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Article

Why Permanent Makeup (PMU) Is Not a Lifetime Application

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Abstract: Permanent makeup (PMU) is a popular form of tattooing applied to the eyebrows, eyelids, and lips for corrective and aesthetic purposes. It also has medical applications, such as reconstructing the breast areola, mimicking hair follicles on the head, and covering scars and vitiligo. Unlike body tattoos, PMU often requires reapplication to maintain color density and shape, as the pigments fade over time. This fading is likely due to the characteristics of PMU colorants rather than the application methods or apparatuses. The aim of our study was to assess the application depth of PMU colorants and tattoo ink after procedures. PMU colorants typically contain larger pigment particles in their composition compared to the nanoparticles found in traditional tattoo inks. We applied both tattoo ink and PMU colorants on SKH-1 mice using a PMU apparatus and a tattoo apparatus. To clarify the semi-permanent nature of PMU compared to the more permanent body tattoos, skin biopsies were performed at various intervals throughout this study. The results showed that PMU and tattoo ink were placed at approximately the same depth but exhibited key differences in behavior. PMU with larger inorganic pigments fades over time, while tattoos with smaller, stable organic pigments ensure permanence.

Keywords: permanent makeup; PMU; permanent makeup colorants; tattoo ink; SKH-1 hairless mice; permanent makeup colorants depth; tattoo ink depth

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1. Introduction

Permanent makeup is a form of tattooing used to enhance the natural appearance of facial characteristics such as the eyebrows, eyelids, and lips. In recent years, the scope of PMU has expanded to include various medical applications. These include: (a) reconstruction of the areola and the nipple following breast surgery, (b) coverage of skin scars, (c) imitation of hair follicles in cases of hair loss of any etiology, and (d) correction of vitiligo [1]. These medical applications have gained popularity and are now considered famous and widely implemented in clinical settings, significantly improving recipients' quality of life [2,3]. While the primary motivation for cosmetic PMU is typically beauty and self-esteem, medical tattoos aim to restore a sense of normalcy for recipients.

Cosmetic tattooing includes both the creation of the permanent makeup effect and the camouflage of injuries or surgical scars. PMU is also known as semi-permanent makeup, micropigmentation, derma-pigmentation, or aesthetic tattoo [4,5]. The use of tattoos for medical purposes dates back thousands of years. Tattoo marks that have been found on preserved mummies show that, among other significances, it was believed that tattoos had healing properties, such as arthritis pain relief, because some appear to be close to traditional acupuncture points [6]. Historically, cosmetic tattooing served various purposes, including tribal rituals and gender-independent decoration, as evidenced by findings in Egypt, Asia, Africa, Europe, and the Americas which demonstrate the significant role in the life of ancient civilizations. Early tattoos were created using primitive tools and natural colorants, such as soot and colorful powders from plants and rocks [7].

Today, body tattooing is primarily decorative and performed with electric devices. The past few years have seen significant advancements in tattooing apparatuses, inks, techniques, and services. Tattooing is increasingly popular, with many celebrities covering their bodies with various designs, influencing their fans and especially young people to get inked. Many individuals obtain their first tattoo during their teenage years or early adulthood, and the number of tattoos often increases over time. Concurrently, PMU has become one of the fastest-growing sectors in the beauty industry, with thousands of women undergoing this procedure daily to enhance their facial features and follow the trends [8].

Both procedures are the same. All pigments are inserted superficially in the papillary layer of the dermis. Due to the puncturing of the skin, an inflammation is initiated. Macrophage cells try to remove the foreign body pigment particles by engulfing them with the phagocytosis procedure. Some macrophages will take up more than one pigment particle and will reach a diameter that will not allow the macrophage and the pigment to enter the lymphatic system [9–12]. As a result, the macrophages containing the pigments remain in place between the collagen bundles of the connective tissue of the dermis and form a visible and permanent or semi-permanent tattoo. After the macrophages have undergone cell death, new macrophages move in and engulf the same pigment agglomerates. This process of phagocytosis and apoptosis is repeated constantly during the lifetime of a tattoo and is described as the pigment capture-release-recapture cycle of dermal macrophages. The permanent character of tattoos and PMU is based on these cellular processes, and, progressively, it fades and blurs [13,14].

Pigment deposited in the epidermis is gradually removed through the skin's natural renewal process, which takes place over a few weeks as the epidermal layer is shed and replaced. During the tattooing or PMU procedure, pigment from the ink cup is transferred into the skin as the needle punctures the skin, creating a series of micro-injuries. This action also generates a vacuum effect that draws the pigment into the dermis. This repetitive process is necessary to build up the desired pigment density and ensure even coverage. [14]. Typically, tattoo apparatuses operate at a frequency of between 25 and 150 Hz, producing between 500 and 4000 needle punctures per square centimeter depending on the type of equipment and the desired outcome [15]. Needle configurations can vary from a single needle to a bundle of thirty or more needles arranged for specific effects. The choice of apparatus settings, needle type, and technique are tailored to achieve the professional's desired results and reflect their individual preferences and expertise in the art of tattooing and permanent makeup [15,16].

In PMU applications, the depth at which pigments are inserted significantly affects the perceived color of the final result. When pigments are placed deeper in the skin, shorter wavelength colors, such as blue, are reflected more intensely than longer wavelength colors, like red. This phenomenon often results in a cooler, bluish tint in applications like eyebrow tattoos. For example, if the pigment is placed too deep, the final appearance can be more bluish rather than the intended color [16,17]. This depth-dependent color shift contrasts with decorative tattoos, where variations in color depth typically have a less noticeable impact on the overall design. Black tattoos, for instance, may appear differently from the original ink color due to the interaction of light with the skin but remain consistent in the design [18].

Both PMU and tattoo pigments interact with light, absorbing and reflecting wavelengths within the visible spectrum based on their color. The appearance of PMU can vary depending on a person's skin tone, which differs in translucency based on ethnicity, anatomical site, and thickness [19].

The chemical composition of tattoo inks and the particle properties of the pigments play a crucial role in determining the final appearance of the tattoo after the healing process. Different compounds can influence whether a pigment appears more opaque or translucent, and they can affect the overall coverage and longevity of the tattoo. Tattoo colorants fall into two main categories: pigments and dyes. Pigments are insoluble particles that range in size from nanometers to micrometers. These particles are physically suspended in the ink and contribute to the color through light reflection and scattering. Dyes, on the other hand, are soluble organic chemicals that are dissolved in a solvent to create a colored solution. Dyes are often derived from crystalline substances which dissolve to impart color to the ink.

To enhance the stability and performance of the dyes, they can be coated with an inorganic base, such as a metallic salt, to form lake pigments. This process increases the dye's stability and prevents it from dissolving, thus mimicking the properties of physical pigments while maintaining the desirable color attributes of dyes.

Pigments can be broadly classified into four categories based on their chemical composition and manufacturing processes:

Organic Pigments: Carbon-based pigments that are known for their bright, vibrant colors. These pigments often have smaller particle sizes, resulting in a more translucent appearance and a broader range of hues.

Inorganic Pigments: Typically made from metal oxides or other mineral compounds. These pigments are generally opaquer and provide strong, durable colors, but can be prone to certain chemical reactions over time.

Carbon Blacks: Produced from the combustion of carbon-containing materials, these pigments are used primarily for black and gray colors and are known for their intense opacity.

Pigment Lakes: Formed by combining dyes with inorganic substances to improve the colorant's stability and performance. These pigments offer a balance between the opacity of pigments and the color richness of dyes [20–22].

Inorganic pigments, often produced through the oxidation of raw materials, face regulatory restrictions due to potential contamination with heavy metals. Tattoo and PMU professionals must understand the properties of pigments to predict outcomes and manage the fading process. Inorganic pigments, commonly used in PMU, can become unstable and oxidize, leading to color changes over time. For instance, iron oxides in PMU can oxidize under the skin, turning reddish after six to eight months, causing the recipient's dissatisfaction. Professionals should choose cooler or neutral shades for facial PMU to mitigate these effects [22].

In the ink manufacturing industry for tattoos and permanent makeup, finely ground solid particles or coated dyes are mixed with carrier liquids and excipients to create colored inks. Carrier liquids consist of two main components: a solvent and a binder. The binders (usually polyethers, polyvinylpyrrolidone, block copolymers, shellac, etc.) are used to bind the pigment particles to each other and to the tattoo needle itself to ease the insertion of the pigment particles in the dermis. Water is the main suspending medium of tattoo ink. Alcohols and polyols are added to control the viscosity, dispersibility, and drying properties of the ink. Additives are used to emphasize or diminish certain characteristics of the inks. They are mainly used to ensure long-term stability through the inclusion of preservatives, viscosity imparting agents, pH-regulating agents, and antioxidants [23,24].

For PMU and tattoo application, it is important not to mix inks and colorants from different brands or product lines because their carrier liquids and chemical compounds can differ. These different substances may lead to the destabilization of the application or cause adverse reactions. Furthermore, the particle size of the pigments may differ due to different raw materials and different processes of milling, which can result in discordance between pigment fractions. Pigment particles from different ink manufacturers can agglomerate during mixing and lose their dispersible properties. Different pigment clusters may cause migration of some fraction of pigment from the insertion site to a different depth or position in the dermis, resulting in visible blowout to the surrounding skin near the application of the tattoo or permanent makeup [25].

Also, different carrier liquids have different viscosity and may not be mixed into a homogenous medium. Manufacturers of permanent makeup colorants and tattoo inks generally present little information on the product label and packet inlet about ingredients. The labeling can be wrong and misleading, and the artist cannot make a qualified guess on the composition to achieve the desired result of the application [25,26].

Inorganic pigments are often produced through oxidation of inorganic chemicals or from raw materials which are available in nature. Their composition consists of metallic salts, which are insoluble in water, oil, and organic solvents. Tattoo inks and permanent makeup colorants based mostly on inorganic components are limited because of regulatory restrictions on the contamination of heavy metals such as cadmium, lead, nickel, and mercury. These heavy metals can be very harmful for human health [26,27].

Furthermore, it is important for the permanent makeup or tattoo practitioner to recognize how the pigments will affect the healed outcome and the fading process. Iron oxide pigments, which are inorganic and mostly used in permanent makeup, are duller than organic pigments and provide more opacity and color strength due to their large particle surface, which reflects more light. It is worth mentioning that iron oxides contained in permanent makeup colorants can be oxidized under the skin and become unstable. This oxidization can turn the application to a reddish color after six to eight months and cause the disappointment of the patient. When inorganic pigments are used for permanent makeup of face areas such as the brows, which are exposed to sunlight, it is recommended to use cooler or neutral shades. Inorganic pigments can also be subdivided into natural or synthetically produced inorganics, which are preferred for permanent makeup application [28,29].

Organic pigments are carbon-based but can contain inorganic elements that add stability. These inks offer a larger selection of bright colors and are mostly used for decorative tattoo application. The small particle sizes of nanoparticles of organic pigments generally result in a more translucid effect. The brightness of the color may not lead to complete coverage. They can be divided into natural and synthetic organic pigments [30–33]. Most tattoo inks have synthetic organic pigments. These kinds of pigments are more likely to be used since synthetic materials are more controlled in their nature of composition. They can be subdivided into azo pigments, polycyclic pigments, and pigment lakes. For tattooed people's safety, in the last few years, many regulations for ink manufacturing have changed with more strict regulations, especially in the European Union [34–36].

The rising popularity of tattooing and PMU has also led to an increased demand for complete or partial tattoo removal. Laser tattoo removal is the most common method for eliminating unwanted tattoos, whether for complete removal or correction of a poor PMU application. Often, a new tattoo can be applied in the same area a few months after removal [10,37].

The purpose of our study was to assess the insertion depth of tattoo and PMU colorants to justify the difference in their longevity. PMU is considered semi-permanent because it fades relatively quickly from the facial skin, whereas decorative body tattoos are generally lifelong with minimal discoloration over time. We applied tattoo ink and PMU colorants to SKH-1 mice using both PMU and tattoo apparatuses and examined the application depth at various intervals from immediately after application up to 56 days post-application. SKH-1 mouse skin is close to human skin because of the hair absence. This specific characteristic helps the PMU and tattoo procedures to be applied easier. Also, the light skin color of these mice makes the application look similar to tattoo and PMU applications on human skin.

2. Materials and Methods

2.1. Tattoo Inks and PMU Colorants

For this study, a common brown PMU colorant intended for the eyebrow area and a black tattoo ink for decorative body tattoos were used. The selection criteria for these types of colorants were their popularity in the tattoo and PMU industry, as they were the choice of many professionals. They were also compliant with REACH regulations. The same criteria were used for the equipment and machines. The PMU colorant (code 810, Nouveau Contour, Weert, The Netherlands) and the tattoo ink (Triple Black, Eternal Ink, Michigan, MI, USA), were purchased from local suppliers. PMU primarily contained inorganic ingredients, while the tattoo ink was a typical carbon black organic pigment.

2.2. *In Vivo Test*

Two groups of ten SKH-1 mice each were selected for the application of the colorants. SKH-1 mice have very light skin and an absence of hair, which is ideal for tattoo application, as they simulate the results of PMU on human skin [11]. All the mice were anesthetized during the procedure, administering IP, a combination of ketamine/xylazine, at a dose of 0.1 mg/20 g mouse wt.

2.3. *Tattoo Procedure*

Both the PMU colorant and tattoo ink were positioned into the papillary layer of the dermis using the same procedure typically performed on human skin. The first group of mice received a PMU application on the back using the brown permanent makeup colorant (code 810, Nouveau Contour, Weert, The Netherlands) and a digital PMU device (Intelligent PMU device, Nouveau Contour, Weert, The Netherlands). The second group received a decorative tattoo application on the back with black tattoo ink (Triple Black, Eternal Ink, Michigan, MI, USA) using a digital tattoo device (Mast tattoo device, Dragonhawk, Shijiazhuang City, China).

Both devices were calibrated to the same speed of 6500 rpm to ensure consistency in application density and speed. A liner needle with a single 3.5 mm stroke was used for both procedures. The application method involved five repetitions of the ink with moderate pressure applied by the handpiece of both the PMU and tattoo devices. All applications were performed by a professional to ensure accuracy comparable to human skin procedures. At the end of this study, all mice were euthanized by cervical dislocation, and skin samples were obtained and kept at Laboratory of Dermatology Aesthetics and Laser Application of the Department of Biomedical Sciences in the School of Health Sciences and Welfare at University of West Attica until further analysis.

2.4. *Histopathological Evaluation*

Histopathological evaluations of the biopsies were conducted to assess the insertion depth and the persistence of the colorants. Skin tissue samples were stained with hematoxylin and eosin to aid in the identification of foreign deposits such as tattoo ink and PMU colorants. The samples were observed under a microscope (Levenhuk MED D45T Digital Trinocular Microscope, Levenhuk, Inc., Tampa, FL, USA), and the depth of colorant deposition was assessed with LevenhukLite MED D45T, software.

3. Results

The tattoo ink and PMU colorants that were used in our study had organic and inorganic ingredients. As previously stated, each type of pigment differs fundamentally in terms of its manufacturing process, particle size, and overall properties. These characteristics influence the tattoo's appearance, durability, and safety. In Table 1, we classify the characteristics of colorants used for PMU and tattoo applications.

Table 1. The classification and characteristics of the colorants used for PMU and tattoo applications.

	Term	Definition	Characteristics	Examples
Colorant types	Dyes	Soluble organic colorants dissolved in a solvent	Indigo, Alizarin Crimson	Generally, more translucent, often derived from crystalline substances
	Pigments	Insoluble color particles suspended in the ink	Titanium Dioxide, Carbon Black	Typically opaque, can be organic or inorganic
Pigment categories	Organic Pigments	Carbon-based pigments known for vibrant colors	Quinacridone, Phthalo Blue	Bright colors, often translucent, smaller particle size
	Inorganic Pigments	Metal oxides or minerals used for strong, durable colors	Iron Oxide Red, Chromium Oxide Green	Opaque, often more durable, can be prone to oxidation
	Carbon Blacks	Produced from carbon combustion for black and gray shades	Lamp Black, Bone Black	Intense opacity, used mainly for black shades
	Lake Pigments	Dyes combined with inorganic bases for enhanced stability	Pigment Red 5 Lake, Yellow 5 Lake	Offers a balance of opacity and dye stability

In our study, all the colorants that were used were compliant with REACH regulations. In Table 2, we present detailed information on the ingredients of the PMU colorant and tattoo ink that were applied on the SKH-1 mice skins.

Table 2. The ingredients of the colorants used in this study according to the information on their labels. (Both colorants are compliant with REACH regulations).

PMU Colorant (Code 810, Nouveau Contour, Weert, The Netherlands)	Tattoo Ink (Triple Black, Eternal Ink, Michigan, MI, USA)
CI77891 CI77491 CI77288 CI77499 CI77492 CI77266 CI56300	CI77266 organic pigments distilled water witch hazel alcohol

Skin biopsies with PMU colorant (I) and tattoo ink (II) taken at 24 h, 7 days, and 56 days post-application are displayed in Figure 1. The tattoo ink was consistently visible in all biopsies, distributed from the epidermis to the lower dermis. PMU colorant was also evident in all samples, spanning from the epidermis to the lower dermis.

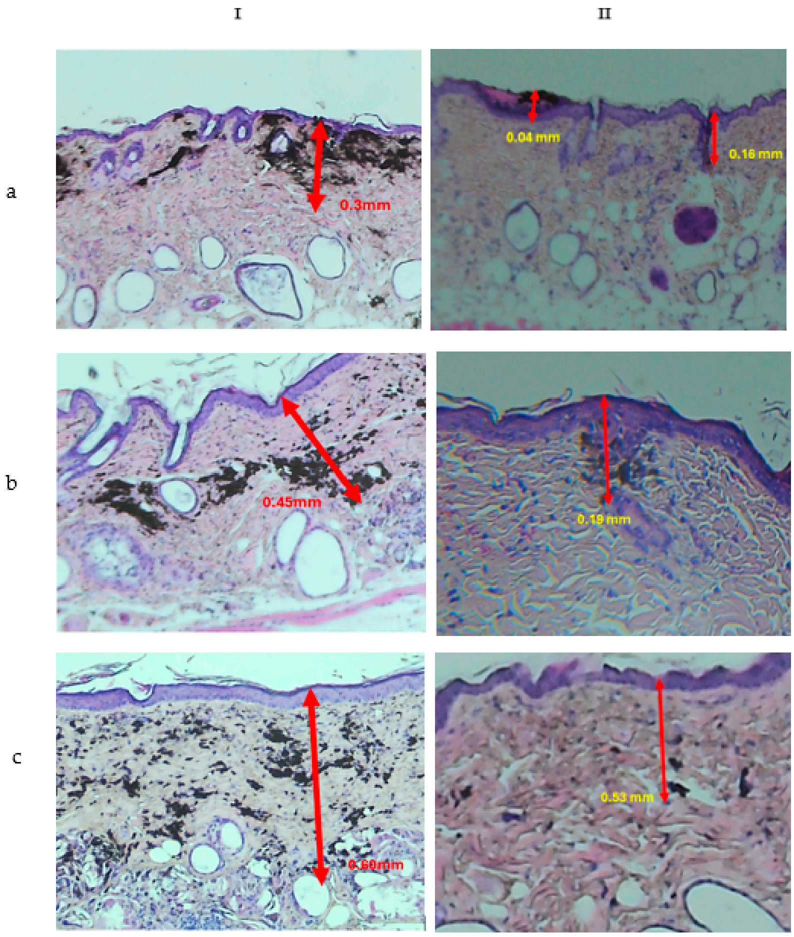

Figure 1. (**I**) Black tattoo ink (Triple Black, Eternal Ink, Michigan, MI, USA) and (**II**) brown permanent makeup colorant (code 810, Nouveau Contour, Weert, Netherlands) on SKH-1 mice (**a**) 1 h after tattooing (4× hematoxylin/eosin), (**b**) 7 days after tattooing (10× hematoxylin/eosin), and (**c**) 56 days after tattooing (10× hematoxylin/eosin).

All skin biopsies from the inked SKH-1 mice contained adequate amounts of ink. Both PMU and tattoo ink applications demonstrated progressive migration of the colorants into deeper skin layers over time. On the first day, the inks were observed primarily in the epidermis (Figure 1a). By the seventh day, they had migrated to the upper dermis (Figure 1b), and by day 56, they were settled in the lower dermis (Figure 1c).

Tattoo ink, with its smaller nanoparticles, is designed to last a lifetime, as evidenced by its stable presence in the lower dermis throughout this study (Figure 1I). In contrast, PMU colorants, which contain larger particles, showed significant migration and reduction over time (Figure 1II). This is likely due to the wound healing process, which facilitates the removal of larger particles. The combination of needle type, ink composition, skin characteristics, pigment deposition depth, and penetration density contributes to the shorter lifespan of PMU compared to tattoos.

On the first day, the penetration depth for tattoo ink was 0.30 mm, compared to 0.04 mm for PMU colorant (Table 3, Figures 1a and 2). This initial difference is likely due to the higher quantity of pigment nanoparticles in the tattoo ink. By the seventh day, the tattoo ink had penetrated to 0.45 mm, while the PMU colorant reached 0.19 mm (Figure 1b). The varying depths are attributed to the different compositions of the colorants, with macrophages containing more organic ink pigments from the tattoo ink than from the PMU colorants.

Table 3. Depth (mm) of tattoo ink and PMU colorants in the skin over time post-application.

Time After Application (Days)	1	7	56
Tattoo Ink	0.30	0.45	0.60
PMU Color	0.04	0.19	0.53
Difference	0.26	0.3	0.07

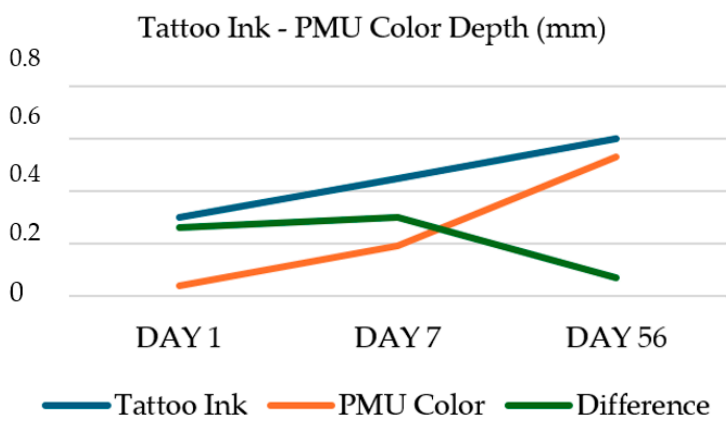

Figure 2. Depth (mm) of tattoo ink and PMU colorants in the skin over time post-Application.

By day 56, both colorants had reached nearly the same depth, with a minimal difference of 0.07 mm (Table 3). Despite the similar penetration depths, the retention of colorant particles differed significantly. The tattoo ink particles remained more abundant and stable, whereas the PMU particles had largely diminished (Figure 1c). This explains why PMU fades within a few months and requires retouching to maintain the desired appearance. PMU typically needs at least two applications, spaced several months apart, to achieve longer-lasting results. Even after the second application, PMU generally fades within one to two years, necessitating periodic reapplication.

Histopathological evaluations showed no tissue damage from the tattooing, underscoring the importance of professional application in achieving optimal outcomes. The histopathological examination revealed distinct patterns of ink and colorant deposition. Initially, both inks were confined to the superficial layers. Over time, the tattoo ink showed a more uniform distribution and deeper penetration, indicative of its nanoparticle composition. The PMU colorant, while initially present in similar regions, showed signs of particle aggregation and migration, which likely contributed to its eventual reduction in visibility.

Macrophage activity was significantly higher around the PMU sites, suggesting an active removal process. This contrasted with the tattoo ink, where macrophage activity was present but less pronounced, indicating a more stable integration of the ink particles into the dermal matrix.

Overall, this study demonstrates clear differences in the behavior of PMU colorants and tattoo inks, providing insights into their respective longevity and the biological processes influencing their permanence. The comparative analysis highlights significant differences in how these colorants behave over time, offering valuable insights for both cosmetic and medical applications. The migration patterns of both tattoo ink and PMU colorants were notably progressive, with both types of colorants moving from the epidermis to the lower dermis over the study period.

4. Discussion

Our study provides an in-depth analysis of the behavior, migration, and retention of tattoo ink and PMU (permanent makeup) colorants in SKH-1 mice skins over a 56-day period. To our knowledge, this is the first in vivo study to evaluate and track the behavior of PMU colorants and tattoo ink over time.

On the first day post-application, the tattoo ink penetrated to a depth of 0.30 mm, whereas the PMU colorant reached only 0.04 mm. By day seven, the tattoo ink had further migrated to 0.45 mm and the PMU colorant to 0.19 mm. At day 56, the final penetration depths were 0.60 mm for the tattoo ink and 0.53 mm for the PMU colorant.

These differences in initial penetration depth and subsequent migration can be largely attributed to the physical and chemical properties of the colorants. Tattoo inks typically are composed of organic pigments with smaller particles, often in the nanoscale, resulting in more vibrant and permanent applications that can penetrate deeper into the skin more readily [35]. This nanoparticle composition not only facilitates deeper initial penetration but also supports continued migration over time as the particles integrate into the dermal layers [36,37].

In contrast, PMU colorants, which are composed of larger inorganic pigment particles, provide more opacity, exhibit more superficial initial placement, and are more prone to fading. The larger particle size hinders deeper initial penetration and makes these particles more susceptible to the skin's natural wound healing process, which tends to remove foreign materials. This difference in particle size and composition is crucial in understanding why tattoo ink exhibits deeper and more stable penetration compared to PMU colorants [38].

Despite the similar final penetration depths observed at day 56, there was a marked difference in the retention and stability of the colorants. Tattoo ink particles remained more abundant and stable within the dermal layers, demonstrating the ink's high level of permanence. This stability is consistent with the intended long-lasting nature of tattoo inks, which are designed to provide lifetime durability [39].

On the other hand, PMU colorants showed significant reduction over time. The larger particles of PMU colorants are more prone to be removed by the skin's healing processes. This ongoing removal process explains why PMU applications typically fade within a few months and require periodic reapplications to maintain the desired cosmetic effect. PMU procedures often necessitate multiple sessions, spaced several months apart, to achieve and maintain longer-lasting results. Even with these repeated applications, PMU generally fades within one to two years, necessitating further reapplications.

In each stage of this study (day 1, 7, 56), tattoo ink particles had an intensive part in the tissue samples. On the other hand, PMU colorants appeared to cover less tissue area. Histopathological evaluations revealed distinct patterns of ink and colorant deposition, as well as varying levels of macrophage activity. Tattoo ink displayed a uniform distribution and deeper penetration, indicative of its stable integration into the dermal matrix. This stable integration was associated with lower macrophage activity around tattoo ink sites, suggesting a less reactive environment and greater permanence of the ink particles [40].

Conversely, PMU colorants showed signs of particle aggregation and migration, coupled with significantly higher macrophage activity. The increased macrophage activity indicates an active biological process aimed at removing the PMU particles from the skin. This process of aggregation and migration, along with the heightened macrophage response, contributes to the reduced stability and faster fading of PMU colorants [41].

The differential behaviors of tattoo ink and PMU colorants can be further understood by considering the underlying biological processes involved. The smaller nanoparticles of tattoo ink are more easily phagocytized by dermal macrophages, which then transport these particles deeper into the skin, where they become more stable. This process results in the long-lasting presence of tattoo ink in the dermal layers, as macrophages containing ink particles become stationary in the dermis [42].

In contrast, the larger particles of PMU colorants are less easily phagocytized and more prone to removal during the wound healing process. The increased macrophage activity observed around PMU sites suggests an ongoing effort by the body to remove these larger particles. This active removal process leads to the aggregation and migration of PMU particles, resulting in their eventual reduction in visibility and the need for repeated applications [41,42].

The findings of this study have several practical implications for clinical practice in both cosmetic and medical tattooing. First, the skill and experience of the practitioner are paramount in achieving optimal outcomes. In addition to the type of ink, the skill of the PMU expert or tattoo artist is crucial in determining the depth and quality of the application. Professional application ensures that colorants are implanted at the correct depth, which is crucial for both initial appearance and long-term retention. Inexperienced practitioners may apply colorants too deeply or too superficially, leading to suboptimal results, including uneven distribution, faster fading, or even adverse reactions [42].

In our study, all applications were performed by a professional using appropriate devices for each procedure. This ensured correct insertion of the colorants in the mice skins, leading to accurate and reliable results.

For PMU procedures, this study highlights the necessity of informing the recipients about the expected longevity and maintenance of their treatments. Given the significant reduction in PMU colorants over time, recipients should be advised that periodic reapplications will be necessary to maintain the desired cosmetic effect. Understanding the natural fading process can help manage recipients' expectations and improve satisfaction with PMU applications.

Our study contributes to the broader understanding of how different types of skin colorants behave over time, with implications for their use in both cosmetic and medical contexts. Our findings show that tattoo ink penetrates deeper and remains more abundant in the skin compared to PMU colorants, explaining the latter's semi-permanent nature. The composition of tattoo inks, with their nanoparticle organic pigments, contributes to their permanence. The insights gained from this research can inform the development of new formulations and techniques aimed at improving the longevity and stability of PMU colorants, potentially reducing the need for frequent reapplications. These insights can guide PMU professionals in selecting colorants and understanding the depth of application required for optimal results. Additionally, understanding pigment behavior is crucial for achieving the desired outcome and managing the fading process effectively. Unfortunately, there is a lack of studies on whether and to which extent tattoo inks might hamper normal wound healing after tattooing. This fact could be a potential study limitation, as well as the mouse skin tissue, which differs from human skin.

As most PMU applications are on the sensitive facial area, ingredient safety is paramount. New formulations could facilitate safer removal options, addressing the growing demand for PMU correction and removal methods. Enhanced formulations with more inorganic ingredients might offer a balance between durability and ease of removal. The possibility of formulating colorants that are easier to remove can lead to more flexible PMU applications, reducing the risk of permanent mistakes and increasing recipients' satisfaction. PMU colorant manufacturers should consider developing safer products with stable formulations.

Future research could explore the long-term effects of repeated PMU applications, the impact of different skin types on colorant behavior, and the development of new colorant formulations with improved stability. Additionally, studies could investigate the potential health impacts of long-term exposure to tattoo inks and PMU colorants, particularly regarding the presence of nanoparticles and their interactions with biological tissues.

5. Conclusions

In conclusion, this study highlights the fundamental differences between PMU colorants and tattoo inks in terms of their behavior in the skin. Despite this similarity in depth placement, the duration of visibility and permanence of these applications on the skin markedly differs. We evaluated the application depth on the first day, the seventh day, and the fifty-sixth day after application, highlighting the structural, particle size, and pigment content differences between tattoo inks and PMU colorants.

Tattoo inks, primarily composed of organic pigments, are characterized by smaller particle sizes and greater pigment stability, contributing to their lifelong permanence. In contrast, PMU colorants, which predominantly use inorganic pigments, exhibit a semi-permanent nature due to their larger particle sizes and gradual fading. This necessitates multiple applications of PMU, unlike the typically single-application requirement for tattoos.

The use of inorganic pigments in PMU offers a potential advantage: easier removal for recipients who change their preferences. However, this characteristic also warrants further research into the safety and efficacy of inorganic pigments, particularly when used on sensitive facial areas. Future studies should aim to identify the specific compounds influencing the duration and safety of PMU colorants, thereby ensuring safer application practices and protecting public health.

In summary, while PMU and tattoo procedures may appear similar, the choice of colorants significantly impacts the longevity and maintenance requirements of the applications. Understanding these differences is crucial for practitioners and manufacturers, emphasizing the need for careful selection of colorants and consideration of their long-term behavior in the skin to achieve the best possible results for both permanent makeup and tattoo applications.

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