Analysis of blue and green REACH Compliant Tattoo Inks

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Abstract

The Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) legislation in Europe has limited the use of certain materials in the manufacturing of tattoo inks; in particular, Pigment Blue 15:3 and Pigment Green 7 have been banned for the use in tattoo inks and permanent makeups and all labels must include an accurate list of ingredients. This study analyzed green and blue inks from five different manufacturers distributed to the European market, all of which claim to be REACH compliant. Nine out of ten inks analyzed were found to not be compliant and four contained banned material. The polymorph of Pigment Blue 15 found in four inks was unable to be determined. The majority of inks showed labeling inaccuracies, including the addition of unlisted poly(ethylene glycol) and propylene glycol. This study highlights issues around REACH compliance of tattoo inks on the European market and the need for manufacturing protocols to ensure accurate labeling.

Introduction

Globally, tattooing is a billion-dollar industry, with an estimated 30% of the United States population having one or more tattoos and some European countries having an even higher occurrence.[1] Although many individuals opt to get a tattoo as a body modification or form of self-expression, there has also been research into functional tattoos that can be used for health diagnostics and sensing.[2,3] With such a large increase in popularity, the practice of tattooing is increasingly regulated by government organizations and regulatory bodies.

Tattooing involves the rapid penetration of a sterile needle into the dermis and the deposition of ink 1.5-2.0 mm below the skin's surface.[4] The carrier solution of the ink, containing water, alcohol, and other materials, is thought to leave the dermal layer, while the pigments are trapped in the skin by fibroblasts and macrophages.[5] Tattoo pigments have been found to leave the skin through the lymphatic system, often making their way to lymph nodes.[6,7] Regulations focus on regulating tattoo ink ingredients to minimize adverse medical events and allergic reactions.[8]

The European Union and the European Chemical Agency have taken major steps towards regulating the tattoo industry. The Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) regulations were passed by the European Union in 2006 and updated in 2020 to include the regulation of tattoo inks and permanent makeups (PMUs); the stated goal in passing this legislation is to gauge the safety of chemicals used in the European Union, protect environmental and human health, and eliminate potentially hazardous materials from being used in the manufacturing of tattoo inks.[9] In particular, REACH regulates materials that may cause irritation and gene mutation, may be carcinogens, and materials that may impact reproductive health. One important aspect of REACH regulations involves the labeling of products. Not only does a product have to display identifying information (i.e., batch and lot numbers) and precautions, but a full and accurate ingredient list must be present on the

packaging to be considered REACH compliant.[10] The newest update of REACH has seen many different materials banned completely or their concentrations limited. After a 24-month transition period to allow manufacturers to find pigment alternatives, January 2023 saw the restriction of Pigment Green 7 and Pigment Blue 15:3 for use in tattoo inks and PMUs to harmonize with regulations already banning these pigments for use in hair dyes.

Work from our group and others demonstrates that tattoo ink mislabeling is a widespread issue in the global tattoo market.[11,12] We recently characterized 54 inks from nine manufacturers available on the United States market and discovered that 45 of those inks contained major discrepancies between the label and what was in the bottle. These discrepancies included unlisted pigments or unlisted additives such as poly(ethylene glycol) (PEG), propylene glycol, hexamethylenetetramine, butylated hydroxytoluene, 2-phenoxyethanol, and several others. In the United States, where most tattoo ink manufacturers are located, the Modernization of Cosmetics Regulation Act (MoCRA) obligates accurate and updated labeling of tattoo inks, however, most of MoCRA is currently not in effect.

With respect to REACH regulations, one uniquely challenging issue for tattoo ink manufacturing is the ban on Pigment Green 7 and Pigment Blue 15:3 for use in tattoo inks. Work consistently shows these are the green and blue pigments used in the vast majority of tattoo inks.[11–13] Some manufacturers have pivoted towards the use of pigments that have previously been unexplored in tattooing, e.g., Pigment Blue 60, Pigment Blue 61, and chromium oxide, though this raises some concerns about the safety of these pigments. For example, the trivalent chromium oxide that is used as a pigment is known to contain hexavalent chromium impurities. Hexavalent chromium can be linked to immunological, neurological, and developmental medical issues, as well as causing contact dermatitis and being linked to cancer.[14,15] In addition, Pigment Blue 60 is a category 2 skin irritant and category 3 specific organ toxicant.[16] As an alternative, other tattoo ink manufacturers still list PB15 as an ingredient, as only one polymorph (PB 15:3) is banned by REACH. This leads to challenges in identification because each polymorph has the same color index number. With the restriction on the use of Pigment Blue 15:3 in tattoo ink, there needs to be a quick and reliable way to differentiate between different polymorphs of this pigment. Raman spectroscopy and X-Ray Diffraction (XRD) are common techniques used for pigment analysis. XRD would be able to differentiate between different polymorphs of Pigment Blue 15, but the instrumentation is more expensive, and a larger sample is needed compared to Raman spectroscopy. Raman spectroscopy is less expensive, non-destructive, does not require a large amount of sample, and requires minimal sample preparation making it a more favorable technique. A study by Anghelone and coworkers used a 532 nm excitation wavelength to differentiate between different PB15 polymorphs using relative intensity ratios of resulting Raman signals.[17] Another study created a flow chart to characterize different polymorphs of Pigment Blue 15 in artist's paint using a 785 nm excitation wavelength and assigned arbitrary strong, medium, and weak classifications to relative peak intensities.[18] To date, there has been no study that differentiates Pigment Blue 15 polymorphs for use in commercial tattoo inks.

In this study, we examine ten of the most common REACH-compliant blue and green tattoo inks. We focus on blue and green inks because the primary pigments typically used in those inks are banned by REACH. We use a combination of NMR spectroscopy, Raman spectroscopy, and X-Ray Fluorescence (XRF) spectroscopy to assess these inks, looking at both the carrier package and the pigments.

Methods

Materials

Ten inks were used for this study: Intenze GenZ Blue Sky, Intenze GenZ Light Grass, Dynamic Platinum Baby Blue, Dynamic Platinum Emerald Green, Quantum Ink Grover, Quantum Ink Pickle Juice, Xtreme Ink Azure, Xtreme Ink Lime Green, BioTek Deep Ocean, and BioTek Green. All inks were sourced directly from the manufacturer and used as received. Pigment Blue 15:1, 15:3, and 15:6 standards were sourced from Kremer Pigments Inc. Deuterated acetonitrile was sourced from Cambridge Isotope Laboratories, Inc and was used as received.

Characterization of Carrier Solution

Inks were centrifuged at 8000 rpm (approximately 3500 g) using a Chemglass Life Sciences Mini Centrifuge for at least 3 hours to remove most of the pigment from the carrier solution. The carrier solution was then distilled in a silicone oil bath set to 230 °C and was stirred to prevent bumping. Distillate was collected below 100 °C while the remaining material was considered pot residue. NMR spectroscopy was performed on both distillate and pot residue using a Bruker Avance III HD 400 MHz instrument and deuterated acetonitrile as a solvent. ^{1}H, ^{13}C, ^{1}H-^{1}H COSY, and ^{1}H-^{13}C HSQC analyses were performed on each sample.

Characterization of Pigments

Initial pigment analysis was performed using an Enwave Optronics, Inc EZRaman-I Series High-Performance Portable Raman Analyzer with a 785 nm excitation laser with the following parameters: 30 mW, 5-second integration, 2 average, 0 boxcar, auto-baseline on. Tattoo inks were cast onto a glass microscope slide and placed in an oven at 120 °C until the samples were dry to the touch. 15 to 20 scans of different points on each sample slide were taken. The resulting spectra were compared to the SOPRANO Raman spectrum database to determine their initial pigment assignments. Pigment Blue 15:1, 15:3, and 15:6 standards were mixed into a slurry containing water and isopropyl alcohol, cast onto a microscope slide, and dried in a 120 °C oven to create standards. 15 to 20 replicates were taken for each standard.

XRF spectroscopy was also performed to confirm the presence of inorganic pigments that were not detected by Raman spectroscopy. A Thermo Electron MicronX instrument with Xpert Analysis software was used for this analysis. A beam width of 1.4 mm and a measurement time of 90 seconds was used.

Differentiation Between Pigment Blue 15 Polymorphs

Three different Raman instruments were used to determine the viability of differentiating polymorphs of Pigment Blue 15 using Raman spectroscopy. Two different excitation wavelengths were also used: 785 nm and 532 nm. The EZRaman-I Series High-Performance Portable Raman Analyzer was used with the same parameters as above. An Alpha300R, WITec Raman Spectroscope was also used. This instrument featured a 785 nm excitation source, 300 g/mm diffraction grating, 1 second integration time, and 10 accumulations, and a power of 60 mW was used. Additionally, a Horiba LabRamHR800 Ev was used with a 532 nm excitation source, 600gr/mm diffraction grating, 5-second acquisition time, and 2 accumulations.

Results

Carrier Solution Analysis

A total of 10 different inks across five different brands were analyzed to determine their carrier solutions (Table S1). All inks were distilled with their distillate collected below 100 °C. Each ink showed evidence of water comprising a large percentage of their carrier solution and nine inks indicated the presence of some low boiling alcohol (ethanol or isopropanol). Ethanol was found in the eight inks, with four explicitly listing it as an ingredient, two listing “alcohol” as an ingredient, and two not having any ingredients listed on their labels. Only Dynamic Emerald Green was found to have isopropyl alcohol in it; this ink did not list any type of alcohol in its ingredient list. Different, unlisted alcohols were also observed in two other inks. Intenze GenZ Light Grass and Blue sky showed evidence of 1,3-butanediol (Figure S3-4) based on a characteristic coupling between ^{1}H NMR peaks at δ1.11 ppm, δ1.56 ppm, δ3.85 ppm, and δ3.58 ppm. This, along with ^{13}C NMR peaks at δ23.5 ppm, δ41.5 ppm, δ60.1 ppm, and δ66.1 ppm, strongly support the presence of 1,3-butanediol.

The pot residue from six inks (Intenze GenZ Light Grass, Dynamic Platinum Baby Blue and Emerald Green, Quantum Ink Pickle Juice, BioTek Deep Ocean and Green and Xtreme Ink Azure and Lime Green) exhibited a ^{1}H NMR peak around δ3.4-3.6 ppm that coupled with a ^{13}C NMR peak around δ 70 ppm, which is characteristic of the $–CH_2–$ repeating polymer unit of PEG.[11,19] This was the only signal observed for PEG as the other peaks are not observed at longer chain lengths of PEG.[11]

Intenze GenZ Blue Sky, Dynamic Platinum Baby Blue and Emerald Green, Xtreme Ink Azure and Lime Green, and BioTek Deep Ocean and Green contained propylene glycol in the pot residue. The BioTek inks did list propylene glycol in their ingredients list, while the others did not. Propylene glycol is a known allergen and has been reported to cause contact dermatitis, itching, and swelling.[20] Both Dynamic Platinum inks did list butylene glycol as an ingredient but there was no evidence of it being present. Like propylene glycol, butylene glycol is used to control the viscosity of tattoo inks and is not known to cause the adverse effects of propylene glycol.[21] Intenze GenZ Blue Sky and the Xtreme inks’ pot residues both displayed coupling between ^{1}H peaks at δ0.88 and δ1.26 ppm. This is characteristic of a long-chain alkane, such as dodecane.[11] Coupling also occurs between these ^{1}H peaks and ^{13}C peaks around δ14, δ23,

δ30, and δ32 in the Dynamic Platinum Baby Blue sample, further supporting the evidence of some type of long-chain alkane being present.

The pot residue of Dynamic Platinum Baby Blue showed coupling between ^{1}H NMR peaks at δ0.82 ppm, δ1.27 ppm, δ1.28 ppm, δ1.51 ppm, δ2.01 ppm, and δ5.35 ppm and ^{13}C NMR peaks at δ18 ppm, δ23 ppm, δ26 ppm, δ27 ppm, δ29 ppm, δ30 ppm, δ32 ppm, δ61 ppm, and δ130ppm. This is consistent with a long-chain alkene (Figure S15-18). The signals at δ0.82 ppm and δ1.51 ppm are assigned to the end methyl groups, with the latter being closer to the double bond. The quartet at δ2.01 ppm corresponds the $–CH_2–$ unit closest to the double bond with the peaks centered around δ1.27 ppm and δ1.28 ppm being assigned to the other singly bonded $–CH_2–$ units. The small peak downfield at are assigned to the hydrogens along the double bond. Overlapping peaks in the ^{1}H NMR spectrum and the low concentration of the alkene did not allow for the integration of the peaks, leaving it unidentified.

Pigment Analysis

Molecular pigments were analyzed by Raman spectroscopy and compared to standard spectra from the SOPRANO Raman spectrum database. Additionally, all pigments were analyzed by XRF spectroscopy to confirm the presence of inorganic pigments, like titanium dioxide, since we did not observe some of these listed pigments in our initial Raman analysis (Table S2).

Out of the 10 inks analyzed, Xtreme Lime Green, Dynamic Emerald Green, Dynamic Baby Blue, and Quantum Ink Pickle Juice contained Pigment Green 7, which is banned by REACH. Three of these inks contained primarily Pigment Green 7, as seen by their Raman spectra in **Figure 1.** Dynamic Platinum Baby Blue and Emerald Green list FD&C Blue No. 1, a copper-free alternative pigment that is commonly used as a food additive.[22] This pigment is also water-soluble, making it unlikely to be an effective tattoo pigment. Quantum Ink Pickle Juice's Raman spectrum shows PG7 and an additional pigment. The peaks not attributable to PG7 were characteristic of Pigment Yellow 74, which is also restricted under REACH regulations.[23]

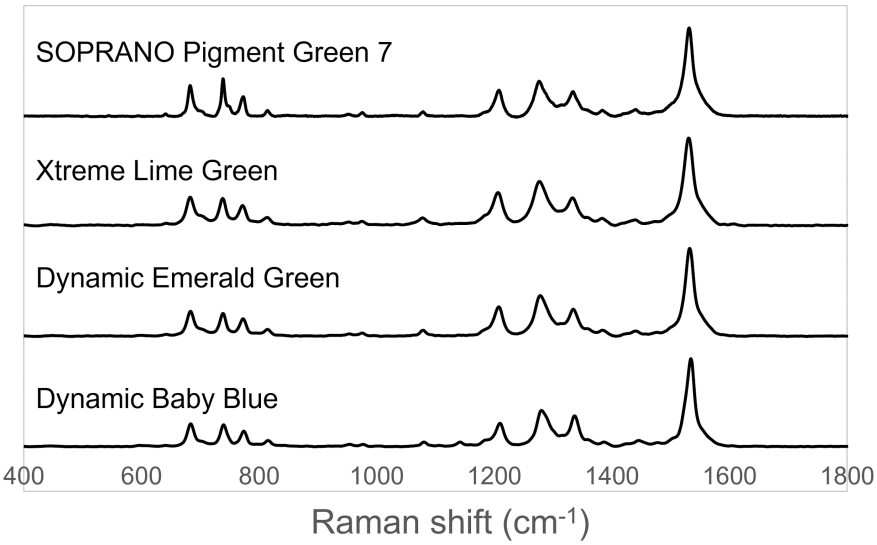

Figure 1. Average Raman spectrum from replicate scans of REACH compliant advertised commercial tattoo inks compared to the Raman spectrum of a standard sample of Pigment Green 7 using the EZRaman-I Series High-Performance Portable Raman Analyzer.

BioTek Deep Ocean contains PB15, matching what is listed on the label. Xtreme Azure also contained PB15, but listed Pigment Blue 60 on its label. Only BioTek Deep Ocean lists the polymorph used in the ink (PB15:1), which specifies that it would be REACH compliant. To determine which PB15 polymorphs these inks contain, the ratios of Raman intensities at 960 cm^{-1}, 1110 cm^{-1}, 1141 cm^{-1}, 1300 cm^{-1}, and 1350 cm^{-1} were analyzed based on the method of Anghelon and coworkers.[29] The ratio of peak intensities at around 1141 cm^{-1} and 960 cm^{-1} was plotted against the ratio of intensities around 1110 and 1350 cm^{-1}. The same 1141/960 cm^{-1} ratio was also plotted against the ratio of the peaks at 1141 cm^{-1} and 1300 cm^{-1}. The sample tattoo inks were analyzed using both 785 nm and 532 nm excitation wavelengths. Figure 2 shows the results of this analysis.

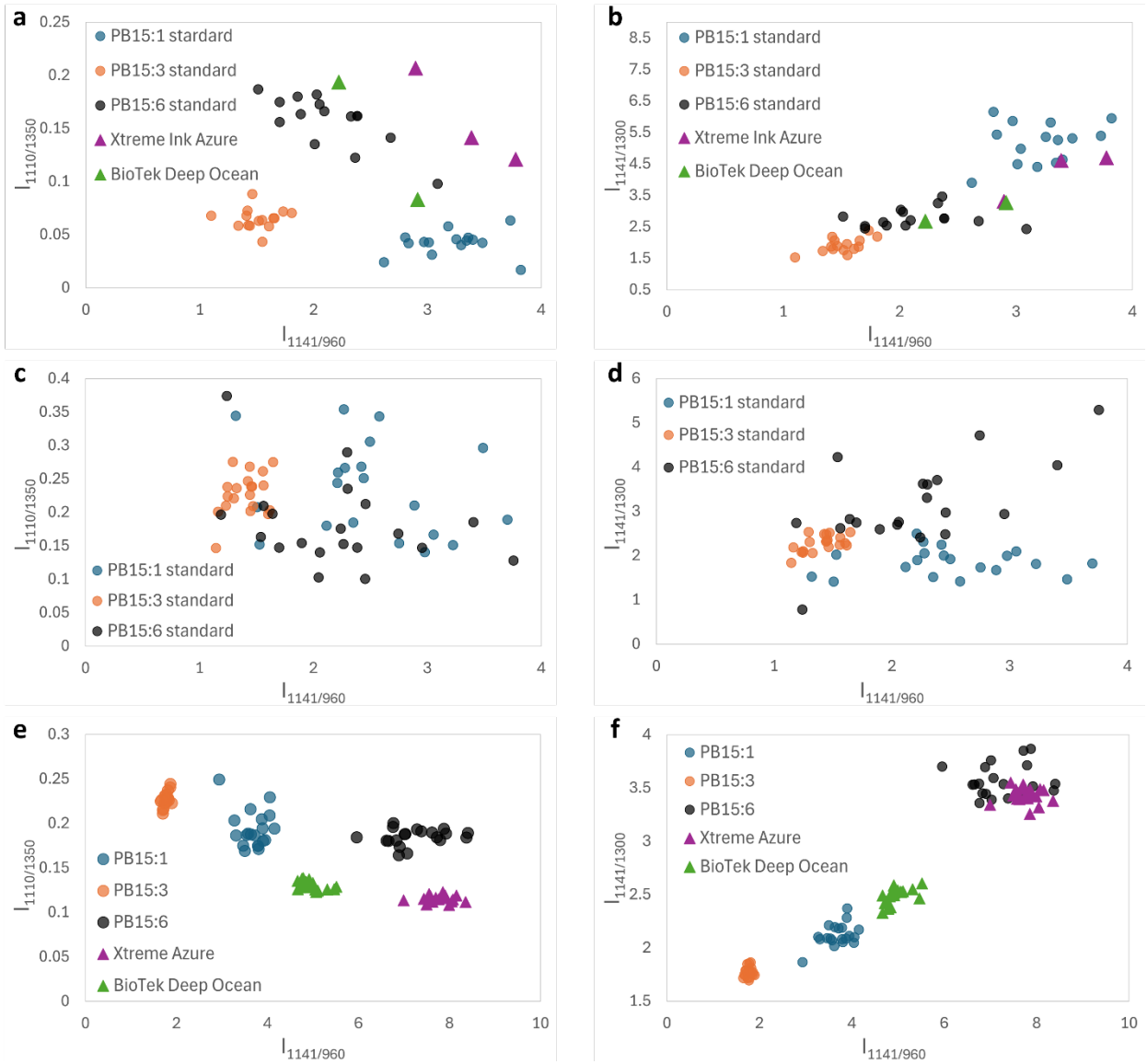

Figure 2. Plot of peak intensity ratios 1141/960 cm^{-1} against 1110/1350 cm^{-1} and 1141/960 cm^{-1} against 1141/1300 cm^{-1} to differentiate polymorphs of PB15. (**a**) and (**b**) use the Horiba LabRamHR800 Ev with 532 nm excitation wavelength, (**c**) and (**d**) used the Alpha300R, WITec Raman Spectroscope with a 785 nm excitation wavelength, and (**e**) and (**f**) used the EZRaman I Series High-Performance Portable Raman Analyzer with 785 nm excitation wavelength.

Figure 2a-b strongly suggests that the PB15 in Xtreme Ink Azure is PB15:1 and BioTek Deep Ocean is PB15:6. This contradicts the results from 785 nm excitation (**Figures 2e-f**), which would assign Xtreme Azure as PB15:1 and BioTek Deep Ocean as having both PB15:1 and PB15:6 character. Results from the Alpha300R WITec Raman Spectroscope did not show conclusive differentiation between polymorphs standards (**Figure 2c-d**), but the EZRaman-I Series High-Performance Portable Raman Analyzer did (**Figure 2e-f**), even though the data was collected using the same excitation wavelength.

Discussion

We classified the 10 tattoo inks analyzed as having major or minor discrepancies based on the following two criteria: major discrepancies contained REACH-banned materials, while minor discrepancies included inks that were mislabeled but did not contain any banned materials. It should be noted that even inks with minor discrepancies are out of compliance with the REACH regulations. Figure 3 summarizes the classifications of the inks in this study.

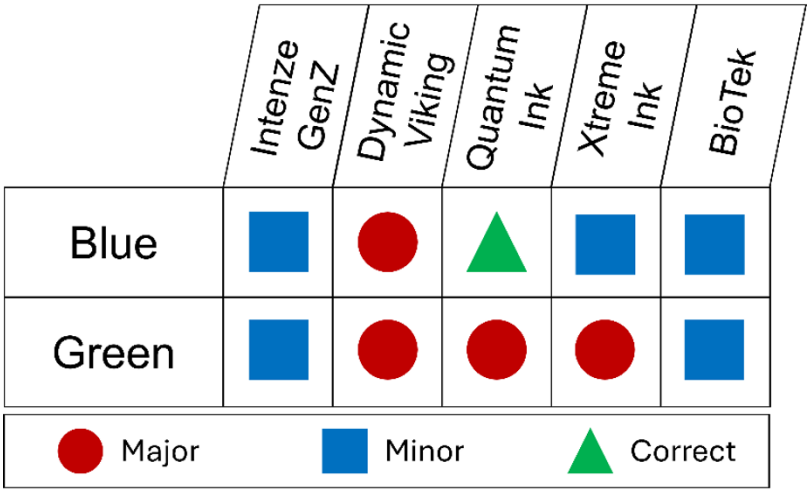

Figure 3. Summary of REACH compliance described as either containing banned material (major), label discrepancies (minor), or having no label discrepancies (correct).

Nine tattoo inks were found to be out of compliance with REACH regulations; each ink analyzed either contained REACH-banned materials and/or had inaccurate labeling. Four of the ten inks showed major discrepancies originating from the pigment. These inks all contained banned PG7. Two of the inks contained some form of PB15, with one of these inks not listing PB15 as an ingredient on its label. One carrier solution contained isopropyl alcohol, a REACH banned materials if concentrations exceed 0.01% w/w.[24] Though the analysis performed is not quantitative, NMR spectroscopy is not a sensitive technique and we estimate a limit of detection around 2000 ppm meaning that the concentration is likely well above the 0.01% w/w threshold. For market surveillance, a quantification would have to be performed. In total, nine of the inks showed inaccuracies in the labeling of the carrier solutions (Table S1).

While not explicitly banned by REACH, several of the ingredients are cause for concern. Polyethylene glycol was found in eight of the inks; PEG is known to be added to tattoo inks to alter the viscosity and surface tension.[25] In high concentrations, PEG is suspected of causing acidosis when metabolized, which could eventually lead to renal and heart failure.[26] Propylene glycol is found in seven of the inks, although it is only listed as an ingredient in the two inks from BioTek. Propylene glycol is a known dermal allergen, causing redness, itching, swelling, and even fluid-filled blisters.[27] Butylene glycol, thought to be a safer alternative to propylene glycol, is listed in the Dynamic Platinum Inks but was not detected in any inks. Although not common, butylene glycol has also been known to elicit allergic reactions, presenting similarly to the dermatitis caused by propylene glycol.[22]

There are multiple polymorphs of PB15 that exist, specifically α, β, γ, χ, and η.[28,29,30] β-copper phthalocyanine (Pigment Blue 15:3) is the most stable of the polymorphs while α and γ are common and considered meta-stable. The differentiation of PB15 polymorphs is a challenge from the perspective of legislation and manufacturing. REACH legislation only bans the use of PB15:3, making the need for an easy and quick method for polymorph differentiation vital to the manufacturing of tattoo inks for the European market. Creating a standard protocol with consistent parameters that could be used across different instruments would ensure that manufacturers can institute good manufacturing practices to test their pigments before incorporating them into their products. Raman spectroscopy is an ideal candidate for this type of analysis since there is minimal sample preparation, quick data collection, and it is non-destructive in nature. One major parameter that should be considered in creating an identification protocol is the excitation wavelength used. There are three commonly used wavelengths: 532 nm, 633 nm, and 785 nm. Our analysis only considered 532 nm and 785 nm as PB15 absorbs light around 630 nm, causing low signal intensity. There should not be a significant shift in the peak wavenumber, as this value is independent of the excitation wavelength used.

Analysis using the Horiba LabRamHR800 Ev with 532 nm excitation wavelength did not match the values listed in previous works.[15] Our values differed significantly and are shown in **Table 1.** Not only do our values differ, but there is overlap in the ranges obtained. This causes differentiation between the polymorphs to be difficult.

Table 1. Intensity ratio ranges of polymorphs of Pigment Blue 15 from Raman analysis using a 532 nm excitation wavelength.

	PB15:1	**PB15:3**	**PB15:6**
$I_{1141/960}$	2.62-3.82	1.1-1.8	1.5-3.09
$I_{1110/1350}$	0.017-0.063	0.043-0.088	0.098-0.187
$I_{1141/1300}$	3.89-6.15	1.53-2.45	2.43-3.46

Data collected using a 785 nm excitation wavelength also yielded inconsistent results. The data collected with the Alpha300R WITec Raman Spectroscope showed significant variation between each replicate of the sample, even when keeping the parameters consistent between samples. There is overlap between all three polymorph standards making it difficult to categorize any ink that was tested using this instrument. On the contrary, data taken with the EZRaman-I Series High-Performance Portable Raman Analyzer was more precise in its measurement, having less variation from sample to sample. Figure 2e suggests that Xtreme Ink Azure to be most like PB15:6 and BioTek Deep Ocean to be closer to PB15:1. The analysis shown in Figure 2f supports this, but the assignment is different from that derived from a 532 nm excitation wavelength. As we cannot determine which assignment is accurate using this method, we are unable to conclusively state that any of the Pigment Blue 15 samples follow REACH regulations.

Conclusion

Since REACH's implementation of regulations for tattoo inks, there has been a cause for concern in the European tattoo ink market, especially with the restriction of PB15:3 and PG7 use. REACH not only bans these two pigments but also mandates that all labels provide an accurate ingredient list with relevant hazard warnings. Nine out of ten inks analyzed across five different brands were found not to be REACH-compliant. All nine of the noncompliant inks contained material not listed on their labels. Only one ink demonstrated agreement between the carrier solution listed on the packaging and the determined composition. Four inks contained banned PG7, while two inks contained some polymorph of PB15. In total, seven inks did not match the pigments listed on the packaging. Additionally, previously established methods for differentiating between different polymorphs of PB15 cannot confidently make these assignments in tattoo inks.

There is a need for a standardized protocol for differentiating between these polymorphs for use in a manufacturing setting if only one of the polymorphs continues to be banned. This protocol should be able to clearly differentiate between polymorphs, but also work across various instruments with the same excitation wavelength. Creating a protocol will assure that tattoo ink manufacturers are using the correct form of PB15, regardless of the source of pigment and the type of instrument being used for the composition analysis.

It is also worth raising a broader question of why only PB15:3 was banned while the other polymorphs were not. Literature suggests that the only difference between the polymorphic structures is how the central copper atom coordinates with the nitrogen in its neighboring ring, altering the packing of the material. Otherwise, from a chemical standpoint, these polymorphs are chemically identical. Heat treating α-copper phthalocyanine (PB15:1) above 300 ºC converts the material to the β-form (PB15:3), and this can be reverted by blocking specific nitrogen atoms with sulfide residues.[12] Additionally, not much is known about the toxicological effects of either PB15 or PG7, though they show a lower occurrence of allergic reaction in tattoo inks when compared to their red and black colored counterparts.[31] There was initial concern due to the link between bladder cancer and the use of certain pigments in hair dyes, causing the use of these pigments to be reviewed by the European Commission's Scientific Committee on Consumer Safety. From what little data is available, both pigments seem to have relatively low levels of acute toxicity.[32] Coupled with the difficulty in correctly assigning pigment polymorphs, this suggests that the prohibition on the use of PB15:3 should be reevaluated.

In total, the number of ink compositions that do not match their listed composition is concerning, both from a legal and ethical viewpoint. Manufacturers may not know what is in their bulk material or the purity of it, highlighting the need for testing materials before use. Testing for composition and purity is much easier before mixing the ingredients into their final product, as separating the tattoo ink into its various components can be challenging. Consumers should be aware of the many ingredients that are added to tattoo inks, such as propylene glycol, given concerns surrounding tattoo safety and potential allergic reactions. Mislabeling of tattoo inks appears to be a widespread issue; as tattoo inks continue to become more regulated and their

compositions held to higher standards, the need for accurate labeling and reliable testing methods is crucial to the industry.

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