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ORIGINAL ARTICLE

Skin-toned tattoo ink: what should one expect in terms of ink darkening and removal when treated with a 755 nm picosecond laser?

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Abstract. *Background:* picosecond lasers have proved to be effective for the removal of tattoos. However, the removal of micropigmentation remains challenging due to the complexity of cosmetic skin-toned inks that contain titanium and iron oxides. *Aim:* the following study aims at further investigating how the concentration of mineral oxides and the fluence can impact the color change, assessing the darkening process and the removal efficiency which occurs when a skin-toned cosmetic tattoo is treated with a picosecond laser. *Methods:* Model ink samples as well as a skin-toned eyebrow tattoo were treated with a picosecond laser using fluences from 0.21 to 5.25 J/cm^2. Digital photographs were taken and the color contrast was analyzed with ImageJ software. Analyses of variance were performed with the Excel software. *Results:* At a fluence threshold, the greyish discoloration of TiO_2 model inks occurred, then the color contrast increased with the fluence until reaching a plateau. Interestingly, a synergetic effect between iron and titanium oxides became a possible occurrence. Darkening was also observed *in vivo* during the treatment of an eyebrow tattoo containing flesh inks. The tattoo became first greenish, then darker and finally the pigmentation started decreasing after the 8^{th} session. 11 treatments were necessary to completely remove the tattoo. *Conclusion:* The 755 nm picosecond laser has demonstrated its efficiency to remove complex tattoos containing flesh pigments. Ink darkening seems to be inevitable during the treatment, however, it should not be seen as a complication but as a part of the elimination process.

Keywords: Picosecond laser, tattoo removal, cosmetic tattoo, mineral pigment, metal oxide

Introduction

Picosecond (PS) lasers have demonstrated their efficiency in tattoo removal[1-4]. Their very short pulse length, close to the thermal relaxation time of pigment particles, makes possible the significant photomechanical breakup of pigments while preventing collateral adverse effects[5]. Nevertheless, the removal of cosmetic micropigmentation remains challenging due to the complexity of cosmetic inks, particularly skin-toned inks. Micropigmentation is typically used to redraw areolas following breast surgery and to camouflage scars or old cosmetic eyebrow tattoos[6,7]. Skin-toned inks include high concentrations of titanium oxide TiO_2 (CI 77891, white pigment), iron oxides Fe_2O_3 (CI 77491, red pigment) and $Fe_2O_3 . H_2O$ (CI 77492, yellow). These metal oxides are known to cause a darkening of cosmetic tattoos during laser treatments[8-15].

With the development of cosmetic tattooing, the demand for removing flesh inks has grown. The present study had two objectives: First, to further investigate, by means of a simple model, how the concentration of mineral oxides and the fluence can impact the color change of flesh inks during laser treatments; second, to assess the darkening process and removal efficiency when a skin-toned cosmetic tattoo has been treated with a picosecond laser.

Materials and methods

Model inks

Iron oxide and titanium oxide (100% purity, Gerstaecker Switzerland) were suspended in tattoo ink thinner (AUA Fee Shading solution) in order to prepare the following inks: TiO_2 50%, TiO_2 25% and Fe_2O_3 4% (w/w). The suspensions were stirred vigorously before use. Model inks were deposited in a very thin layer (one passage) on a white sheet in a predefined rectangular area (4 x 2 cm) using a cotton swab. The resulting samples were then air-dried.

Laser treatments

All samples were treated with a picosecond laser (650 ps, Cynosure, USA) using fluences ranging from 0.21 to 5.25 J/cm^2. Six replicates were performed.

Color analyses

Digital photographs were taken under the same conditions (light source and room) before and immediately after treatment. The grayscale intensity before and after laser treatment was analyzed with ImageJ software (US National Institutes of Health). The color variation was calculated using the following formula:

$I_{untreated\ ink}$ is the mean grayscale intensity for five untreated ink sites selected randomly. $I_{treated\ ink}$ is the grayscale intensity of laser-treated sites. Two measurements per replicate were performed (2 x 6 = 12 measurements per experiment).

Statistical analyses

Analyses of Variance (ANOVA, one factor) were carried out with the Excel software. Differences were considered as significant when *p* £ 0.05.

Clinical case

The patient (49 years old, Fitzpatrick skin type II) came with an eyebrow tattoo created with dark permanent make-up (12-months aged) camouflaged by a skin-toned ink (7-months aged). Prior to the first laser treatment, a consultation was carried out in order to review the medical history and explain the procedure. Informed explanatory consent was obtained in writing. Laser treatments were carried out with a Picosure Laser (755 nm, 650 ps) using fluences of 1.45 - 5.25 J/cm^2. The patient received 11 treatments at 4-week or 8-week intervals when a fluence of 5.25 J/cm^2 was used. The patient was contacted 24 hours after each treatment to determine any side effects.

Results

Since 50 to 10% titanium oxide and 2 to 6% iron oxide can be found in commercially-available skin-toned inks, we assessed the chemical behavior of TiO_2 50%, 25%, 12.5 % and Fe_2O_3 4% model inks at fluences ranging from 0.21 to 3.36 J/cm^2. The resulting color contrasts were analyzed and are shown in Figures 1 and 2. In Figure 1, regardless of the TiO_2 concentration, the curves followed a similar pattern: At a fluence threshold a greyish discoloration occurred, after which the darkening increased with the fluence until reaching a plateau. The thresholds for which the white pigment turned grey were between 0.25 and 0.33 J/cm^2 for TiO_2 50% and 25%, and between 0.33 and 0.57 J/cm^2 for TiO_2 12,5%. When inks were treated using the same fluence, the greater the concentration of titanium oxide, the greater the importance of the darkening. Above a fluence value, 1.31 and 2.33 J/cm^2 for TiO_2 50% and TiO_2 25% respectively, the resulting color contrast remained stable around 40-50%. No grey discoloration was observed when Fe_2O_3 4% ink was treated with a fluence ranging from 0.21 to 5.25 J/cm^2 (Figure 2, only results below 0.85 J/cm^2 are shown). This suggests that, under our experimental conditions, iron oxide Fe_2O_3 might not interact with the laser.

Fe_2O_3/TiO_2 (4%/50% and 4%/12.5%) model inks were treated with picosecond laser at fluences ranging from 0.21 to 0.85 J/cm^2. As shown in Figure 2, a grey discoloration occurred in the mixed oxide inks. Interestingly, the color change was observed at a lower fluence when TiO_2 was associated to Fe_2O_3. Thus, grey discoloration was detected at 0.21 J/cm^2 for Fe_2O_3/TiO_2 4%/50% (*vs.* 0.33 J/cm^2 for TiO_2 50%) and at 0.33 J/cm^2 for Fe_2O_3/TiO_2 4%/12.5% (*vs.* 0.57 J/cm^2

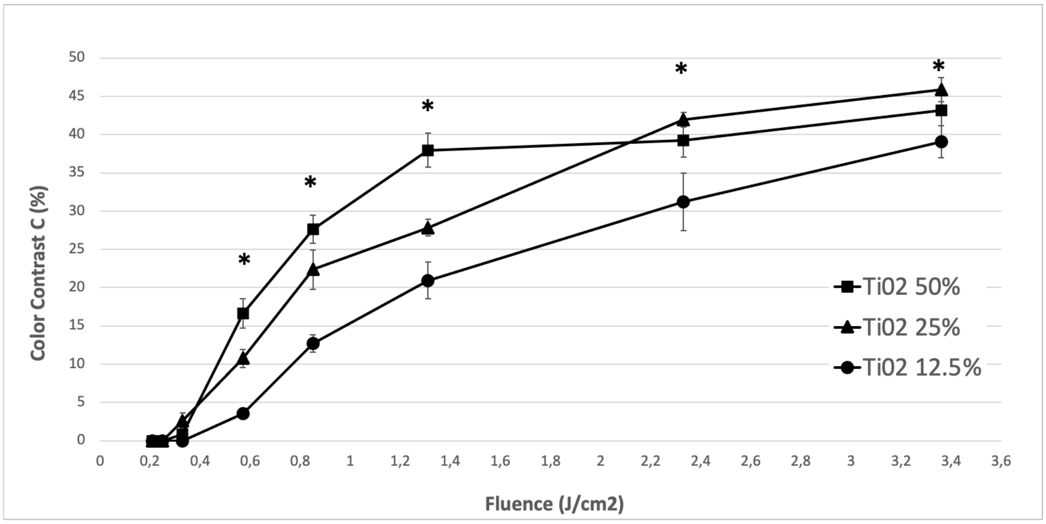

Figure 1. Color variation of titanium oxide inks as a function of laser fluence (* means $p < 0.05$, significant statistical differences).

for TiO_2 12.5%). Overall, the color variations were more important than those obtained only with titanium oxide (Fe_2O_3 did not induce any color change at these fluences) suggesting a possible synergetic effect between iron and titanium oxides.

As shown in Figure 3, color discoloration was also observed *in vivo* during the laser treatment of a flesh ink located on the eyebrow. The exact ink composition was not known. During sessions 1 to 3, the tattoo was treated with fluences ranging from 1.45 to 2.33 J/cm^2 and became greenish. Since flesh inks generally include yellow pigments, the association of blue and yellow colors could be responsible for the resulting green coloration. Fluences from 2.68 to 3.36 J/cm^2 were then employed from sessions 4 to 7. The overall color became darker. The pigmentation started decreasing

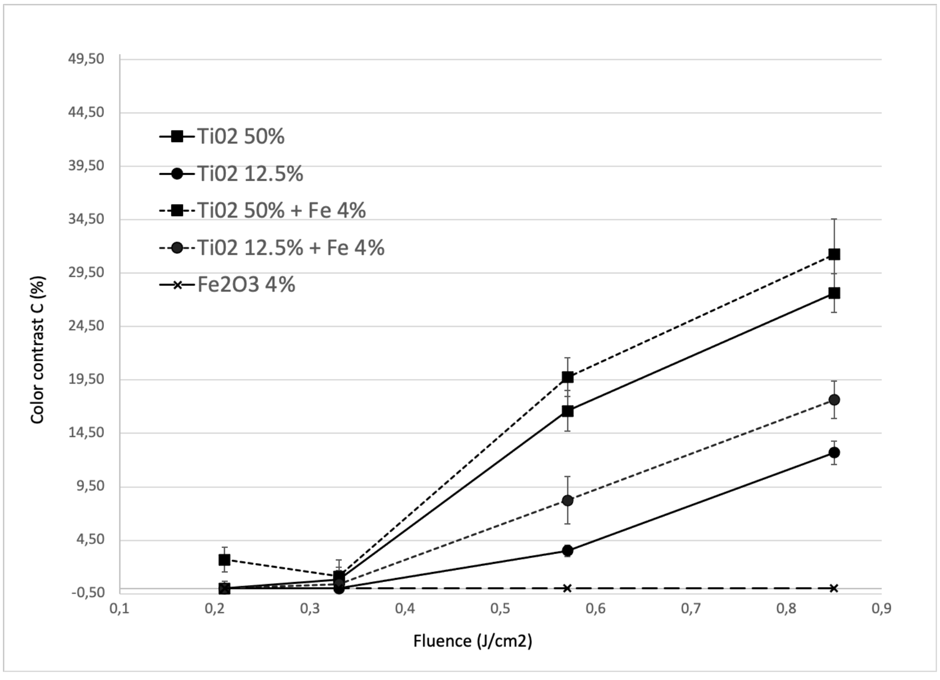

Figure 2. Color variation (darkening) of titanium oxide inks with and without Fe2O3 4% as a function of laser fluence.

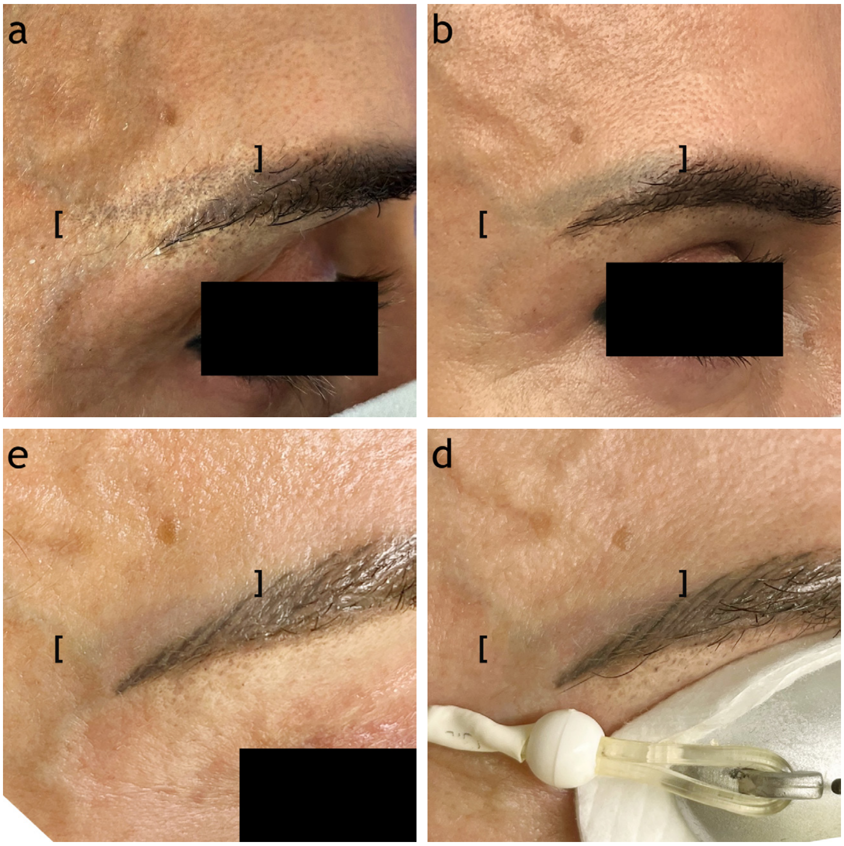

Figure 3. Color changes of an eyebrow tattoo created with dark and skin-toned inks when treated with a picosecond laser. a before the treatment. b after 3 treatments. c after 8 treatments. d after 10 treatments. e after 11 treatments.

after session 8 with a significant reduction at session 10 (3.97 to 5.25 J/cm^2). All pigments were removed after one additional laser session (5.25 J/cm^2). A few days after each session, the patient showed redness and, from the seventh session, some crusts. No scars or dyschromia were observed.

Thus, a 755 nm picosecond laser proved to efficiently remove skin-toned cosmetic tattoos. Nevertheless, a complete removal required a large number of sessions. Leu *et al* have demonstrated by means of transmission electron microscopy that white pigment tattoo particles were the largest, iron red particles were intermediate and black carbon particles were the smallest[16]. The size of TiO_2 particles might be one factor explaining the high number of sessions required for fragmentation and removal. Moreover, flesh inks are generally used to camouflage older tattoos, which means a greater ink density and chemical complexity. The values for fluences employed during a clinical treatment were far above the threshold of discoloration in Figure 1, suggesting that color change might be inevitable if the patient wants to completely remove a flesh cosmetic tattoo.

Discussion and conclusion

Titanium and iron oxides are known to be responsible for the grey discoloration during treatment with nanosecond and picosecond lasers. The color change is attributed to the reduction of Fe(III) and Ti(IV) into Fe(II) and Ti(III) respectively[15]. Our study on titanium inks at 755 nm showed that the intensity of the grey discoloration was dependent on the initial concentration and the fluences used during the treatment. No discoloration was observed at low fluences, suggesting that a threshold energy is required to initiate the reduction reaction. Although the impact of laser wavelength and pulse duration on ink darkening has already been reported on, this is the first time that a significant impact of fluence and pigment concentration has been demonstrated. Additionally, a potential synergetic effect between iron and titanium oxide has been evidenced. This might be due to a greater reduction of titanium or the activation of Fe(III) reduction. Further experiments should be conducted in order to better understand the mechanisms behind this synergetic effect.

The 755 nm picosecond laser has demonstrated its efficiency in removing complex cosmetic tattoo containing flesh pigments. Due to many unknowns inherent to cosmetic tattoos (*i.e.* ink composition, number of pigment layers), it would be very difficult to predict color changes during treatment. As high fluences would be required, darkening seems to be inevitable in fully removing skin-toned pigments. Patients should be informed prior to starting laser tattoo removal. However, color changes should not be seen as a complication but rather as part of the elimination process.

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