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Occurrence and Preliminary Health Risk Assessment of Phenol Residues in Children's Cosmetics

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Abstract: *This study systematically investigated the residue levels and distribution characteristics of phenol in commercially available children's cosmetics. A total of 118 batches of children's cosmetics were randomly collected from e-commerce platforms in China. Phenol residues were analyzed using high-performance liquid chromatography with fluorescence detection. The overall detection rate was 24.6%, with residues mainly distributed in the range of 0.20~2.0 mg/kg. A child-specific health risk assessment using the margin of safety (MoS) approach was performed with exposure parameters adjusted for children (daily application amounts derived from SCCS guidelines by body surface area adjustment; dermal absorption rate: 97.6% worst-case; body weights: 9.65 kg for infants 0~3 years for skincare products, 32 kg for school-age children 6~12 years for makeup products). All MoS values for positive samples substantially exceeded the SCCS safety threshold of 100, indicating no significant health risk to children under normal use conditions. However, the detection rate of 24.6% highlights the need for continued monitoring. This study provides baseline occurrence data for phenol residues in children's cosmetics in the Chinese market.*

Keywords: *Children's cosmetics, Phenol,Residue level,Health risk assessment, Exposure assessment*

1. Introduction

Phenol (C_6H_5OH, CAS No. 108-95-2) is a high-production-volume chemical widely used in the synthesis of resins, plastics, pharmaceuticals, and disinfectants. Global phenol production exceeds 10 million metric tons annually. Phenol enters the environment primarily through industrial effluents, wastewater discharge, and degradation of phenolic compounds. Human exposure occurs via inhalation contaminated air, ingestion of contaminated food and water, and dermal contact with consumer Phenol is also a metabolite of various aromatic compounds and can be detected in urine of the general population [1].

Toxicologically, phenol is rapidly absorbed through the skin and mucous membranes. Acute can cause local corrosion, cardiac arrhythmias, and central nervous system depression. Chronic in animal studies has been associated with liver and kidney damage, and phenol is classified as a Category 2 germ cell mutagen (H341) by the EU CLP regulation [2]. The oral LD_{50} in rats ranges from to 600 mg/kg bw, and the no-observed-adverse-effect level (NOAEL) for chronic toxicity is approximately 25 mg/kg bw/day based on a 90-day oral toxicity study in rats [1]. The dermal absorption rate of phenol in cosmetic matrices is estimated to be 18.8–97.6% under in vitro conditions [3-4]. Given toxicity, phenol is listed as a prohibited ingredient in cosmetics under both the EU Cosmetic and China's Safety and Technical Standards for Cosmetics (2015 edition, currently under revision)[6].

Despite the prohibition, phenol may still be introduced into children's cosmetic products as a technically unavoidable trace impurity through raw materials such as phenoxyethanol and 4-hydroxyacetophenone, or through contamination during manufacturing. Children's skin is thinner than adult skin, with a less developed barrier function and a higher body surface area-to-body weight ratio, making them potentially more susceptible to chemical exposure. Therefore, safety assessment of phenol residues in children's cosmetics is particularly important. However, systematic data on the occurrence of phenol residues in children's cosmetics in the Chinese market and their potential health implications remain limited. This study aims to: (1) investigate the occurrence and distribution of phenol residues in children's cosmetics available in the Chinese market; (2) conduct a child-specific health risk assessment to evaluate consumer safety; and (3) provide baseline data for regulatory reference regarding children's cosmetic products.

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1.1 Instruments and Reagents

1.1.1 Instruments

High-performance liquid chromatograph (Agilent Technologies, USA) equipped with a fluorescence detector; ultrasonic cleaner (KUDOS Ultrasonic Instrument Co., Ltd., Shanghai, China); centrifuge (Thermo, Germany); 0.45 μm organic phase filter membrane (Jinteng Experimental Equipment Co., Ltd., Tianjin, China).

1.1.2 Reagents

Phenol standard (CAS No. 108-95-2, purity ≥ 99.90%, ANPEL Laboratory Technologies Inc., Shanghai, China); methanol (chromatographic grade, Merck, Germany); ultrapure water (18.2 MΩ·cm).

1.2 Sample Collection

A total of 118 children's cosmetic samples were randomly collected from e-commerce platforms (Taobao, Tmall, JD.com,etc.) in China, during March to June 2025, covering a range of price segments (low, medium, high) to enhance representativeness. Children's cosmetics were defined based on labeled target population ("children," "infants," "baby," etc.) or intended use (moisturizing creams, diaper creams, children's sunscreens). The sample set included 83 skincare products (children's moisturizing creams, lotions, diaper creams) and 35 makeup products (children's lipsticks, eyeshadows, nail polishes). All samples were stored at room temperature in the dark and analyzed within three months of collection.

1.3 Extraction

We weigh 1.0 g of the sample (accurate to 0.001 g) into a 10 mL color comparison tube with a stopper. We add methanol to the mark, and vortex for 30 seconds to ensure thorough mixing of the sample with the extraction solvent. Seal the tube tightly, perform ultrasonic extraction for 20 minutes, and allow it to cool to room temperature. We take an appropriate amount of the sample solution and centrifuge it at a speed of 14,000 r/min for 5 minutes. We filter the supernatant through a microporous membrane (0.45 μm) , and collect the subsequent filtrate as the test solution.

1.4 Instrumental analysis

Chromatographic separation was performed on a C_{18} column (250 mm × 4.6 mm, 5 μm) maintained at 30 ℃. The mobile phase consisted of methanol and aqueous solution (40:60, v/v) at a flow rate of 1.0 mL/min. The injection volume was 10 μL, and fluorescence detection was performed with excitation at 270 nm and emission at 300 nm (detection wavelength set at 280 nm).

1.5 QA/QC

A procedural blank (methanol without sample) was processed with each batch of 20 samples to monitor potential background contamination. An instrumental daily calibration check standard was analyzed after every 10 samples to verify instrument stability and performance. Recovery tests were conducted for each batch by spiking matrix samples with known concentrations of phenol, yielding a mean recovery rate of 95%, which confirms the accuracy of the method and the absence of significant matrix effects. The method detection limit for phenol was determined to be 0.2 mg/kg, based on a signal-to-noise ratio of 5:1.

2. Results and Discussion

2.1 Occurrence of Phenol Residues in Cosmetics

Phenol residues were detected in 29 out of 118 children's cosmetic samples (detection limit 0.2 mg/kg), resulting in an overall detection rate of 24.6%. Among 83 children's skincare products, phenol was detected in 20 batches (24.1%), with concentrations ranging from 0.33 to 5.6 mg/kg. For 35 children's makeup products, phenol was detected in 9 batches (25.7%), with concentrations ranging from 0.21 to 3.3 mg/kg. Among the positive samples, approximately 80% exhibited phenol residues

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concentrated within 0.20–2.00 mg/kg (Fig. 1). Only 6 batches (5.1% of total samples) exceeded a phenol concentration of 2.0 mg/kg, indicating that phenol residues in the majority of children's cosmetics are maintained at low levels.

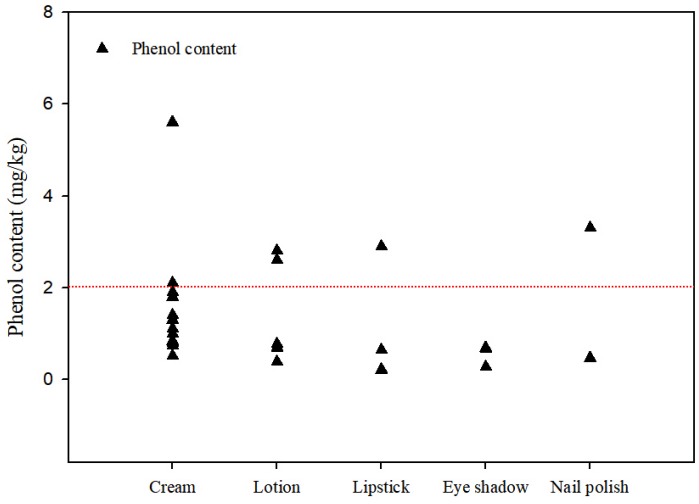


Fig.1 Phenol residues in cosmetics

2.2 Distribution Characteristics

The distribution of phenol residues varied across different categories of children's cosmetics (Table 1). In children's skincare products, among 52 children's moisturizing cream samples, phenol was detected in 16 batches (range 0.33~5.6 mg/kg, median 1.1 mg/kg, 95th percentile 4.8 mg/kg). For 31 children's lotion samples, phenol was detected in 6 batches (range 0.39~2.8 mg/kg, median 0.74 mg/kg, 95th percentile 2.6 mg/kg). The detection rate and concentration range were higher in creams than in lotions, which may be attributed to the greater solubility and stability of phenol in lipid-rich matrices.

In children's makeup products, among 15 children's lipstick samples, phenol was detected in 4 batches (range 0.21~2.9 mg/kg, median 0.43 mg/kg). For 10 children's eyeshadow and 10 children's nail polish samples, phenol was detected in 4 eyeshadows (range 0.27~0.69 mg/kg, median 0.67 mg/kg) and 2 nail polishes (0.47 and 3.3 mg/kg, median 1.88 mg/kg). Children's nail polishes showed the highest median concentration among all categories, possibly due to the organic solvent systems used in their formulations, which may enhance phenol solubility and retention.

Tab.1 Distribution of phenol residues in different types of cosmetics

Product category	N	Concentration range (mg/kg)	Median Concentration (mg/kg)	95th P
Cream	16	0.33~5.6	1.1	4.8
Lotion	6	0.39~2.8	0.74	2.6
Lipstick	4	0.21~2.9	0.43	2.7
Eyeshadow	4	0.27~0.69	0.67	0.69
Nail polish	2	0.47~3.3	1.88	—*

*95th percentile not calculated due to small sample size (n=2)

The Kruskal–Wallis test revealed a statistically significant difference in phenol concentrations across product categories ($H = 12.37$, $p = 0.015$). Post-hoc pairwise comparisons with Bonferroni correction (adjusted $\alpha = 0.005$) showed that children's cream products had significantly higher median concentrations than children's eyeshadows ($p = 0.003$). No other pairwise differences reached statistical significance, likely due to the limited sample sizes in some categories (e.g., children's nail polish, n=2).

The observation that creams (oil-rich matrices) show higher phenol levels than lotions (water-rich matrices) aligns with the physicochemical properties of phenol. Phenol is moderately lipophilic (log Kow ~1.5), which favors partitioning into lipid phases. This may explain both the higher detection rates and higher concentrations in oil-based products compared to aqueous lotions. However, this mechanistic interpretation is based on physicochemical principles rather than experimental verification

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and should be confirmed by future studies directly measuring phenol partitioning in children's cosmetic formulations..

2.3 Preliminary Health Risk Assessment

To evaluate the potential health risks associated with phenol residues in children's cosmetics, a risk assessment was performed using the margin of safety (MoS) approach recommended by the Scientific Committee on Consumer Safety (SCCS) [7], with exposure parameters specifically adjusted for children.

2.3.1 Exposure and Hazard Characterization

The systemic exposure dosage (SED) was calculated using the following equation from the SCCS Notes of Guidance [7]:

$$SED\ (mg/kg/day) = (C \times D \times DAp) / BW$$

Where:

C : concentration of phenol in the children's cosmetic product (mg/kg)

D: daily amount of children's cosmetic product applied (g/day)

DAp: dermal absorption rate (%)

BW : children body weight (kg)

The margin of safety (MoS) was calculated as:

$$MoS = NOAEL / SED$$

According to SCCS guidelines, an MoS greater than 100 is considered safe for consumers [5].

Daily application amounts were based on SCCS [7]: 7.82 g for body lotion, 1.54 g for face cream, 2.16 g for hand cream, 0.057 g for lipstick, and 0.51 g for nail polish (referencing liquid foundation). Exposure data for children were derived from adult daily exposure data by adjusting for the body surface area of adults and children, following SCCS guidelines [5]. Body surface area data for children and adults were obtained from the Exposure Factors Handbook of Chinese Population [8-10]. Accordingly, the estimated daily application amounts for children are as follows: 2.25 g for body lotion, 0.44 g for face cream, 0.62 g for hand cream, 0.039 g for lipstick, and 0.35 g for nail polish.

The dermal absorption rate (DAp) in children may be higher than in adults due to their incompletely developed skin barrier function. Based on published in vitro studies [3,4], absorption rates for phenol range from 20% to 97.6%. A worst-case value of 97.6% was adopted in this assessment to provide a conservative estimate of exposure.

Body weight (BW) was determined according to the Exposure Factors Handbook of Chinese Population (Children's Volume) [8-9]. Representative average body weights for different age groups are as follows: infants (0–3 years): 9.65 kg; preschool children (3–6 years): 17.6 kg; school-age children (6–12 years): 32 kg. For skincare products, the risk assessment was performed using the infant age group (0–3 years), whereas for makeup products, the school-age children group (6–12 years) was employed.

NOAEL: 25 mg/kg bw/day from a 90-day oral toxicity study in rats [1]. An assessment factor of 100 (10× for interspecies differences, 10× for inter-individual variability) was applied, yielding a human equivalent NOAEL of 0.25 mg/kg bw/day for dermal exposure. Although some experts recommend an additional safety factor for children due to immature metabolic systems, the standard assessment factor of 100 was used in this study to maintain comparability with adult assessments.

2.3.2 Risk Characterization

For the 20 skincare products with detectable phenol residues, the calculated SED values ranged from 1.48×10^{-5} to 1.28×10^{-3} mg/kg/day, with a median value of 1.22×10^{-4} mg/kg/day. The corresponding MoS values ranged from 196 to 16882, with a median MoS of 2,213(Tab.2). For the 9 makeup products with detectable phenol residues, the SED values ranged from 2.51×10^{-7} to 3.51×10^{-5} mg/kg/day, with a median value of 8.01×10^{-7} mg/kg/day. The MoS values ranged from 7,125 to 995,695, with a median MoS of 312,083(Tab.2).All MoS values were well above the SCCS safety threshold of 100, indicating that under normal use conditions, phenol residues in the tested children's

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cosmetics pose no significant health risk to children.

Tab.2 Summary of Systemic Exposure Dosage (SED) and Margin of Safety (MoS) for Phenol Residues in Cosmetics

Product Category	N	SED Range (mg/kg/day)	Median SED (mg/kg/day)	MoS Range	Median MoS
Skincare products	20	$1.48\times 10^{-}5 – 1.28 \times 10^{-}3$	$1.22 \times 10^{-}4$	196– 16,882	2,213
Makeup products	9	$2.51 \times 10^{-7} – 3.51 \times 10^{-5}$	8.01×10^{-7}	7,125 – 995,695	312,083

The lowest MoS value (196) was observed for a children's moisturizing cream product with the highest phenol concentration (5.6 mg/kg), using conservative child body weight (9.65 kg) and usage amount (2.25 g/day). Even in this worst-case scenario, the MoS exceeds the threshold by a factor of >1.5. For the vast majority of products, MoS values are tens to thousands of times above the threshold, providing wide safety margins.

2.3.3 Comparison with Toxicological Reference Values

To further contextualize the exposure levels, the calculated SED values were compared with established toxicological reference values. The European Food Safety Authority (EFSA) has set a tolerable daily intake (TDI) for phenol of 1.5 mg/kg bw/day, based on hematological effects observed in animal studies[11]. The maximum SED estimated from children's cosmetics in this study (1.28×10^{-3} mg/kg/day) is approximately 1,170 times lower than this TDI. Even when applying the more conservative NOAEL-based threshold of 0.25 mg/kg/day, the maximum SED remains 195 times lower. Furthermore, the U.S. Environmental Protection Agency (EPA) reference dose (RfD) for phenol is 0.3 mg/kg/day[12], and the maximum SED in this study is roughly one 230th of this value. Collectively, these comparisons strongly reinforce the conclusion that phenol residues in children's cosmetics do not pose a health concern under the assessed exposure conditions.

3. Conclusion

This study provides systematic data on the occurrence of phenol residues in children's cosmetics in the Chinese market. Among 118 samples analyzed, phenol was detected in 24.6% of samples, with concentrations predominantly below 2.0 mg/kg. A child-specific health risk assessment using the MoS approach demonstrated that all MoS values for positive samples substantially exceeded the safety threshold of 100, with the lowest MoS of 196 still exceeding the threshold by a factor of >1.5. Comparison with toxicological reference values (EFSA TDI, US EPA RfD) further reinforced the safety conclusion. These findings indicate that under normal use conditions, phenol residues in the tested children's cosmetics pose no significant health risk to children. However, the detection rate of 24.6% highlights the need for continued monitoring.

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