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Effects of Bleaching and Dyeing on Drug Detectability in Hair Samples

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Introduction

Hair analysis has emerged as a reliable and non-invasive method of detecting drug use, offering advantages such as long detection windows, ease of sample collection, and resistance to sample adulteration. In forensic toxicology, employment screening, substance abuse treatment, and criminal justice proceedings, hair drug testing has become a routine practice. The incorporation of drugs into the hair matrix provides a retrospective timeline of exposure, allowing for the assessment of chronic or repeated drug use. However, cosmetic hair treatments-especially bleaching and dyeing-pose significant challenges to the integrity and accuracy of hair drug analysis. With the rising popularity of chemically treated hair, especially among women and young individuals, questions have been raised about the impact of such treatments on drug stability, detectability, and concentration levels in hair samples [1-3].

Once integrated into the cortex, drugs bind to melanin and keratin fibers through various chemical interactions, including ionic and hydrophobic bonding. Hair color, porosity, and cosmetic treatment can influence the concentration and stability of these compounds. Melanin content, for instance, plays a crucial role in drug binding. Basic drugs such as cocaine, amphetamine, and codeine have a strong affinity for melanin. Consequently, darker hair tends to retain higher drug concentrations compared to lighter hair. Bleaching involves the use of oxidizing agents such as hydrogen peroxide or persulfates to decolorize hair by breaking down melanin pigments. The process also disrupts disulfide bonds in keratin, increasing porosity and degrading the hair structure. Hair dyeing uses permanent or semi-permanent coloring agents that penetrate the cortex to deposit pigments. Oxidative dyes involve an initial bleaching step followed by color development using Paraphenylenediamine (PPD) and couplers. These treatments alter the internal matrix, damage cuticle scales, and modify chemical composition.

Description

Cocaine is among the most studied drugs in relation to cosmetic treatment. Studies have shown that bleaching can reduce cocaine concentrations by up to 50–80%, while its metabolites (benzoylecgonine, norcocaine) are even more susceptible to degradation. Repeated bleaching cycles exacerbate this effect. Dyeing shows moderate impact, with reductions in cocaine content ranging from 20–50% depending on the dye type and hair color. Metabolite-to-parent drug ratios are often altered, complicating interpretation. Opiate levels significantly decrease after hair bleaching. A study by Kintz et al. reported up to 75% loss of morphine and codeine after one bleaching session. 6-Monoacetylmorphine (6-MAM), the heroin-specific metabolite, is particularly labile and may disappear entirely, leading to potential false negatives. Dyeing has less dramatic effects but can still reduce concentrations by 20–40%, depending on hair porosity and treatment duration. Amphetamine derivatives are also sensitive to oxidative degradation. Bleaching may lead to 40–70% reduction in methamphetamine concentrations. Metabolites like amphetamine (from methamphetamine) are more prone to chemical alteration. Coloring shows variable effects but can alter metabolite ratios, potentially obscuring evidence of ingestion.

Tetrahydrocannabinol (THC) has a high lipophilicity, binding strongly to hair lipids. Despite this, bleaching can reduce THC content by 30–60%, especially after repeated applications. 11-nor-9-carboxy-THC (THC-COOH), the key metabolite used to confirm cannabis use, may be degraded or fall below detection thresholds. Dyeing has less pronounced effects but can still cause metabolite distortion, particularly if heat or ammonia is involved. Benzodiazepines such as diazepam and alprazolam are also vulnerable to chemical treatments. Bleaching reduces levels by 20–60%, while dyeing shows moderate reductions. Drug polarity and hair melanin levels influence these effects. Cosmetic hair treatment introduces several challenges for toxicological interpretation. Reduced concentrations may fall below the analytical cutoff, resulting in a missed detection despite prior drug use [4,5].

Testing for both parent drug and multiple metabolites provides a more robust picture. If a parent drug is present without expected metabolites, cosmetic alteration should be suspected. In cases where cosmetic treatment compromises the hair sample, alternative matrices such as nails, blood, urine, or oral fluid may be considered. While reducing analytical cutoffs might detect lower drug levels, it also increases the risk of false positives from environmental contamination. Therefore, this strategy should be applied selectively and contextually. In forensic and legal settings, inaccurate hair drug results due to bleaching or dyeing can lead to miscarriages of justice. To mitigate these risks, experts must provide contextual interpretation and educate courts and agencies about the limitations of testing in treated hair. Laboratories should disclose when cosmetic treatment may have compromised the sample and report results with appropriate qualifiers.

Conclusion

Hair drug testing is a powerful tool in toxicology, offering extended detection windows and robust evidence of drug use. However, the widespread use of bleaching and dyeing introduces significant vulnerabilities, potentially leading to reduced drug detectability, false negatives, and misinterpretation of results. Scientific evidence consistently shows that chemical treatments degrade drug compounds, alter metabolite ratios, and reduce overall analyte concentrations. The extent of these effects varies by drug class, treatment type, and hair characteristics, underscoring the need for case-specific analysis. To maintain the integrity of hair drug testing, professionals must incorporate cosmetic treatment history, use advanced analytical techniques, apply contextual interpretation, and educate stakeholders about potential limitations. As hair treatments become more common and diverse, evolving our testing strategies and forensic standards is essential to ensure fair, accurate, and scientifically grounded outcomes.

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Conflict of Interest

None.

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