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Review article

The use of personal hair dye and its implications for human health

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ABSTRACT

Hair dye products now represent one of the most rapidly growing beauty and personal care industries as both men and women commonly change hair color to enhance youth and beauty and to follow fashion trends. Irrespective of economic and education status, people dye their hair to emphasize the importance given to appearance. Despite adverse reactions, many people continue dyeing mainly for cosmetic purposes. This paper provides a comprehensive review on various aspects of hair dying products, especially with respect to the hair-coloring process, classification, chemical ingredients, possible human health impacts, and regulations. Permanent hair dye, which is the most commonly used product type, is formed by an oxidative process involving arylamines to bring about concerns with long-term exposure. Hence, significant efforts have been put to understand the possible side effects of such exposure including cancer risk. However, hair dyes and their ingredients are mainly identified to have moderate to low acute toxicity such as the cause of allergic contact dermatitis. Although some hair dye components are reported to be carcinogenic in animals, such evidence is not consistent enough in the case of human studies. Consequently, further research is desirable to critically address the significance of this issue, especially with respect to the safety of hair dye ingredients.

Contents

1. Introduction

Hair is an indicator of attractiveness, femininity, masculinity, health, and beauty. As society focuses more and more on youthfulness and beauty, hair dyeing has become popular among both men and women pursuing such value or fashion trends. Globally, hair colorants are a rapidly growing industry of over $7 billion (The Economist, 2015). Hair dyeing involves treatment of the hair with various natural and/or artificial chemical compounds mainly for cosmetic purposes (e.g., to cover gray hair, to change to a color regarded as more fashionable or desirable at a given time, etc.).

The association between hair dye application and the development of cancer has been a topic of debate over the past several decades. Hair dyes come in two forms: (i) oxidative (permanent) and (ii) non-oxidative (semi-permanent and temporary) (USFDA, 2014). Permanent

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dyes consist of primary intermediates (e.g., p-phenylenediamines (PPDs) and p-aminophenols) and couplers (e.g., m-aminophenols and m-hydroxyphenols) in the presence of peroxide (USFDA, 2014). Non-oxidative hair dyes include colored compounds that stain hair directly. Some of the chemicals used in hair dye products are reported to be carcinogenic in animals (Bolt and Golka, 2007). Likewise, the International Agency for Research on Cancer (IARC) reported that some of the chemicals in hair dye are probably carcinogenic to those who are exposed to them occupationally (e.g., hairdressers and barbers). However, hair dye products have not yet been classified as carcinogenic for personal users (IARC, 2010).

Given the widespread use of hair dye products around the globe, scientists have tried to determine the association between hair coloring products with health risk. In this review article, we provide a critical assessment of this issue by exploring the impact of hair dye on human health. This effort will help to gain better knowledge regarding contradictory or controversial myths about the use of hair dye and its possible cancer risk. To this end, the available data for meta-analytic studies for bladder, hematological, breast, skin, ovarian, and cervical malignancies have been evaluated on a parallel basis. Based on this review, we aim to provide up-to-date knowledge on the use of hair dye products and their possible impact on human health.

2. Types of hair dye

Graying of the scalp hair is an inevitable physiologic process with human aging. The cause of this process has been ascribed to the loss of pigment-forming melanocytes from the hair follicles, which reflects a loss of the melanocyte stem cell population in aging hair follicles (Kim et al., 2012). Coloring agents can be used to remove natural color and/or add new color. The three most common classifications of artificial hair color are permanent, semi-permanent, and temporary (USFDA, 2014).

Hair is made up of the root and shaft. The shaft has three layers; the cuticle consisting of tightly packed colorless cells, the cortex containing natural color pigments that determine color, and the medulla as a hollow core. The larger molecules of temporary hair dyes are unable to penetrate into the cortex; on the other hand, the smaller molecules of semi-permanent hair dyes easily penetrate into the cortex but diffuse out easily in subsequent washes (Madnani and Khan, 2013). In the case of permanent hair dye, the smaller dye precursors penetrate into the cortex and undergo oxidation to form large colored molecules that tend to remain within the cortex with the least possibility of diffusion (Lewis et al., 2013). Permanent hair dyes are not easily removable by shampooing. In contrast, temporary dyes are easily washed out in one shampoo rinse, while semi-permanent dyes are removed in 4 to 12 shampoos (USFDA, 2014). Temporary and semi-permanent products are direct dyes relying on van der Waals forces for adhesion; hence, they do not require chemical reactions to impart color (USFDA, 2013). Permanent dyes are actually colorless precursors and contain hydrogen peroxide (as oxidizing agents) and ammonia (as alkaline) (NCI, 2014). The depth of penetration between different types of hair dye is shown in Fig. 1.

The combination of oxidizing and alkaline agents causes swelling of the hair cuticle. Swelling facilitates diffusion of the colorless precursor into the hair cortex, which bleaches the natural melanin pigment. Eventually, oxidation of the colorless precursor proceeds into large colored molecules to be trapped inside the hair cortex (USFDA, 2013). However, the hair shaft can sustain oxidative damage with permanent hair dye use. The damage is accentuated with the use of dark-colored dyes (e.g., black and dark-brown) because darker shades need higher concentrations of precursors (Bonefeld et al., 2010). The destructive nature of permanent hair dyes, especially dark-colored dyes, is reflected in the epidemiological evidence, demonstrating its potential association to human malignancy.

On the other hand, semi-permanent hair color contains an alkaline agent other than ammonia (e.g., ethanolamine and sodium carbonate) with a reduced level of hydrogen peroxide (relative to permanent hair color) (NCI, 2014). The alkaline agents employed in semi-permanent colors are less effective in removing the natural pigment of hair than ammonia; hence, semi-permanent colors cause less damage than the permanent counterpart. Semi-permanent hair color only partially penetrates the hair shaft and thus is washed out after shampooing several times (Madnani and Khan, 2013). Semi-permanents lack or contain very low levels of developer, peroxide, or ammonia; therefore, they should be less harmful to damaged or fragile hair. Temporary hair color is available in various forms including rinses, shampoos, gels, sprays, and foams, and it is commonly used to color hair for special occasions (e.g., costume parties or Halloween). The pigment molecules in temporary hair color are large, do not penetrate the cuticle layer, and are easily removed with a single shampooing (USFDA, 2013). Temporary hair color can nonetheless persist on hair that is excessively dry or damaged in a way that allows migration of the pigment to the interior of the hair shaft (Madnani and Khan, 2013). Table 1 lists ingredients generally used in modern hair dye formulations.

3. Toxic and/or hazardous components of hair dye

The two main chemical ingredients involved in the hair coloring process that helps color last longer than 12 shampoos are (1) hydrogen peroxide (also known as the developer) and (2) ammonia (Lewis et al., 2013). The former is known to initiate the color-forming process to create longer-lasting color. Increased developer concentration increases the amount of sulfur that is removed from the hair, causing hardening of the hair (Helaskoski et al., 2014). This is why, for the majority of hair coloring, the developer is maintained at a 30% volume or less. However, ammonia can facilitate the lightening of hair by acting as a catalyst when the permanent hair color comes together with peroxide (Helaskoski et al., 2014). Like all alkalines, ammonia tends to separate the cuticle to facilitate the penetration of the hair color to the cortex of the hair.

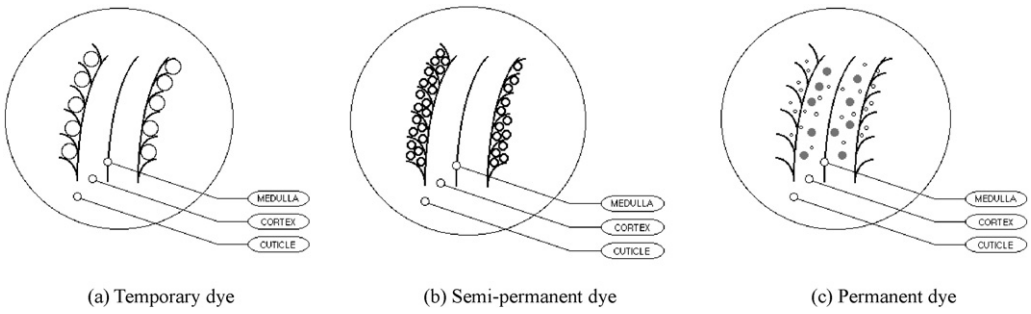

Fig. 1. Depth of hair dye penetration based on hair dye type.
Madnani and Khan, 2013.