

p-Phenylenediamine and other allergens in hair dye products in the United States: a consumer exposure study

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Summary

Background. Hair dye products constitute an important source of allergen exposure, and contribute importantly to allergic contact dermatitis in consumers and hairdressers.

Objectives. To evaluate the presence of potent contact sensitizers in oxidative hair dye products intended for home use on the US market.

Methods. Ingredient labels of 107 hair dyes from 10 major brands were examined and used to assess the prevalence of hair dye substances known to be potent contact sensitizers.

Results. One hundred and six of 107 (99%) products contained at least one potent sensitizer, and the average product contained six (range 0–11). *p*-Phenylenediamine (PPD) was found in 83 products (78%), but resorcinol (89%), *m*-aminophenol (75%), *p*-aminophenol (60%) and toluene-2,5-diamine (21%) were also frequently identified.

Conclusions. Potent contact sensitizers were almost universally included in the hair dyes investigated in the United States. Although PPD is a common allergen, resorcinol and *m*-aminophenol were found more frequently. In total, 30 potent sensitizers were found. Clinicians should consider other allergens in addition to PPD when evaluating patients with suspected hair dye allergy.

Key words: allergens; allergic contact dermatitis; consumer product safety; exposure analysis; hair dye; market survey; patch testing; *p*-phenylenediamine.

Hair dyes are widely used by men and women in the United States, and are known to frequently contain potent contact allergens. Recent reports in the media have highlighted cases of significant morbidity, and

even suggested mortality associated with hair dye use in consumers in both Europe and the United States (1). It is known that *p*-phenylenediamine (PPD) is a frequent ingredient in hair dye products sold in Europe, as illustrated by two recent market surveys from Spain and Sweden (2, 3). PPD is a potent contact sensitizer, and relatively high and stable prevalence rates of contact allergy to PPD are observed in European dermatitis patients. (4) Furthermore, the literature has also highlighted cases of additional adverse events associated with PPD exposure, including: immediate hypersensitivity reactions, systemic toxicity following ingestion, hair loss, and a potentially increased risk of malignancy (5–9). A better understanding of the common ingredients in consumer hair dye products is important, because the definitive treatment for allergic

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Conflicts of interest: Dathan Hamann and Carsten Hamann are the sons of Curtis Hamann, the owner of SmartHealth (Phoenix, AZ, USA), which manufactures and sells patch test products through its subsidiaries. The remaining authors have no relevant conflicts of interest.

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Table 1. Hair dye product information for products included in a study of the prevalence of hair dye substances categorized as potent skin sensitizers in hair dye products on the US market in 2012

Company	Brand	Number of products
Bigen	Permanent powder	4
Bigen	Speedy	3
Clairol	Perfect 10	3
Clairol	Root touch-up	4
Clairol	Natural instincts	5
Clairol	Nice'n easy	5
Clairol	Gray solution	2
Clairol	Textures and tones	2
Clairol	Balsam color	2
Fat foam	–	4
Garnier	Herbashine	3
Garnier	Nutrisse Nourishing color creme	6
Garnier	Nutrisse Ultra Color	4
John Frieda	Precision foam colour	3
Just for Men	–	4
Just for Men	Mustache & beard	3
Just for Men	Touch of gray	2
L'Oréal Paris	Sublime mousse	4
L'Oréal Paris	Crème gloss color	4
L'Oréal Paris	Feria	5
L'Oréal Paris	Root rescue	5
L'Oréal Paris	Excellence creme	6
L'Oréal Paris	Superior preference	5
L'Oréal Paris	Colour rays	1
Revlon	ColorSilk Beautiful Color	5
Revlon	ColorSilk Luminista	6
Softsheen Carson	Hi rez	2
Softsheen Carson	Dark & Lovely	4
Softsheen Carson	Dark & Natural	1
Total		107

Table 2. Hair dye substances categorized as potent contact sensitizers and their relative frequencies in oxidative consumer hair dye products (n = 107) on the US market in Phoenix, Arizona 2012

Allergen (INCI name)	Percentage of products
Resorcinol	89
<i>p</i> -Phenylenediamine ^a	78
<i>m</i> -Aminophenol ^a	75
<i>p</i> -Aminophenol ^a	60
<i>N,N</i> -Bis(2-hydroxyethyl)- <i>p</i> -phenylenediamine ^a	41
2,4-Diaminophenoxyethanol ^a	36
4-Amino-2-hydroxytoluene ^a	36
2-Methylresorcinol	32
Toluene-2,5-diamine ^a	21
1-Naphthol	21
2-Methyl-5-hydroxyethylaminophenol	19
Phenyl methyl pyrazolone	12
2-Amino-3-hydroxypyridine	7
6-Hydroxyindole	7
Hydroxybenzomorpholine	7
Hydroxypropyl bis(<i>N</i> -hydroxyethyl- <i>p</i> -phenylenediamine) ^a	6
4-Chlororesorcinol	3
Basic Brown 17	3
Hydroxyethyl-2-nitro- <i>p</i> -toluidine	3
1,2,4-Trihydroxybenzene	2
1-Hydroxyethyl-4,5-diamino pyrazole ^a	2
2-Amino-6-chloro-4-nitrophenol	2
4-Hydroxypropylamino-3-nitrophenol	2
5-Amino-6-chloro- <i>o</i> -cresol	2
Basic Brown 16	2
<i>m</i> -Phenylenediamine	2
1-Acetoxy-2-methylnaphthalene	1
2-Nitro- <i>p</i> -phenylenediamine ^a	1
<i>p</i> -Methylaminophenol ^a	1

^aDesignates allergens that were reported as either a free base, sulfate, or HCl.

contact dermatitis is identification and avoidance of the causative contact allergen. Although there are no current exposure studies of common allergenic hair dye compounds in the United States, a high and stable prevalence rate of contact allergy to PPD has been identified among North American dermatitis patients (4).

The aim of this study was to evaluate oxidative (known also as permanent) hair dye products available to consumers for home use in the United States for the presence of PPD and other potent skin sensitizers.

Materials and Methods

In order to approximate the products available on the US market, hair dye products were investigated in Phoenix, Arizona, USA. Phoenix is a large metropolitan city with a large selection of supermarkets and pharmacies.

Stores expected to sell hair dye products to consumers were visited in the spring of 2012, including department

stores, supermarkets, superstores (e.g. Walmart), pharmacies, and hair salons. Hair dye products for home consumer use were not sold at any of five hair salons visited, and were not included in the selection. On the basis of this general survey, ingredient labels of 107 different hair dyes from 10 different companies were assessed in stores across the city (Table 1).

Product selection was modelled after similar European studies, for the sake of comparison (2, 3). The selection included as many brands as possible. No products were re-recorded if found at a subsequent store. Products were purchased systematically: within each sub-brand, the darkest blonde shade, one 'regular' light brown shade, one 'regular' dark brown shade, one 'regular' black shade and two additional colours were purchased. If any of these shades was not available, a similar shade was chosen; if no similar shade was available, it was not replaced by any other shade (Table 1).

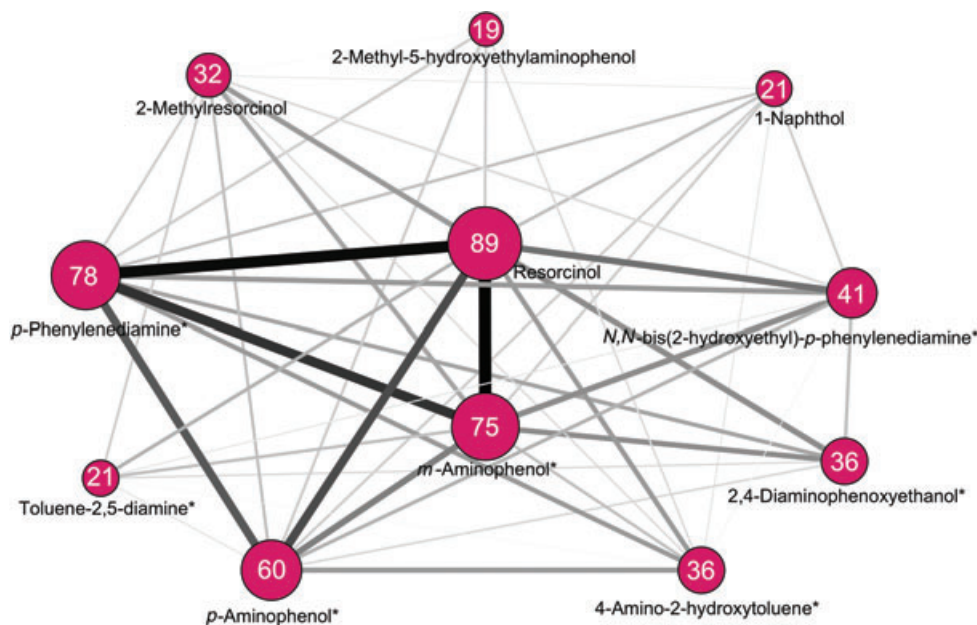


Fig. 1. Network diagram showing hair dye substances identified on the labels of > 15% of examined oxidative hair dye products on the US market. Circles indicate the prevalence rates of substances as percentages. Lines show the concomitant use of substances in products. Thicker, darker lines indicate a higher frequency of concomitant use (*allergens that were reported as either a free base, sulfate, or HCl).

Table 3. The top 10 hair dye substances categorized as potent contact allergens that were most frequently present in oxidative hair dye products (%) by country

Top 10 allergens		
United States	Spain (Yazar 2012) (3)	Sweden (Yazar 2009) (2)
Resorcinol (89)	Resorcinol (81)	Resorcinol (82)
<i>p</i> -Phenylenediamine* (78)	<i>m</i> -Aminophenol (76)	Toluene-2,5-diamine (sulfate) (80)
<i>m</i> -Aminophenol* (75)	<i>p</i> -Phenylenediamine (50)	<i>m</i> -Aminophenol (68)
<i>p</i> -Aminophenol* (60)	Toluene-2,5-diamine (sulfate) (49)	2-Methylresorcinol (39)
<i>N,N</i> -Bis(2-hydroxyethyl)- <i>p</i> -phenylenediamine* (41)	4-Amino-2-hydroxytoluene (35)	4-Amino-2-hydroxytoluene (35)
2,4-Diaminophenoxyethanol* (36)	2-Methylresorcinol (33)	<i>p</i> -Aminophenol (25)
4-Amino-2-hydroxytoluene* (36)	<i>p</i> -Aminophenol (32)	2,4-Diaminophenoxyethanol-HCl (25)
2-Methylresorcinol (32)	2,4-Diaminophenoxyethanol-HCl (30)	4-Amino- <i>m</i> -cresol (18)
Toluene-2,5-diamine* (21)	<i>N,N</i> -Bis(2-hydroxyethyl)- <i>p</i> -phenylenediamine sulfate (18)	4-Chlororesorcinol (18)
1-Naphthol (21)	Phenyl methyl pyrazolone (15)	<i>p</i> -Phenylenediamine (16)

*Designates allergens that were reported as either a free base, sulfate, or HCL.

Previous studies have investigated allergens in hair dye products in Europe (2, 3). In these studies, a comprehensive list of hair dye substances categorized as potent skin sensitizers was compiled on the basis of assessments by the European Commission's Scientific Committee on Consumer Products (SCCP) and the Scientific Committee on Consumer Safety (SCCS) of animal data, and ranking by quantitative structure–activity relationships, published by Søstved et al. (10–12). All hair dye substances that had been categorized as strong or

extreme skin sensitizers by the SCCP and SCCS and/or strong or moderate skin sensitizers by Søstved et al. were included in the list. This list of potent skin sensitizers was also used in the present study.

Ingredient labels were assessed, the potent sensitizers were recorded in Microsoft Excel™, and the prevalence and pattern of concomitant occurrence were calculated with an open-source network-analysis program, PAJEK (<http://pajek.imfm.si/doku.php?id=pajek>), as in a prior study (3).



Fig. 2. (a) An example of a product marketed to men that includes the word 'natural' in the brand name and the phrase 'ammonia-free'. This product contains allergens, including *p*-phenylenediamine, resorcinol, and *m*-aminophenol. (b) An example of a product marketed to women that includes the words 'clinically proven less damaging', 'natural', 'healthier', 'antioxidants', 'vitamins', and 'ammonia-free'. This product contains allergens, including *p*-phenylenediamine, resorcinol, and *p*-aminophenol.

Results

The results of our study are shown in Table 2 and Fig. 1. One hundred and six of 107 (99%) products contained one or more potent contact sensitizers, with the average product containing six potent sensitizers (range 0–11). Nearly every product (99%) contained more than one potent sensitizer. PPD was found in 83 products (78%). Other commonly found potent hair dye sensitizers included: resorcinol (89%), *m*-aminophenol (75%), and *p*-aminophenol (60%). Toluene-2,5-diamine or its sulfate was declared as an ingredient in 21% of the hair dye products. PPD and toluene-2,5-diamine were not used together in any product. Nine per cent of the products were marketed directly to men.

Discussion

Here, we present the first market survey from the United States investigating the most frequently occurring potent contact sensitizers in consumer hair dyes. Contact sensitizers were extremely common in hair dye products, with 99% of studied hair dyes containing potent skin sensitizers.

Comparison with European studies

Our data are consistent with prior studies conducted in Sweden in northern Europe and Spain in southern Europe (2, 3). PPD, resorcinol and aromatic amines such as *m*-aminophenol were commonly found in hair dye products in the United States, as well as in Sweden

and Spain (Table 3). Notably, PPD and *p*-aminophenol were more common in the United States than in Spain and Sweden. Among the three studies, Sweden had the lowest percentage of hair dye products containing PPD (16%), whereas 80% contained toluene-2,5-diamine. It has been shown previously that northern European countries have statistically lower rates of PPD positivity in patch test patients than central and southern Europe (13). Although cultural norms and societal trends are important, there may be an association between increased PPD allergy prevalence in patch test patients and regions in which PPD is a frequent hair dye ingredient. However, no hair dye allergen except PPD is regularly used in the diagnostic patch testing of dermatitis patients. The prevalence of allergy to toluene-2,5-diamine and other hair dye substances remains largely unknown.

As expected, PPD is frequently found in consumer hair dye products in the United States. The North American Contact Dermatitis Research Group reported prevalence rates of PPD allergy in patch test patients to be 5.0% for 2005–2006, 5.3% for 2007–2008, and 5.5% for 2009–2010 (14–16). Hair dyes represent a significant source of consumer exposure to sensitizing allergens, in addition to causing allergic contact dermatitis in sensitized individuals.

Conservative figures indicate that >30% of adult women and up to 10% of men aged > 40 years are regular hair dye users (17). In a survey-based study in Denmark, 18% of male and 75% of female responders reported dying their hair at some point (18). In another US study, > 50% of hair dye users cited the desire to conceal greying hair as

a motivation for using hair dye products (17). As the US population ages, it is possible that more Americans will use hair dye products. In a recent national environmental health survey in Sweden, it was reported that 27% of 12-year-old girls and 9% of the boys had dyed their hair (19).

Allergic contact dermatitis caused by PPD might manifest as scalp dermatitis, generalized facial dermatitis, peri-orbital dermatitis or peri-oral dermatitis in consumers, and as hand eczema in hairdressers. The hair dye products studied are sold directly to consumers, who have no training in hair dying and may not follow directions carefully. For example, consumers who self-apply without protective gloves may also experience hand dermatitis (20). Hair dyes are not intended for prolonged skin contact, which may cause irritant contact dermatitis and even chemical burns. Prolonged skin contact may increase the likelihood of sensitization. Cases in India and Sudan have even highlighted the ingestion of over-the-counter consumer hair dye products as a means of suicide (21, 22). It is also well known that hairdressers suffer from contact allergy and allergic contact dermatitis caused by PPD and other hair dye substances (23).

Resolution of allergic contact dermatitis related to contact allergens found in hair dye products relies on accurate identification of the allergen with subsequent avoidance of products containing the allergen and possible cross-reactors. Although PPD is a potent sensitizer that is responsible for many cases of hair dye dermatitis, our study and studies in Europe have shown that many other potent allergens are found with similar frequencies in oxidative hair dye products. Of the top 10 most frequent allergens in our study (Table 3), only PPD is included in the North American and European baseline series. Patch testing with additional allergens is therefore strongly recommended.

After diagnosis of contact allergy, patient education concerning avoidance of the specific sensitizing substance is recommended. Allergen and/or product databases may be used by clinicians to recommend products without particular allergens on a patient-to-patient basis.

The packaging and branding of hair dye products may contribute to consumer confusion and difficulty in avoiding particular allergens for sensitized individuals. For example, hair dye products generally contain a dye and a developer and/or conditioner. The ingredients for these are generally placed into two or three lists, which may be found on separate locations on the product box. Additionally, products containing PPD and other allergens are often marketed to consumers with words or phrases that include or resemble 'protect', 'natural', 'healthy', 'herbal', 'nutrients/nutritious', 'antioxidant', 'ammonia-free', etc., which may also give customers the impression of safety or limited risk (Fig. 2).

Approximately 9% of the products featured male models and were marketed to men, including products specifically for beards and facial hair. As the purpose of the study was not to identify any sex-related differences in exposure to hair dye substances, it is not known how representative the sample is in this respect. Nevertheless, the authors remind clinicians that males may present with dermatitis related to hair dye use.

Although home hair dye kits probably do not play a large role in occupational allergic contact dermatitis, PPD is an important cause of occupational contact allergy and allergic contact dermatitis in hairdressers, affecting 40–50% of hairdressers with contact dermatitis (23). PPD allergy is also associated with beauty occupations, professional drivers, bar workers, printers, and bakers (24). Additionally, PPD has many known cross-reactors, such as benzocaine, black rubber mix, and *p*-aminobenzoic acid (PABA). Hair dye products used at home may provide initial sensitization to allergens or cross-reacting allergens that can be found in occupational or non-occupational settings, for example black rubber mix allergens used in the manufacture of rubber products or PABA in sunscreens.

The authors reiterate that potent contact allergens are nearly ubiquitous in oxidative consumer hair dye products. Most products contain multiple potent contact allergens. Clinicians should be aware that hair dye dermatitis may go undiagnosed if patients are patch tested with only the North American baseline series.

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