)70651-9

Barua, S. (2015). Laser-tissue interaction in tattoo removal by Q-switched lasers. *Journal of Cutaneous and Aesthetic Surgery*, *8*(1), 5–8. https://doi.org/10.4103/0974-2077.155063

Bauer, E.M., Cecchetti, D., Guerriero, E., Quaranta, S., Ripanti, F., Postorino, P., Tagliatesta, P., & Carbone, M. (2022). "For Asia Market Only": A green tattoo ink between safety and regulations. *Molecules*, *27*(11), Article 3491. https://doi.org/10.3390/molecules27113491

Bauer, E.M., De Caro, T., Tagliatesta, P., & Carbone, M. (2019). Unraveling the real pigment composition of tattoo inks: The case of bi-components phthalocyanine based greens. *Dyes and Pigments*, *167*, 225–235. https://doi.org/10.1016/j.dyepig.2019.04.018

Bauer, E.M., Scibetta, E.V., Cecchetti, D., Piccirillo, S., Antonaroli, S., Sennato, S., Cerasa, M., Tagliatesta, P., & Carbone, M. (2020). Treatments of a phthalocyanine-based green ink for tattoo removal purposes: Generation of toxic fragments and potentially harmful morphologies. *Archives of Toxicology*, *94*(7), 2359–2375. https://doi.org/10.1007/s00204-020-02790-7

Bäumler, W. (2020). Chemical hazard of tattoo colorants. *La Presse Médicale*, *49*(4), Article 104046. https://doi.org/10.1016/j.lpm.2020.104046

Blau, L., Menegon, R.F., Ferreira, E.I., Ferreira, A.G., Boffo, E.F., Tavares, L.A., Heleno, V.C.G., & Chung, M.-C. (2008). Synthesis and total 1H-and 13C-NMR assignment of cephem derivatives for use in ADEPT approaches. *Molecules*, *13*(4), 841–854. https://doi.org/10.3390/molecules13040841

Bocca, B., Sabbioni, E., Mičetić, I., Alimonti, A., & Petrucci, F. (2017). Size and metal composition characterization of nano- and microparticles in tattoo inks by a combination of analytical techniques. *Journal of Analytical Atomic Spectrometry*, *32*(3), 616–628. https://doi.org/ 10.1039/c6ja00210b

Brungs, C., Schmid, R., Wolf, C., Berg, T., Korf, A., Heuckeroth, S., Hayen, H., van der Bent, S.A.S., Maijer, K.I., Rustemeyer, T., & Kärst, U. (2022). Tattoo pigment identification in inks and skin biopsies of adverse reactions by complementary elemental and molecular bioimaging with mass spectral library matching. *Analytical Chemistry*, *94*(8), 3581–3589. https://doi.org/10.1021/acs.analchem.1c04922

Chalmers, S., Harwood, A.E., Morris, N.B., & Jay, O. (2019). Do tattoos impair sweating? *Journal of Science and Medicine in Sport*, *22*(11), 1173–1174. https://doi.org/10.1016/j.jsams.2019.08.001

Desmedt, B., Vanhamme, M., & Deconinck, E. (2022). The purity of tattoo inks, screening substances of high concern. *Regulatory Toxicology and Pharmacology*, *129*, Article 105123. https://doi.org/10.1016/j.yrtph.2022.105123

Engel, E., Spannberger, A., Vasold, R., König, B., Landthaler, M., & Bäumler, W. (2007). Photochemical cleavage of a tattoo pigment by UVB radiation or natural sunlight. *JDDG: Journal der Deutschen Dermatologischen Gesellschaft*, *5*(7), 583–589. https://doi.org/10.1111/j.1610-0387.2007.06333.x

References

Fels, P., Lachenmeier, D.W., Hindelang, P., Walch, S.G., & Gutsche, B. (2023). Occurrence and regulatory evaluation of contaminants in tattoo inks. *Cosmetics*, *10*(5), Article 141. https://doi.org/10.3390/cosmetics10050141

Feng, G., Zhu, M., Liu, L., & Li, C. (2019). A quantitative one-pot synthesis method for industrial azo pigments with recyclable wastewater. *Green Chemistry*, *21*(7), 1769–1776. https://doi.org/10.1039/c8gc03982h

Foerster, M., Schreiver, I., Luch, A., & Schüz, J. (2020). Tattoo inks and cancer. *Cancer Epidemiology*, *65*, Article 101655. https://doi.org/10.1016/j.canep.2019.101655

Food and Drug Administration. (2015, June). *Tattoos and permanent makeup*. https://www.fda.gov/media/93379/download#page=2

Forte, G., Petrucci, F., Cristaudo, A., & Bocca, B. (2009). Market survey on toxic metals contained in tattoo inks. *Science of the Total Environment*, *407*(23), 5997–6002. https://doi.org/10.1016/j.scitotenv.2009.08.034

González-Villanueva, I., Álvarez-Chinchilla, P., & Silvestre, J.F. (2018). Allergic reaction to 3 tattoo inks containing Pigment Yellow 65. *Contact Dermatitis*, *79*(2), 107–108. https://doi.org/10.1111/cod.13004

Hauri, U. (2011). *Inks for tattoos and PMU (permanent make-up)/organic pigments, preservatives and impurities such as primary aromatic amines and nitrosamines*. State Laboratory of the Canton of Basel-Stadt. https://www.yumpu.com/en/document/read/23763193/inks-for-tattoos-and-pmu-permanent-make-up-organic-pigments-

Hauri, U., & Hohl, C. (2015). Photostability and breakdown products of pigments currently used in tattoo inks. *Current Problems in Dermatology*, *48*, 164–169. https://doi.org/10.1159/000369225

Heywood, W., Patrick, K., Smith, A.M., Simpson, J.M., Pitts, M.K., Richters, J., & Shelley, J.M. (2012). Who gets tattoos? Demographic and behavioral correlates of ever being tattooed in a representative sample of men and women. *Annals of Epidemiology*, *22*(1), 51–56. https://doi.org/10.1016/j.annepidem.2011.10.005

Høgsberg, T., Loeschner, K., Löf, D., & Serup, J. (2011). Tattoo inks in general usage contain nanoparticles. *British Journal of Dermatology*, *165*(6), 1210–1218. https://doi.org/10.1111/j.1365-2133.2011.10561.x

INTENZE Advanced Tattoo Ink. (2025) *Material safety data sheets*. https://intenzetattooink.com/pages/material-safety-data-sheets

Kiszla, B.M., Elmets, C.A., & Mayo, T.T. (2023). Quantitative analysis of restricted metals and metalloids in tattoo inks: A systematic review and meta-analysis. *Chemosphere*, *313*, Article 137291. https://doi.org/10.1016/j.chemosphere.2022.137291

Klügl, I., Hiller, K.-A., Landthaler, M., & Bäumler, W. (2010). Incidence of health problems associated with tattooed skin: A nationwide survey in German-speaking countries. *Dermatology*, *221*(1), 43–50. http://dx.doi.org/10.1159/000292627

Kurz, B., Schreiver, I., Siewert, K., Haslboeck, B., Weiss, K.T., Hannemann, J., Berner, B., von Eichborn, M.I., Berneburg, M., & Baeumler, W. (2023). Investigation of adverse reactions in tattooed skin through histological and chemical analysis. *Dermatology*, *239*(5), 782–793. https://doi.org/10.1159/000530949

Lehner, K., Santarelli, F., Penning, R., Vasold, R., Engel, E., Maisch, T., Gastl, K., König, B., Landthaler, M., & Bäumler, W. (2011). The decrease of pigment concentration in red tattooed skin years after tattooing. *Journal of the European Academy of Dermatology and Venereology*, *25*(11), 1340–1345. https://doi.org/10.1111/j.1468-3083.2011.03987.x

Lichnyi, A.A., Nam, I.F., & Dikman, E.Y. (2021). Optimization of laser radiation parameters for an affect on pigments, based on titanium dioxide (TiO_2). *XV International Conference on Pulsed Lasers and Laser Applications*, *85*. https://doi.org/10.1117/12.2616446

Matsika, A., Srinivasan, B., Phillips, G.E., & Strutton, G.M. (2016). A review of tattoo-related medical complications: Why the Australian tattoo industry should be regulated. https://www.researchgate.net/publication/321274157_A_review_of_tattoo-related_medical_complications_why_the_Australian_tattoo_industry_should_be_regulated

Minghetti, P., Musazzi, U.M., Dorati, R., & Rocco, P. (2019). The safety of tattoo inks: Possible options for a common regulatory framework. *Science of the Total Environment*, *651*(Pt. 1), 634–637. https://doi.org/10.1016/j.scitotenv.2018.09.178

Moseman, K., Ahmed, A., Ruhren, A., & Swierk, J.R. (2024). What's in my ink: An analysis of commercial tattoo ink on the US market. *Analytical Chemistry*, *69*(9), 3906–3913. https://doi.org/10.1021/acs.analchem.3c05687

Musgrave, I. (2014). Tattoo inks—Poison pigments? *Chemistry in Australia*, 16–19. https://search.informit.org/doi/10.3316/ielapa.703590811315497

National Industrial Chemicals Notification and Assessment Scheme. (2018). *Characterisation of tattoo inks used in Australia*. Australian Government Department of Health. https://www.industrialchemicals.gov.au/sites/default/files/2020-05/Characterisation%20of%20tattoo%20inks%20used%20in%20Australia%20%5BPDF%20456KB%5D.pdf

Negi, S., Bala, L., Shukla, S., & Chopra, D. (2022). Tattoo inks are toxicological risks to human health: A systematic review of their ingredients, fate inside skin, toxicity due to polycyclic aromatic hydrocarbons, primary aromatic amines, metals, and overview of regulatory frameworks. *Toxicology and Industrial Health*, *38*(7), 417–434. https://doi.org/10.1177/07482337221100870

Negi, S., Shukla, S., Patel, S.K., Vikram, A., Gaur, P., Kamar, M.D., Pathania, D., Kotian, S.Y., Bala, M., Rana, P., Bala, L., Yadav, A.K., Ray, R.S., & Dwivedi, A. (2023). Benzo(ghi)perylene (BgP) a black tattoo ingredient induced skin toxicity via direct and indirect mode of DNA damage under UVA irradiation. *Chemico-Biological Interactions*, *379*, Article 110508. https://doi.org/10.1016/j.cbi.2023.110508

Niederer, M., Hauri, U., Kroll, L., & Hohl, C. (2018). Identification of organic pigments in tattoo inks and permanent make-up using

continued on page 18

References *continued from page 17*

laser desorption ionisation mass spectrometry. *F1000Research*, *6*, Article 2034. https://doi.org/10.12688/f1000research.13035.2

Oskarsson, A., & Reeves, A.L. (2007). Chapter 29: Barium. In G.F. Nordberg, B.A. Fowler, M. Nordberg, & L. Friberg (Eds.), *Handbook on the toxicology of metals* (3rd ed., pp. 407–414). Elsevier. https://doi.org/10.1016/B978-012369413-3/50075-6

Poon, K.W.C., Dadour, I.R., & McKinley, A.J. (2008). In situ chemical analysis of modern organic tattooing inks and pigments by micro-Raman spectroscopy. *Journal of Raman Spectroscopy*, *39*(9), 1227–1237. https://doi.org/10.1002/jrs.1973

Renzoni, A., Pirrera, A., Novello, F., Lepri, A., Cammarata, P., Tarantino, C., D'Ancona, F., & Perra, A. (2018). The tattooed population in Italy: A national survey on demography, characteristics and perception of health risks. *Annali dell'Istituto Superiore di Sanità*, *54*(2), 126–136. https://doi.org/10.4415/ann_18_02_08

Riffo, G., Ramírez-Lama, C., & Bennun, L. (2020). Elemental quantification in intradermal tattoo-inks by means of total reflection X-ray fluorescence. *Journal of Cosmetics, Dermatological Sciences and Applications*, *10*(1), 33–53. https://doi.org/10.4236/jcdsa.2020.101005

Scherrer, N.C., Zumbuehl, S., Delavy, F., Fritsch, A., & Kuehnen, R. (2009). Synthetic organic pigments of the 20th and 21st century relevant to artist's paints: Raman spectra reference collection. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *73*(3), 505–524. https://doi.org/10.1016/j.saa.2008.11.029

Schmitz, I., Prymak, O., Epple, M., Ernert, C., & Tannapfel, A. (2016). Squamous cell carcinoma in association with a red tattoo. *JDDG: Journal der Deutschen Dermatologischen Gesellschaft*, *14*(6), 604–609. https://doi.org/10.1111/ddg.12730

Schreiver, I., Hutzler, C., Andree, S., Laux, P., & Luch, A. (2016). Identification and hazard prediction of tattoo pigments by means of pyrolysis—gas chromatography/mass spectrometry. *Archives of Toxicology*, *90*, 1639–1650. https://doi.org/10.1007/s00204-016-1739-2

Senaldi, C., Pakalin, S., Contor, L., Piccinini, P., & Bianchi, I. (2016). *Safety of tattoos and permanent make-up: Final report*. Publication Office of the European Union. https://dx.doi.org/10.2788/011817

Serup, J., Hutton Carlsen, K., Dommershausen, N., Sepehri, M., Hesse, B., Seim, C., Luch, A., & Schreiver, I. (2020). Identification of pigments related to allergic tattoo reactions in 104 human skin biopsies. *Contact Dermatitis*, *82*(2), 73–82. https://doi.org/10.1111/cod.13423

Serup, J., Sepehri, M., & Hutton Carlsen, K. (2017). Classification of tattoo complications in a hospital material of 493 adverse events. *Dermatology*, *232*(6), 668–678. https://doi.org/10.1159/000452148

Vasold, R., Naarmann, N., Ulrich, H., Fischer, D., Könlg, B., Landthaler, M., & Bäumler, W. (2004). Tattoo pigments are cleaved by laser light—The chemical analysis in vitro provide evidence for hazardous compounds. *Photochemistry and Photobiology*, *80*(2), 185–190. https://doi.org/10.1111/j.1751-1097.2004.tb00069.x

Wang, X., Josefsson, L., Meschnark, S., Lind, M.-L., Emmer, Å., Goessler, W., & Hedberg, Y.S. (2021). Analytical survey of tattoo inks—A chemical and legal perspective with focus on sensitizing substances. *Contact Dermatitis*, *85*(3), 340–353. https://doi.org/10.1111/cod.13913

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