Probabilistic assessment of exposure to nail cosmetics in French consumers

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A B S T R A C T

The aim of this study was to assess probabilistic exposure to nail cosmetics in French consumers. The exposure assessment was performed with base coat, polish, top coat and remover. This work was done for adult and child consumers. Dermal, inhalation and oral routes were taken into account for varnishes. Exposure evaluation was performed for the inhalation route with polish remover.

The main route of exposure to varnishes was the ungual route. Inhalation was the secondary route of exposure, followed by dermal and oral routes. Polish contributed most to exposure, regardless of the route of exposure. For this nail product, P50 and P95 values by ungual route were respectively equal to 1.74 mg (kg bw week)$^{-1}$ and 8.55 mg (kg bw week)$^{-1}$ for women aged 18–34 years. Exposure to polish by inhalation route was equal to 0.70 mg (kg bw week)$^{-1}$ (P50) and 5.27 mg (kg bw week)$^{-1}$ (P95). P50 and P95 values by inhalation route were respectively equal to 0.08 mg (kg bw week)$^{-1}$ (P50) and 1.14 mg (kg bw week)$^{-1}$ (P95) for consumers aged 18–34 years exposed to polish remover. This work provided current exposure data for nail cosmetics, and a basis for future toxicological studies of the uptake of substances contained in nail cosmetics in order to assess systemic exposure.

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1. Introduction

As defined in the second article of the European Regulation (EC) No 1223/2009, a cosmetic product corresponds to “any substance or mixture intended to be placed in contact with the external parts of the human body (epidermis, hair system, nails, lips and external genital organs) or with the teeth and the mucous membranes of the oral cavity with a view exclusively or mainly to cleaning them, perfuming them, changing their appearance, protecting them, keeping them in good condition or correcting body odours” (EU, 2009). This Regulation, repealing the Directive No 76/768/EEC and taking effect from 11 July 2013, states that cosmetic products found on the European market have to be safe for consumer health when applied under normal or reasonably foreseeable conditions of use (EU, 2009). As mentioned in the Regulation, a safety assessment has to be done prior to placing a cosmetic product on the market. In case of cosmetic products, no pre-marketing authorization procedure is required. The safety assessment is entirely performed under the responsibility of the industry (Pauwels and Rogiers, 2010). In order to perform a safety evaluation on cosmetic products, the assessor needs to possess relevant toxicological data of all composing ingredients and accurate exposure data to assess systemic exposure (EU, 2009).

Some cosmetic consumption or exposure data are available in Europe. The European cosmetics industry (Cosmetics Europe) has published adult exposure data for shampoo, shower gel, antiperspirant, toothpaste, mouthwash, body lotion, hand cream, facial moisturiser, hair styling products, lipstic and liquid foundation. The amount of products used was obtained from the Edinburgh population in Scotland. The frequency enquiry was carried out in Denmark, France, Germany, Great Britain and Spain (Hall et al., 2007, 2011; McNamara et al., 2007). These values are currently used by the Scientific Committee on Consumer Safety (SCCS) to estimate daily exposure levels of European consumers for these cosmetic products (SCCS, 2012). Biesterbos et al. assessed the frequency and the amount of thirty-two types of personal care products used by the Dutch adult population. Tested products included general hygiene, shaving care, skin care, hair care, nail care, makeup and tanning products (Biesterbos et al., 2013). Manova et al. determined the frequency of use of face cream, make up foundation, lip care, lipstic, aftershave lotion/balm, body lotion, hand cream and sunscreen. This study was conducted among children, adolescents and adults in Switzerland (Manova et al., 2013).

Among nail cosmetics, nail polish is a lacquer applied to human finger and/or toenails to decorate the nail plate. Nail polish is available in various forms, such as base coat and top coat. Base coat can be applied to the nail before the application of polish. Base coat promotes polish adhesion and reduces staining of the natural nails.
Top coat can be used after applying nail polish. It forms a hardened barrier for the nail to prevent chipping. Nail polish is composed of up to 70% organic solvents (such as ethyl acetate, butyl acetate or ethyl alcohol), cellulose nitrate (10%), plasticizer (such as acetyl tributyl citrate, phthalates), synthetic resin (alkyd, sulfonamide or acrylic resins) and coloring (organic or inorganic pigments). Base coat consists of more than 10% synthetic resin. Top coat contains more cellulose nitrate and plasticizer but less synthetic resin (RIVM, 2006; Andre and Baran, 2009). The consumer is exposed to nail polish, base coat and top coat by the dermal route, but also by inhalation in the solvents contained in products. Upon application of varnishes, solvents evaporate inducing the drying of products. The film formed becomes tough, stable and waterproof. The oral route can be a relevant means of exposure for consumers practicing onychophagia (i.e. nail biting).

Nail varnishes can be removed with polish remover. Polish remover dissolves nitrocellulose and removes lipids from the nail plate. This product is composed of a mixture of more than 95% solvents (such as acetone, ethyl acetate, butyl acetate and water), with small amounts of oil added to counteract the drying effect of the solvents. Nail polish remover may also contain perfume, coloring, preservatives, vitamins or UV absorbers (RIVM, 2006; Andre and Baran, 2009). Consequently, the consumer is mainly exposed to this cosmetic by inhalation in organic solvents.

Nail cosmetic consumption data are very limited in Europe. Biesterbos et al. demonstrated that 51% and 47.7% of Dutch women use nail polish and nail polish remover. The mean amount used per application was estimated at 0.3 g and 2.0 mL, respectively (Biesterbos et al., 2013). Currently, the exposure assessment to nail cosmetics has been made in Europe. Therefore, the safety of consumers cannot be guaranteed.

The aim of this study was to assess the exposure in French consumers to cosmetics on finger nails including base coat, polish, top coat and nail polish remover using the Monte Carlo probabilistic method. This evaluation was performed for adult and child consumers. Dermal, inhalation and oral routes were taken into account for base coat, polish and top coat. Exposure was assessed by inhalation for nail polish remover.

2. Materials and methods

2.1. French enquiry

A web questionnaire survey was conducted in March 2013 by a national survey company. This enquiry enabled us to collect information on usage patterns of base coat, polish and top coat on finger nails, i.e. percentage of users, frequency of use, wearing time and number of coats applied. The frequency of use was investigated for each season of the year. The percentage of users and frequency of use were also obtained for polish remover. Participants were asked about their bodyweight and if they practiced onychophagia in the presence of nail cosmetics. The enquiry was made among adult French women aged 18–85 years. Mothers were questioned on practices concerning their children to determine the percentage of users and the frequency of application. Complementary data were obtained for children aged 0–17 years.

Adult women were selected to form a nationally representative panel. Selections were realized using quota by age, socio-professional category, size of household, geographical area and degree of urbanization.

2.2. Experimental data

2.2.1. Volunteers

Volunteers were recruited by different communication sources (press articles, public notices, flyers etc.) in the Brest area in Western France. Study subjects entered a room specially arranged for cosmetic tests. Participants were asked to read and sign a consent form informing of the terms and conditions of the test. If children under 18 years wanted to participate, they had to be accompanied by a parent. Subjects were not remunerated for their participation in the study.

Volunteers filled in a questionnaire to obtain information on products habitually used (base coat, polish, top coat and/or polish remover) and to collect personal data: age, place of residence, socio-professional category, body weight and height.

Products habitually used by the volunteer were offered: base coat, different colored or colorless polishes, top coat and nail polish remover. All test products were commercialized and purchased on French markets. Volunteers were invited to adhere to their personal habits of product use. During the test, setting and drying time of base coat, polish and top coat used were measured and the number of coats applied was noted. The time of use of nail polish remover was also measured. The quantity of each nail cosmetic used was determined by differential weighing before and after use, always in the absence of the volunteer. All subjects were invited to repeat the experiment in order to assess the intra-individual variability regarding the amount of nail cosmetic applied per use. All tests were performed on different days. Photography of the hands of participant was taken and was analysed with the software Image J to estimate the surface and the width of finger nails. Nail wall area, which is the area of skin around the nail, was estimated by multiplying the perimeter of the nail bed by 1 mm (i.e. arbitrary value defined by RIVM – Netherlands National Institute for Public Health and the Environment) (RIVM, 2006).

2.2.2. Evaporation kinetics: determination of the breathable fraction

Base coat, polish and top coat were each rapidly spread in a Petri dish (diameter of 36 mm) placed on a precision balance to determine the loss of weight (which corresponds to the evaporation of solvents). Nail polish remover was applied on a cotton pad. The tested quantities were chosen in order to be the most representative of real conditions. Evaporation rates were determined by weighing the cosmetic product at regular intervals. Experiments were conducted for 30 min for base coat, polish and top coat; and for 15 min for polish remover. Then, the percentage of evaporation was calculated and was used to define the breathable fraction (BFT) for each product, the experiments were performed at least in triplicate.

2.3. Probabilistic exposure assessment

Each parameter was described by a distribution. Probabilistic exposure assessment was performed using Monte Carlo random simulations with @Risk 6 software (Palisade Corp.) running on Excel. This method, in which the parameters are described by a distribution, is the most practical and common probabilistic exposure assessment. The probabilistic exposure assessment was used to integrate individual variability and parameter uncertainty (US EPA, 2001). From a practical point of view, in a probabilistic exposure assessment, one or more parameters in the exposure equation are defined as a probability distribution rather than a single value. Similarly, the output of a probabilistic exposure assessment is a range or probability exposure distribution.

In this study, for each parameter, the values were adjusted to theoretical distributions with the chi-squared goodness of fit test using the @Risk software.

Exposure distributions were assessed by 10,000 iterations according to recommendations of the US EPA (US EPA, 2001). Median and P95 values of Weekly Exposure Dose (WED) distribution were provided for each exposure route and each age class (0–12, 13–17, 18–34 and 35–85 years). The life-long exposure was calculated for each age class weighted by the duration of exposure.

2.3.1. Base coat, polish and top coat

Exposure was assessed for the dermal route on nails or on nail walls (i.e. skin around the nail) (Eq. (1)), inhalation route (Eq. (2)) and oral route (Eq. (3)): Oral exposure was assessed only for consumers who practiced onychophagia.

\[
\text{WED}_{\text{d}} = \sum_{n=1}^{2} \left( \frac{F \times Q \times (1 - BFT_n)}{BW} \times \frac{1}{BFT_n} \times \%C_n \right)
\]  

\[\text{WED}_{\text{x}} = \sum_{n=1}^{2} \left( \frac{F \times Q \times BFT_n \times IR \times T}{V \times BW} \times \%C_n \right)
\]  

\[\text{WED}_{\text{D}} = \sum_{n=1}^{2} \left( \frac{F \times Q \times (1 - BFT_n)}{BW} \times \frac{1}{BFT_n} \times \%C_n \right)
\]
2.3.2. Nail polish remover

Exposure to nail polish remover was assessed for the inhalation route with the following equation.

\[ \text{WED}_i = \frac{Q \times BF_i \times IR \times T}{V + BW} \]

where \( \text{WED}_i \): Weekly Exposure Dose for inhalation exposure route (mg/week); \( Q \): quantity of product applied on nail per coat (mg/week); BF: breathable fraction calculated for a time of application equal to 70 min for base coat and top coat and 30 min for nail polish (unitless); D: duration before the removal of nail polish (days); GC: nail growth rate (cm/day) (Yamaesiri et al., 2010); NW: nail width (cm); NA: nail area (cm²); IR: inhalation rate (m³/h) (US EPA, 2011); T: time of using (day); V: volume of the breathable air (i.e., 1 m³, RIVM, 2006) and BW: body weight (kg bw).

3. Results

3.1. National enquiry

Among the 1512 adult French women interviewed (18–85 year-olds), 88% reported using cosmetics on finger nails at least once a year. 69% of 301 children aged 0–17 years wore nail products at least once a year. 12% of adults (6% of 18–34 year-olds and 14% of 35–85 year-olds) and 31% of 0–17 year-olds (44% of 0–12 years and 3% of 13–17 year-olds) never use nail cosmetics. Frequencies of use for adults and for children were described by a distribution to differentiate the regular consumers and the occasional consumers. Women and children whose frequency of use was greater than 0.188 times a week (this value corresponds to the 10th percentile of the distribution of the frequencies of use) were classified as regular users. Inversely, women and children whose frequency of use was below 0.188 times a week were classified as occasional users. 73% of 18–34 year-olds and 58% of 35–85 year-olds were thereby classified as regular consumers of nail cosmetics. 22% of 0–12 year-olds and 80% of 13–17 year-olds were classified as regular consumers (Table 1). Only women and children classified as regular consumers were then taken into account in the exposure assessment.

Among the regular adult consumers, 88% reported getting their manicures at home, 11% at home and at nail salon and 1% at nail salon only.

Nail polish was used by 98% of regular adult consumers. Base coat was applied by 60% of 18–34 year-olds and by 63% of 35–85 year-olds. Top coat was used by 43% of 18–34 year-olds and by 32% of 35–85 year-olds. Products were applied in one or two coats. Nail polish remover was used by 98% of adult consumers (Table 2).

The frequency of use of nail cosmetics was on average equal to 1.40 week⁻¹ for children aged 13–17 years, 1.27 week⁻¹ for adults aged 18–34 years, 1.11 week⁻¹ for adults aged 35–85 years and 0.91 week⁻¹ for children aged 0–12 years. The wearing time, which corresponds to the time between application and removal of varnish (base coat, polish and/or top coat) was on average equal to 1.02 weeks for adults aged 18–34 years and equal to 0.89 weeks for women aged 35–85 years. All frequency and wearing time values are presented in Table 3.

28% of women aged 18–34 years and 11% of women aged 35–85 years reported practicing onychophagia in the presence of varnishes.

3.2. Experimental data

3.2.1. Volunteers

110 Volunteers participated in the study. All participants were at least 18 years of age. The average age was 25 years old (SD = 10 years). The median and P95 ages were 22 and 48 years, respectively. The volunteers included 86% of people without active employment (students, housewives etc.), 5% of employees, 4% of artisans, 3% of executives and 2% of retired people.

The average, median and P95 amounts of polish applied per coat were respectively equal to 200.3 mg, 189.5 mg and 316.5 mg. The setting and drying time of polish was equal to 8.8 min (mean), 8.3 min (P50) and 17.7 min (P95). The results obtained with base coat and top coat are presented in Table 4. Eleven volunteers agreed to repeat the experiment at least 3 times in order to assess the intra-individual variability for the amount of polish applied per use. The results showed a standard deviation ranging from 4.5 mg to 45 mg. In general, the standard deviation increased with increasing amounts applied on the nails (Fig. 1).

The average, median and P95 quantities of polish remover were respectively equal to 2679 mg, 1859 mg and 6587 mg. Nail polish remover was used for 4.1 min (mean), 2.9 min (median) and 9.4 min (P95) (Table 3).

The width of nails and surface area of nails and nail walls were measured for adults. The mean, P50 and P95 width values were equal to 9.6 cm, 9.5 cm and 11.5 cm, respectively. The nail area values were equal to 10.4 cm² (mean), 10.1 cm² (P50) and 14.8 cm² (P95). The nail wall area values were equal to 2.7 cm² (mean), 2.7 cm² (P50) and 3.3 cm² (P95). Due to the lack of experimental data among children aged 0–18 years, estimations of nail and nail wall surfaces were assessed. First, total skin surface area was estimated for adults using the Boyd formula (Boyd, 1935; EPA, 2011). The ratio of surface areas between nails (or nails walls) and total skin was calculated for each volunteer. Then, a parametric distribution was adjusted for this parameter. By using the skin body surface area of US children (US EPA, 2011), it was possible to estimate nail and nail wall surface areas for children. The mean, P50 and P95 nail area values were equal to 3.5 cm², 3.5 cm² and 4.8 cm², respectively. Nail wall area values were equal to 0.9 cm² (mean), 0.9 cm² (P50) and 1.2 cm² (P95) (Table 5).

3.2.2. Evaporation kinetics: Determination of the breathable fraction

For each nail cosmetic, the determination coefficient was equal to 0.99 with a logarithm regression curve for base coat, polish (presented in Fig. 2) and top coat; and with a linear regression curve for nail polish remover (Fig. 2). The equations obtained with these tests were used to estimate the percentage of the evaporated mass (i.e. breathable fraction, BF) necessary for exposure calculations. For example, equation \( y = 0.139 \times \ln t + 0.0233 \) was used to assess
the percentage of evaporation of nail polish according to time of application (Fig. 2).

3.3. Probabilistic exposure assessment

3.3.1. Base coat, nail polish and top coat

The main route of exposure was the ungual way. Inhalation was the secondary route of exposure, followed by dermal (nail wall) and oral routes (Table 6).

Polish: Polish contributed most to exposure, regardless of the route of exposure. Life-long exposure by the ungual route was equal to 2.17 mg (kg bw week)$^{-1}$ (P50) and 6.94 mg (kg bw week)$^{-1}$ (P95). Life-long exposure by inhalation was equal to 0.74 mg (kg bw week)$^{-1}$ (P50) and 3.89 mg (kg bw week)$^{-1}$ (P95).

Among age classes, children aged 0–12 years were the most exposed to polish by ungual route, with P50 and P95 values respectively equal to 2.31 mg (kg bw week)$^{-1}$ and 16.24 mg (kg bw week)$^{-1}$. Children aged 13–17 years were the most exposed to polish by inhalation and oral route. Exposure by inhalation was equal to 0.83 mg (kg bw week)$^{-1}$ (P50) and 7.25 mg (kg bw week)$^{-1}$ (P95). P50 and P95 values were respectively equal to 0.15 mg (kg bw week)$^{-1}$ and 1.30 mg (kg bw week)$^{-1}$ for the oral route (Table 6).

Top coat: Life-long exposure by the ungual route was equal to 0.94 mg (kg bw week)$^{-1}$ (P50) and 2.93 mg (kg bw week)$^{-1}$ (P95); and equal to 0.43 mg (kg bw week)$^{-1}$ (P50) and 1.86 mg (kg bw week)$^{-1}$ (P95) by inhalation.

Children aged 13–17 years were also the most exposed to top coat, regardless of the way of exposure. P50 and P95 values were respectively equal to 1.23 mg (kg bw week)$^{-1}$ and 6.8 mg (kg bw week)$^{-1}$ for nails. Exposure by inhalation was equal to 0.61 mg (kg bw week)$^{-1}$ (P50) and 4.37 mg (kg bw week)$^{-1}$ (P95) (Table 6).

Base coat: Life-long exposure by the ungual route was equal to 0.35 mg (kg bw week)$^{-1}$ (P50) and 1.19 mg (kg bw week)$^{-1}$ (P95); and equal to 0.07 mg (kg bw week)$^{-1}$ (P50) and 0.32 mg (kg bw week)$^{-1}$ (P95) by inhalation.

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Table 2

<table>
<thead>
<tr>
<th>Base coat</th>
<th>Polish</th>
<th>Top coat</th>
<th>Nail polish remover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users (%)</td>
<td>Coats applied</td>
<td>Users (%)</td>
<td>Coats applied</td>
</tr>
<tr>
<td>1 Coat</td>
<td>2 Coats</td>
<td>1 Coat</td>
<td>2 Coats</td>
</tr>
<tr>
<td>18–34 years$^a$</td>
<td>60$^a$</td>
<td>95$^a$</td>
<td>5$^a$</td>
</tr>
<tr>
<td>35–85 years</td>
<td>63</td>
<td>98</td>
<td>2</td>
</tr>
</tbody>
</table>

Data were obtained from a web enquiry realized with 1512 adult aged 18–85 years. Parameters were calculated only for regular users of nail cosmetics, i.e. users with frequency of use of nail cosmetics superior to 0.188 times a week.

$^a$ Example: Among regular users aged 18–34 years, 60% use base coat. 95% of base coat users apply product in 1 coat, and 5% in 2 coats.

Table 3

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>n</th>
<th>Frequency of use of nail cosmetics (varnishes and polish remover) (week$^{-1}$)</th>
<th>Wearing time of varnishes (week)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean SD P50 P95</td>
<td>Mean SD P50 P95</td>
</tr>
<tr>
<td>0–12</td>
<td>44</td>
<td>0.91 0.99 0.59 2.60</td>
<td>– – – –</td>
</tr>
<tr>
<td>13–17</td>
<td>78</td>
<td>1.40 1.31 1.00 4.67</td>
<td>– – – –</td>
</tr>
<tr>
<td>18–34</td>
<td>286</td>
<td>1.27 1.09 0.94 4.00</td>
<td>1.02 0.86 1.00 4.00</td>
</tr>
<tr>
<td>35–85</td>
<td>644</td>
<td>1.11 0.98 0.88 3.34</td>
<td>0.89 0.71 1.00 2.00</td>
</tr>
</tbody>
</table>

Data were obtained from a web enquiry realized with 1512 adult aged 18–85 years and 301 children aged 0–17 years. Parameters were calculated for regular users, i.e. users with frequency of use of nail cosmetics superior to 0.188 times a week.

Frequency of application was requested for each season. The frequency presented in Table 2 corresponds to the annual frequency of use.

n: Number of regular users.

Table 4

<table>
<thead>
<tr>
<th>Quantity (mg/coat) and setting and drying time (min) for base coat, polish and top coat. Quantity (mg) and time of use (min) for nail polish remover.</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Mean SD P50 P95</td>
</tr>
<tr>
<td>Base-coat</td>
</tr>
<tr>
<td>Nail polish</td>
</tr>
<tr>
<td>Top-coat</td>
</tr>
<tr>
<td>Nail polish remover</td>
</tr>
</tbody>
</table>

n: Number of volunteers who used nail product(s).
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Table 5
Surface (cm²) and width (cm) data of nails and nail walls.

<table>
<thead>
<tr>
<th>Area (cm²)</th>
<th>Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Young children (0–12 years)</td>
<td>Nail</td>
</tr>
<tr>
<td></td>
<td>Nail wall</td>
</tr>
<tr>
<td>Adults and adolescents</td>
<td>Nail</td>
</tr>
<tr>
<td></td>
<td>Nail wall</td>
</tr>
</tbody>
</table>

Experimental data were obtained with 71 adults. All photographs available were used in surface and width calculation. These values were also used for adolescent users (13–17 years). Area data were estimated for children (0–12 years) as mentioned in Section 3.2.1.

Fig. 2. Kinetic of the evaporation of polish (A) and polish remover (B). Each curve represents the percentage of evaporation of polish in function of time. Experiences were done in triplicate, with initial amount of product applied in Petri dish equal to 164.5 mg, 183.3 mg and 221.0 mg. A regression curve ($R^2 = 0.99$) was selected in order to define the evaporation of polish: $% \text{evaporated} = 0.0006 t^2 + 0.0356 t - 0.0017$.

Among age classes, children aged 13–17 years were the most exposed to base coat, regardless of the route of exposure. P50 and P95 values were respectively equal to 0.46 mg (kg bw week)$^{-1}$ and 2.63 mg (kg bw week)$^{-1}$ for nails. Exposure by inhalation was equal to 0.10 mg (kg bw week)$^{-1}$ (P50) and 0.76 mg (kg bw week)$^{-1}$ (P95) (Table 6).

3.3.2. Nail polish remover

Life-long exposure by inhalation to polish remover was equal to 0.05 mg (kg bw week)$^{-1}$ (P50) and 0.62 mg (kg bw week)$^{-1}$ (P95). Young people aged 0–12 years were the most exposed to remover, with median and P95 values equal to 0.11 and 2.05 mg (kg bw week)$^{-1}$, respectively (Table 5).

4. Discussion

This work provided data regarding the usage patterns of four nail cosmetics consumed by adult French women: base coat, polish, top coat and polish remover. Different parameters including the percentage of users, frequency of use, wearing time and number of coats of varnishes applied were obtained by a national enquiry. The amount of use, time of use and application area were obtained by laboratory experiments. Additional data including the percentage of users of varnishes and the frequency of use were collected for children. An exposure assessment was realized by dermal exposure for varnishes, on the nails and on the skin around the nails. Inhalation and oral routes were also taken into account for these three products. An exposure assessment was realized by inhalation for nail polish remover. Currently, consumption data for nail cosmetics are very limited in Europe, and no data are available for the French population. Moreover, this is the first assessment of exposure to nail cosmetics. Through this work, the authors aimed to create a national database containing current consumption and exposure data for nail cosmetics.

4.1. Strengths and weaknesses of the study

The internet survey was conducted by a national survey company. The use of web questionnaires as a method of data collection in research is now well established. E-questionnaires have been demonstrated to offer an inexpensive, quick and convenient way to collect data. Web enquiries have been shown to reach a large geographical span, and could be an inclusive method for the participation of marginalised groups, such as those with mobility or communication difficulties (Borsch-Supan and Klaus Winter, 2004; Hunter, 2012; Walker, 2013). In this enquiry, 1512 women were selected by quota methods according to age, socio-professional category, size of household, geographical area and degree of urbanization. Quotas were used to form a sample representative of the French population. However, problems of representativeness can exist with online survey. Some people, such as low income, homeless and elderly people do not have internet access. These people were therefore not present in the sample. Moreover, the individuals who agreed to participate in the survey could be a priori interested in the topic.

The number of volunteers (i.e. 110 test subjects) who participated in the laboratory experiments was fairly high. The participants were mainly young adults aged 18–24 years. Two main reasons could explain the young age of volunteers: the high consumption of nail cosmetics with consequently an interest in the study, and/or greater availability. In the exposure calculation, quantity and setting and drying time parameters were described by a distribution regardless of age. A Mann and Whitney statistical test was assessed for each parameter between young women (18–24 year-olds) and women aged 25–62 with polish and polish remover. No statistically significant difference was observed except for setting and drying time of nail polish. However, the setting and drying time could be modulated by parameters a priori independent of the experiment, such as the time (or the lack of time) available to volunteers. Thus, it has been considered that age was not a factor influencing this exposure parameter, although a statistical difference was observed.
Quantity values of polish obtained with all participants (*n* = 97) were adjusted to the distribution, with P5 and P95 values equal to 104 and 304 mg/coat, respectively.

Inter-individual variability was assessed with 11 volunteers who applied polish at least three times. The average amount of nail polish applied ranged from 134 to 291 mg/coat (Fig. 1). These values were included in the distribution of quantities among all consumers. Consequently, inter-individual variability was taken into account in the distribution of quantity.

Intra-individual variability was also assessed for the eleven volunteers (Fig. 1). The average quantity distribution was calculated for each volunteer. A normalized standard deviation equal to 7.7 mg/coat was observed. This normalized standard deviation was inferior to the standard deviation obtained for all participants (*SD* = 73.8 mg/coat). Consequently, intra-individual variability was taken into account in the distribution of quantity.

The same experiments were realized with base-coat and top-coat. The number of experiments and volunteers was lower, but the results were similar to those for polish (data not shown).

Some data essential for the exposure assessment were not available for children (0–12 years) and adolescents (13–17 years). No information was obtained for the types of varnishes used, the number of coats applied and the wearing time. It was supposed that children aged 0–12 years used only one coat of polish. For these young people, onychophagia practice was not taken into account. Authors supposed that adolescents aged 13–17 years used nail products in the same way as young adults aged 18–34 years. Consequently, some parameters obtained with 18–34 year-olds (percentage of users of base coat and top coat; number of coats applied; wearing time) were used for 13–17 years.

Exposure was calculated by dermal, inhalation and oral routes for base coat, polish and top coat; and by inhalation route for nail polish remover.

Exposure by oral way was assessed only for users who practiced onychophagia. Setting and drying time and quantity data obtained during experiences with volunteers for base coat, polish and top coat were utilized for all age classes. Time of use and quantity data obtained during experiences with volunteers for nail polish remover were utilized for all age classes.

### Table 6

Weekly exposure to nail cosmetics (mg (kg bw week)⁻¹).

<table>
<thead>
<tr>
<th></th>
<th>Exposure (mg (kg bw week)⁻¹)</th>
<th>0–12 Years*</th>
<th>13–17 Years*</th>
<th>18–34 Years</th>
<th>35–85 Years</th>
<th>Life-long</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>P5</td>
<td>P95</td>
<td>P5</td>
<td>P95</td>
<td>P5</td>
</tr>
<tr>
<td><strong>Base coat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dermal – Nail</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.46</td>
<td>2.63</td>
<td>0.38</td>
</tr>
<tr>
<td>Dermal – Nail wall</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.12</td>
<td>0.71</td>
<td>0.10</td>
</tr>
<tr>
<td>Inhalation</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.10</td>
<td>0.76</td>
<td>0.09</td>
</tr>
<tr>
<td>Oral*</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.04</td>
<td>0.29</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>Polish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dermal – Nail</td>
<td></td>
<td>2.31</td>
<td>16.24</td>
<td>2.13</td>
<td>12.54</td>
<td>1.74</td>
</tr>
<tr>
<td>Dermal – Nail wall</td>
<td></td>
<td>0.60</td>
<td>4.60</td>
<td>0.57</td>
<td>3.37</td>
<td>0.46</td>
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<tr>
<td>Inhalation</td>
<td></td>
<td>0.59</td>
<td>5.95</td>
<td>0.83</td>
<td>7.25</td>
<td>0.70</td>
</tr>
<tr>
<td>Oral*</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.15</td>
<td>1.30</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>Top coat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dermal – Nail</td>
<td></td>
<td>0</td>
<td>0</td>
<td>1.23</td>
<td>6.8</td>
<td>1.03</td>
</tr>
<tr>
<td>Dermal – Nail wall</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.32</td>
<td>1.88</td>
<td>0.26</td>
</tr>
<tr>
<td>Inhalation</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.61</td>
<td>4.37</td>
<td>0.52</td>
</tr>
<tr>
<td>Oral*</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.09</td>
<td>0.73</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Nail polish remover</strong></td>
<td></td>
<td>0.11</td>
<td>2.05</td>
<td>0.10</td>
<td>1.46</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Exposure was calculated by dermal, inhalation and oral routes for base coat, polish and top coat; and by inhalation route for nail polish remover.

* It was supposed that children aged 0–12 years used only one layer of polish. For these young people, it was not taken into account onychophagia practice. Wearing time data of 18–34 years were used for 0–12 years.

** It was supposed that adolescents aged 13–17 years used nail products in the same way that 18–34 years. In consequence, some parameters obtained with 18–34 years (i.e. percentage of users of base coat and top coat; number of coats applied; wearing time) were used for 13–17 years.

Consumption data for toenails were also obtained for 1512 adults and 301 children. 84% of 18–34 year-olds and 78% of 35–84 year-olds reported using cosmetics on toenails at least once a year. 61% of 301 children aged 0–17 years wore nail products on toenails at least one year. 20% of adults (16% of 18–34 year-olds and 22% of 35–85 year-olds) and 39% of children (51% of 0–12 year-olds and 12% of 13–17 year-olds) never used nail cosmetics on their toenails. As mentioned for fingernails, frequencies of use for adults and for children were adjusted to a distribution to differentiate regular consumers and occasional consumers; 61% of 18–34 year-olds and 54% of 35–85 year-olds were thereby classified as regular consumers. 21% of 0–12 year-olds and 65% of 13–17 year-olds were classified as regular consumers. The frequency of use of nail cosmetics on toenails was on average equal to 0.88 week⁻¹ (SD = 0.86) for adults aged 18–34 years, 0.80 week⁻¹ (SD = 0.81) for 35–85 year-olds, 0.70 week⁻¹ (SD = 0.97) for children aged 0–12 years and 0.64 week⁻¹ (SD = 0.69) for 13–17 year-olds. The wearing time was on average equal to 2.07 weeks (SD = 1.30) for adults aged 18–34, and equal to 1.69 weeks (SD = 1.12) for women aged 35–85 years.
Only 12 volunteers applied varnishes to their toenails during laboratory tests. Consequently, it was impossible to correctly assess the exposure to nail cosmetics on toenails with limited data on the quantity, time of use and application area. Preliminary data showed that the average quantity of polish applied per coat was equal to 152.5 mg (SD = 67.7 mg). The mean setting and drying time was equal to 3.8 min (SD = 2.0). The nail area was equal to 7.6 cm² (SD = 1.7 cm²). No data for base coat, top coat or remover were obtained.

Exposure to nail polish by the ungual route does not appear to be negligible, according to preliminary frequency and quantity data obtained. With more experimental data, it would be essential to assess exposure to varnishes and remover applied to toenails, and also to assessing the combined “fingers and toes” exposure.

4.2. Comparison of data with literature

Only two publications have reported consumption data for nail cosmetics. Biesterbos et al. (2013) have demonstrated that 51% and 48% of adult Dutch women used polish and polish remover, respectively. In a study realized in California, polish has been demonstrated to be applied by 53% of adult women, 45% of children aged 0–5 years and 79% of children aged 6–17 years (Wu et al., 2010). In the presented study, 62% of adult women and 40% of children less than 18 years old used nail varnishes regularly. Furthermore, 61% of these women used polish remover. These values are in the same order of magnitude as those available in literature. Wu et al. (2010) found a frequency of use of polish equal to 0.53, 0.38 and 0.35 week⁻¹ for adult women, children aged 6–17 years and children aged 0–5 years, respectively. In our study, the frequency of use was equal to 1.11 week⁻¹ (for women aged 35–85 years), 1.27 week⁻¹ (18–34 years), 1.40 week⁻¹ (13–17 years) and 0.91 week⁻¹ (0–12 years). The higher frequency observed in this study can be explained by the fact that only regular consumers were taken into account. Biesterbos et al. (2013) have established a mean amount per application equal to 0.3 g for nail polish and 2.0 mL for polish remover. In our study, the mean quantity of nail polish was also equal to 0.3 g/use for adults, and the mean amount of polish remover was estimated at 2.7 g. To the authors’ knowledge, no exposure data have been published for nail cosmetics.

The Netherlands National Institute for Public Health and the Environment (RIVM) has proposed a “Cosmetics Fact Sheet” to assess the risks for the consumer by using a computer program ConsExpo (RIVM, 2006). The parameter values used by RIVM were compared to data obtained in the present study. Most values were in the same order of magnitude, except for the inhalation rate parameter and polish remover amount per use (Table 7).

5. Conclusion: from an external to a systemic exposure assessment

Consumers were most exposed to varnishes by the ungual route. Inhalation was the secondary route of exposure, followed by dermal (nail wall) and oral routes.

The nail plate is a highly keratinized tissue. It protects the tips of the fingers and enables tasks such as the handling of small objects and scratching. The nail plate is characterized by a low permeability to diffusing substances (Brown et al., 2009; Walters et al., 2012). Transfer through the nail should be lower according to molecules and consequently, systemic exposure by the ungual route could be limited. Inversely, inhalation has been documented as an easy and fast means of exposure due to strong absorption of molecules in the respiratory tract (ATSDR, 2009).

Parlett et al. (2013) demonstrated that exposure to nail polish was significantly associated with urinary monoethyl phthalate concentration in women. Another study showed that pregnant women who consumed nail polish presented statistically significantly higher levels of urinary monobutyl phthalate (Buckley et al., 2012). These metabolites have been correlated with reproductive toxic effects in humans (Meeker et al., 2009).

Our study focused on external exposure, i.e. no absorption parameter has been taken into account. This study provides a basis for future toxicological studies of the uptake of substances contained in nail cosmetics. In order to complete this work and to characterize the health risk, it appears important (i) to assess the external exposure compound by compound (Chevillotte et al., in press), and (ii) to introduce the absorption parameter in order to assess systemic exposure for each compound, and for each route of exposure.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Transparency Document

The Transparency document associated with this article can be found in the online version.
Acknowledgments

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References


