CASE REPORT

A case of chemical scalp burns after hair highlights: experimental evidence of oxidative injuries

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Abstract

Hair highlights are quite common procedures carried out in hair salons by using a mixture of a lightening powder containing persulfates with a suspension containing hydrogen peroxide: a representative case of chemical scalp burns is described as a consequence of this treatment. The aim of the paper is to demonstrate the strict relationship between the scalp damage and the commercial products used in a case of hair highlighting. The results of some chemical analyses have been reported, showing, in particular, that the chemical reactivity of the mixture changes in the time, thus strongly suggesting that the procedure for the application of the mixture is critical for the occurrence of possible accidents. The presence in the powder of chemical compounds bearing aliphatic chains as surfactants explains the appearance of dramatic symptoms after days due to a slow dissolution of the oxidant compounds in the stratum corneum of skin with no effect in reducing injury of palliative treatments. Safety suggestions and recommendations for producers and workers are also included.

Keywords

Chemical scalp burn, hair highlight, oxidative injury, hydrogen peroxide, persulfates

History

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Introduction

Even if hair highlights are quite common procedures performed in hair salons, only very few cases of cutaneous adverse effects including secondary scalp burns have been described. The most common complains associated with the use of hair care agents are hair breakage and/or hair loss¹ or skin sensitization². Nevertheless some examples of chemical scalp burns have been reported in the scientific literature and directly related with the use of hydrogen peroxide combined with the highlighting mixture³–¹². In all the described cases the procedure involved the following steps: (i) decolorizing of the melanin pigments; (ii) exposure to a low temperature hair dryer to accelerate the bleaching and (iii) rinsing the hair with water and washing with a neutralizing shampoo. During the first step, aluminum foils to select strands of hair and protect surrounding area, are used. The decolorizing process is an oxidation reaction induced by a mixture of hydrogen peroxide and persulfates immediately prepared before use, in the presence of sodium metasilicate to increase the pH. Because of the severe reaction conditions required for destruction of the chromophore of hair pigments, side reactions with the hair proteins, containing a large percentage of oxidizable groups, simultaneously occur: hydrogen peroxide oxidizes, in particular, disulfide bonds of the cortical matrix and of the cuticle with degradation of hair proteins and weakening of the cell membrane complex, until its breakdown¹³. Also methionine, tyrosine, lysine and histidine, in addition to cystine, are degraded to the greatest extent by strong oxidants and at pH ranging from 9 to 11 the hydrolysis of peptide and amide bonds also occurs¹³. On the basis of the detailed studies reported¹³ it appears that alkaline damage is important to the cell membrane complex lipids and proteins doing epicuticle susceptible to damage from further chemical and physical stresses. After bleaching, typically a dyeing process is carried out: permanent dyes generally consist of p-diamines and p-aminophenols that are oxidized by hydrogen peroxide to active intermediates which then react inside the hair with color couplers (i.e. substituted resorcinols or m-phenylenediamines) forming colored compounds, usually gray or brown-black shades. The persulfates accelerate the bleaching process by making the hair “porous” facilitating hair dye absorption.

In the cases reported in the literature misuse or failure to comply with the usage instructions have been proposed to be the origin of scalp burns, such as scalp contact with aluminum foils overheated by the hair dryers, toxic reactions to hair dye chemicals or use of an incorrect concentration of hydrogen peroxide.

Here we describe the representative case of a young woman who experienced a large ulceration on occipital scalp...
after 12 days from a hair highlighting process performed in a hair salon, with consequent surgical intervention and strong social embarrassment. In order to understand the reason of the chemical burn we carried out some chemical analyses on the products used (‘‘lightening powder’’ and ‘‘oxidation cream’’) with the aim to propose further regulatory indications concerning the use of these caustic, and in principle dangerous, chemicals.

Methods

A commercial ‘‘oxidation cream’’ containing hydrogen peroxide (6%, 20 vol), salicylic acid, phosphoric acid, disodium phosphate and cetearyl alcohol was used together with a commercial ‘‘lightening powder’’ containing potassium, sodium and ammonium persulfates, sodium stearate and magnesium carbonate hydroxide. pH measurements have been carried out by using a Radiometer PHM210 pHmeter, at 20°C. The pHmeter was calibrated with standard buffer solutions at pH 4, 7 and 10. The data (accuracy ± 0.1 units) are averaged from five measurements. The oxidative power of the mixture has been determined by a iodometric titration in the presence of ammonium molybdate as catalyst according to standard methods, being the method less susceptible to interferences by organics and able to measure mg/L level of H₂O₂. A typical procedure was the following: after the preparation of the oxidizing mixture, it was diluted with 50 mL of deionized water and stirred for 5 min in a close 100 mL flask. The pH was measured. Then, 2–3 drops of ammonium molybdate solution (prepared by dissolving ammonium molybdate (9 g) in 10 mL NH₄OH (6M), followed by addition of NH₄NO₃ (24 g) and dilution to 100 mL) were added. The suspension was acidified by adding 0.3 mL of 1M water solution of H₂SO₄ and 5 mL of 0.1M water solution of KI were added. The color of the suspension turned from white/gray to brown due to the formation of iodine (according to the reaction: oxidant + 2I⁻ + 2H⁺ → 2H₂O + I₂). The iodine formed, which is stoichiometrically related to the oxidative power of the sample, was then titrated with sodium thiosulfate (0.1M water solution) according to the reaction 2S₂O₅²⁻ + I₂ → S₄O₆²⁻ + 2I⁻, under nitrogen atmosphere, in the presence of starch as indicator (2 mL). During the titration the suspension becomes colorless. The titration is considered ended when the suspension is stable (no violet color) for 1 min. We observed that during the time the titrated suspension become again brown indicating that the oxidation of iodide to iodine was going on in the time: for this reason we collected the data after 30 min and averaged the values of three measurements. ¹H NMR solution spectrum was obtained at 298 K on a Bruker AvanceIII-200 spectrometer operating at 200.12 MHz; δ values (parts per million, ppm) are relative to Me₄Si. The infrared spectra, carried out as KBr pellets or in liquid film, were taken on a Perkin-Elmer Spectrum 100 FT IR Spectrophotometer (CsI films); the frequencies are given in cm⁻¹. The microanalyses and morphologies of the samples have been studied by E.S.E.M. (Environmental Scanning Electronic Microscope, Philips XL 30-XRF embedded). Some data (Spectra and Tables) are reported in the Supplementary material.

Case study

Clinical and circumstantial data

A 29-year-old woman underwent a hair bleach and dye procedure at a local hairdressing salon. It was not the first time, and the patient had no known allergies. During the hair highlighting process, using a second amount of highlighter mixture, being the first consumed, the woman complained of a strong burning sensation on the scalp in the parietal-occipital region. The bleaching mixture was washed out with water and a neutralizing shampoo was used. The treatment was terminated with hair drying. Over the next few days scalp erythema and pain become more prominent: the woman went back to the hairdresser who gave her a palliative product. Twelve days after pain become more severe, so that she was seen by an urgent care physician and diagnosed with a chemical burn (Figure 1a). Forty-two days after, due to the erythematous ulceration enlarging area, a surgical intervention was performed with removal of burned area and reconstruction. In the parietal-occipital region a scarring alopecia of 15 × 4 cm remained evident (Figure 1b). The anatomical-pathologic analysis showed necrosis of epidermis with inflammatory and granulation tissue having giant cells containing hair fragments.

Chemical analyses

The hair highlight treatment is based on the preparation, immediately before use, of a mixture of ‘‘lightening powder’’
and ‘‘oxidation cream’’ in a 1:1 ratio (usually, not well indicated if w/w or V/V) to apply to selected hair strands.

The ‘‘lightening powder’’ typically contains ammonium (10–15%), potassium (20–30%) and sodium (20–30%) persulfates together with sodium stearate and other surfactant agents. The FTIR (Supplementary Figure C1) showed the presence of strong signals at 1275, 1060, 694 and 558 cm⁻¹ of the persulfates and an intense absorption in the range 2966–2850 cm⁻¹ of aliphatic chains. The ‘‘oxidation cream’’ contains usually 6% hydrogen peroxide (10–30%), long chain and ethoxylated alcohols together with some phosphates and diposphonic acids. The FTIR (Supplementary Figure C2) showed the presence of strong signals due to the aliphatic chains (signals in the range 2957–2850 cm⁻¹) and of the OH (3400 cm⁻¹) of the phosphonic acid moieties in the presence of hydrogen peroxide.

The ¹H NMR of the solution obtained by treating (at room temperature for 5 min) the ‘‘lightening powder’’ (100 mg) with CDCl₃ (1 mL) in order to extract lipophilic compounds (Supplementary Figure C3) showed the presence of intense signals in the region 0.5–2.0 ppm characteristic of the aliphatic chains, indicating the easy extraction from the powder of lipophilic components.

The fluorescence analysis by ESEM on a medium sample of the lightening powder (Supplementary Figure C4) showed the presence of a high quantity of carbon (ca 35% w/w) indicating that a significant amount of aliphatic surfactants with lipophilic character are contained in the mixture. In Figure 2, the ESEM image of the powder together with the fluorescence analyses of some particles is reported. It can be observed that particles with quite different dimensions are present, ranging from few units to 100 microns, thus showing reasonably different mixing and solubility behavior.

In order to understand if the scalp burn would be originated by a wrong preparation of the mixture we carried out a series of measurements of pH and oxidative power on different mixtures prepared by varying the ratio between the two commercial products used in the case of interest (the suggested ratio is 1/1 without indication if V/V or w/w). A first relevant observation concerns the fact that the ‘‘powder’’ and the ‘‘cream’’ are not easily mixed, but the balance of hydrophobic and hydrophilic properties of the two products together with the presence of large particles, promotes the formation of agglomerates which can be dissolved in each other with difficulty, when the mixing is not carried out mechanically but only by hand stirring.
As for risk characterization from exposure for workers and consumers in EU RAR the following sentence is reported in a footnote of Supplementary Table 4.4: “skin irritation has been observed. It is likely that not H$_2$O$_2$ alone, but the combined exposure with ammonium persulfate and dye compounds, e.g. amines, causes irritation or allergic symptoms when hydrogen peroxide concentration in the applied mixture is as regulated (6% or lower)”. Oxidative agents (e.g. hydrogen peroxide) have been recently classified within chemicals involved in burns also from a forensic point of view.

On the basis of the histopathological evidence and of the chemical and toxicological properties of the compounds present in the product of interest, in the case here reported (a young woman who experienced a 15 × 4 cm ulceration on occipital scalp) we are reasonably convinced that the scalp burns secondary to hair salon procedure was not due to individual allergic reactions (as often these events are classified) but originated by the direct contact with hair-lightening suspension together with a possible catalytic and thermal effect due to the aluminum foils. It is noteworthy that in all the cases of scalp burn after hair bleaching reported in the literature, the dramatic symptoms appeared after some days. We explain this feature with the presence in both component of the active mixtures of lipophilic compounds as surfactants (bearing long -CH$_2$- chains) which improve a slow dissolution of the oxidant compounds in the stratum corneum of skin containing hydrophobic lipids such as ceramides (45–50%), cholesterol (25%) and long-chain free fatty acids, thus explaining why subsequent treatment had no effect in reduce injury, too. It was reported that the drug partition coefficient ($\log K_{ow}$) influences the follicular penetration. It is also to note that scalp is one of the anatomical region with higher percutaneous penetration index due to the size and number of follicles, sebum composition and closeness of capillaries to the surface of the skin. Also humidity and temperature are known to improve the dermal absorption. Furthermore, surfactants contained in the mixtures can behave as “enhancers” for transdermal permeation. Owing to the fact that oxidizing power strongly depended from the ratio between the components, the possible presence in the mixture of agglomerates with a higher content of lightening powder, could give rise to “hot spots” able to induce severe damage to the skin. The difficult mixing of the components each other also explained the difference of the oxidizing power in the time: so that it is reasonable to presume that the mixture penetrated in the stratum corneum continued its oxidative reaction with the severe tissue damaging observed in the time.

Furthermore, it is known that alkali compounds have been implicated in injuries by different mechanisms (exothermic saponification of fats, water extraction from cells, reaction with amide protons with consequent protein hydrolysis). The products formed favor the penetration into the tissue, causing the chemicals to reach deeper tissue layers. Thus, the characteristic feature of chemical burns is the prolonged period during which the burning effect continues after the initial injury, depending the severity of injury on mechanism of action, concentration, strength of penetration and duration of the contact.

**Discussion**

Persulfate and hydrogen peroxide are the active ingredients in the highlighting mixtures: as shown in Supplementary Table C1 the mixtures exhibit strongly basic pH values with high oxidizing power. It is known that the direct contact of persulfates in high concentration with tissues results in coagulative necrosis together with denaturation of proteins causing cell damage via cytotoxic effects. It has been stated that these products could give potentials urticarial reactions at concentrations greater than 17.5%. In a study involving hairdressers, occupational asthma was found in 51% and allergic occupational dermatitis in 36% of study participants. It is noteworthy that reactions to ammonium persulfate may be delayed and symptoms may not appear for days, or even months or years after repeated exposure. Once ammonium persulfate sensitivity is acquired, it can be a life-time response.

Hydrogen peroxide is also a powerful oxidizing agent whose toxicokinetics are reviewed in the EU RAR. It was estimated that from hairdressing procedures 12 mg/kg body weight per day is the potential dermal exposition with insignificant systemically distributed amount of hydrogen peroxide. Nevertheless repeated treatments with H$_2$O$_2$ 6% for 30 min have been shown to be strongly irritant for skin of rats.
Conclusion

The chemical analyses carried out on the hair-lightening mixtures demonstrated that they are intrinsically dangerous, in particular, owing to the presence of surfactants which improve the transdermal permeation of oxidants and caustic components, giving rise to a prolonged period during which the burning action continues with no effect of lenitive treatments. Furthermore the oxidative power, which is strictly dependent on the composition of the mixture (note that the ratio is not clearly indicated in the manual) and is difficult to homogeneously mix, increases with the time, so that the manual procedure become crucial for the adverse effects occurrence.

Even if the hair highlighting products have warning labels of the caustic nature of their chemical, the authors underline the health hazard represented by these procedures, which could be in principle reduced by some improvements by manufacturers such as the preparation of one-dose packing, the use of new surfactants to achieve better dispersion, the availability of suitable mixing devices. Finally, stronger recommendations to workers for themselves and consumers safety must be evidenced in the data sheets, in particular the absolute prevention of the contact of the active mixtures with the scalp to avoid burns.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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Supplementary material available online