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Review

Review: Drug concentrations in hair and their relevance in drug facilitated crimes

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ABSTRACT

Segmental hair analysis can provide valuable retrospective information on the history of drug exposure in victims of drug facilitated crimes (DFC). This is now possible with availability of sensitive tandem MS techniques such as GC-MS/MS and LC-MS/MS allowing drugs to be detected at pg/mg concentrations after a single dose. In this review hair concentrations of 35 psychoactive drugs given in 20 controlled dose studies are reviewed and compared to the 25 different drugs detected in reported case work. The most common drugs were the benzodiazepines and related hypnotics, gamma-hydroxybutyrate (GHB), ketamine and methamphetamine. Those concentrations reported in DFC were mostly similar or higher than that seen in controlled dose studies. The factors that affecting interpretation of segmental hair results including hair color, growth rates, sample preparation and surface contamination are discussed.

1. Introduction

Robbery, battery, maltreatment or sexual assault committed on a victim who is under the influence of a psychoactive substance is defined as a drug facilitated crime (DFC) particularly where drug(s) have been given surreptitiously.[1] Rape or other types of sexual assault are referred to as drug facilitated sexual assault (DFSA), and are usually the most common type of DFC.[2] In DFC substances that cause sedation and amnesia are preferred, particularly if they can be dissolved readily in drinks without being detected by the victim.[3]

Psychoactive substances most often detected include the sedating benzodiazepines, related hypnotics and sedatives such as zopiclone and zolpidem, anesthetics, gamma-hydroxybutyrate (GHB) and drugs of abuse such as cannabis and even the amphetamine-type stimulants that also can facilitate an altered state of mind.[4] A Canadian study showed that DFSA was most frequently detected with the most common drugs in urine being cannabinoids (40%), cocaine (32%), amphetamines (14%), MDMA (9.2%), ketamine (2.3%) and GHB (1.1%).[5] One U.K.-based organization specifically established to provide support for victims of this crime has, for example, reported a 256% increase in the number of DFC between 1995 and 2005.[6] Seventy-six positive cases were identified from a total of 434 (17.5%) cases of suspected DFSA for the 12 month period to 2003 in Australia with the most common drugs cannabinoids, benzodiazepines, opiates and antidepressants.[4] In 2010, the French reported that there was an increase in DFC following periods of apparent inactivity.[7] In China, the majority of these cases are robberies and have also been increasing in prevalence.[8]

In DFC the types of forensic or medicolegal samples that are required for toxicological examination depend, in part, on the elapsed time since assault.[9,10] While blood and urine are the conventional specimens for documenting drug exposures a 24–72 h or longer delay between a victim's report and the ingestion of drug means that the use of hair testing is a useful specimen particularly for shorter half-life drugs. Segmental analysis has also been used to determine a possible period of exposure.[11]

The role of hair testing as an alternative or complementary matrix has expanded across the spectrum of toxicological investigations and, consequently, samples of hair are routinely collected during criminal investigations.[12] However, there are limitations in the interpretation of hair analyses due to interindividual differences, variable growth rates of hair and uncertainty over the mechanism of entry of drug into hair. A number of reviews have been written on this subject with only some listed here,[3,13–18]

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but none have reviewed the ability to detect single controlled doses in humans and how this compares to reported hair concentrations in DFC.

The aim of this manuscript was to review published papers documenting hair concentrations of psychoactive drugs given in controlled dose studies and contrast this with those drug concentrations reported in case work relating to DFC to improve our understanding of the interpretation of drug concentrations in hair analyses.

2. Review method

The authors systematically reviewed Google scholar and PubMed databases for all available English language publications where concentrations of drugs were measured in hair from controlled administration of psychoactive drugs and in case reports or other publications reporting hair toxicology data in adult victims of DFC. Cases involving children were not included in this review. The keywords used were 'drug-facilitated', 'hair','single dose', 'drug facilitated assault', 'rape' and combinations of these terms. A key focus was to review publications in which segmental analyses had been used to determine hair concentration after controlled doses of possible drugs used in adult DFC, and those that reported concentrations in actual adult DFC cases.

All reported hair concentrations were adjusted to two significant figures in situations where more than 3 were reported.

2.1. Advantages and limitations associated with hair testing

Hair has particular advantages for toxicological analysis, such as ease of collection, non-invasiveness, stability and storage of samples.

However, hair is not a simple matrix; instead it is a complex matrix composed of different layers in the hair.[14] While there are similarities between hair of different ethnic origin and body region there are also significant differences in thickness and hair pigmentation that can influence uptake and retention of substances. Generally dark pigmented hair tends to bind greater amounts of drug than less pigmented hair (i.e. blond).[19,20] This is because eumelanin, the main pigment in hair that gives its color, is responsible for most of binding to drugs.[19,21] This leads to different amounts of drug in hair, assuming all other variables can be controlled, and has led to concern over racial bias, for example against Asian and African American peoples since they usually have black hair and consequently will (usually) have more drug in hair for the same amount of drug used.

Most drugs are believed to bind to the melanin pigments found in colored hair.[19,20,22–25] In numerous studies here has often been a good relationship between the drug levels and that of melanin content in hair.[15,26,27] For zolpidem, Villain[28] compared the incorporation into white and black hair and found the concentration of zolpidem was 0.4 pg/mg or less in the white part of the hair and 40 pg/mg in the black part of the hair. Miyaguchi et al.[29] using micropulverized extraction detected zolpidem at 18 ng/mg in black hair and 0.12 ng/mg in white hair derived from the same donor.

Similar variations in the concentration of drugs in different pigmented hair have been observed, particularly for basic drugs. These also include cocaine,[19] codeine[20] and ketamine.[24]

Head hair grows at variable rates, depending on whether it is in one of three growth stages: anagen (growing stage), catagen (transition stage) and telogen (resting stage).[14,30] The duration of these stages varies between people and also within a person. Hence, no one strand will necessarily reflect the overall growth of hair during the period in question.

The usual practice is to cut the hair strands into short segments and, following analysis, show detection of drug in the section that was developing as a follicle at the time of the exposure. Ideally there is no drug detection in the other segments. While this will not prove surreptitious administration it does confirm exposure to the drug. Analysis can provide a history of drug exposure and the use of 1 cm per month is invariably used to give an approximate window of exposure.[11,13] However, the growth rate in head hair is known to vary from about 0.5 to 1.5 cm per month,[13] with much more variable growth rates from other parts of the body. This does mean that interpretations need to consider this variable growth into account, and not necessarily assume all hair grows at about 1 cm per month.

However, even in controlled studies, some drug is often detected in neighboring segments. The possible reasons for the positive band broadening can be diffusion from sweat or other secretions,[8,31] variations in growth rate and sample collection.[30] Variations in growth rate and sample collection contributes to the apparent axial distribution of a drug along the hair fiber.[30] This issue was reinforced by detection of d^5-cocaine in multiple segments after a single dose.[32] There was also considerable intersubject variability in the time drug first appeared in hair and the presence of drug in the hair sections over time.

It has been proposed that the highest drug concentration must be detected in the segment corresponding to the period of the alleged assault and that the measured concentration must be at least 3 times higher than those measured in the previous or the following segments.[13] While this might be a useful criteria there is no actual evidence that this approach will be foolproof in all cases. Moreover, drug presence cannot prove whether exposure was clandestine or deliberate.

In contrast to controlled drug administration studies, hair collection in actual cases was often not controlled by scientists. This makes the interpretation of segmental results more complex, particularly if a significant time has elapsed since exposure, thereby causing a spread of drug concentrations due to different hair growth phases.[33]

2.2. Analytical considerations

This article is not a review of analytical considerations of drug testing in hair, however it is relevant to include some comments on analysis.

Over the last decade, considerable advances have occurred in the ability to detect drugs in hair following low repeated doses, or even single doses, especially with the affordable and sensitive tandem MS instruments, such as GC-MS/MS and LC-MS/MS. This allows drugs and metabolites to be detected at pg/mg levels including those after a single dose[8,34–37] including segmental hair analysis in DFC.[38]

The use of highly sensitive broad screening method is obligatory when investigating DFC. The Society of Forensic Toxicologists (SOFT) DFSA Committee has published a list with 80 analytes including drugs and metabolites relevant in DFC/DFSA cases although this is designed primarily for urine analyses.[39] Positive concentrations in hair segments may be very low and below detectable limits. A negative hair result cannot necessarily exclude the administration of the detected drug particularly as concentrations are low and more difficult to detect single low doses than urine.[27]

While MS/MS techniques are applied widely today, GC-MS detection is suitable for detecting higher concentrations in hair for less potent drugs, e.g. cocaine[32] and codeine[40,41] in hair at ng/mg levels after a single dose of 25–120 mg.

Sample preparation before extraction (cutting or grinding),[25] as well as the stage of incubation (hydrolysis or not)[42] and the choice