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Poison and Proof: Forensic Toxicology and the Science of Drug-Facilitated Crime

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Abstract

Drug-facilated crimes, such as drug-facilated sexual assault (DFSA), pose a serious problem for forensic science and the criminal justice system because incapacitating agents can have a short half-life and numerous pharmacological effects. The review considers the contribution of forensic toxicology to the detection, identification and interpretation of the toxic components of DFCs. It addresses the pharmacological properties of potentially involved substances such as alcohol, benzodiazepines, γ-hydroxybutyrate (GHB), ketamine, opioids, cannabinoids, stimulants, antihistamines and novel psychoactive substances (NPS). The review also discusses the collection and storage methods for biological specimens, current analytical methods including GC–MS, LC–MS/MS and HRMS, toxicokinetics, detection wind006Fws, and polydrug exposure. Further, it identifies forensic, legal, and ethical issues in the Indian scenario, presents new technologies such as 'AI', 'Metabolomics', and advanced analytical platforms that are likely to further bolster the science of toxicological work and enhance the scientific integrity of the toxicological evidence.

Keywords; Forensic Toxicology; Drug-Facilitated Crime (DFC); Drug-Facilitated Sexual Assault (DFSA); Toxicological Evidence; High-Resolution Mass Spectrometry (HRMS).

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1 Introduction

The toxic substances have a dual role in forensic investigation covered by the phrase "Poison and Proof". Poisons and psychoactive drugs have been used throughout history to incapacitate, injure, and kill victims, but they are also important forensic clues that can help elucidate the nature of a crime and connect victims, suspects and crime events. Forensic toxicology has significantly advanced the investigation of poisoning and drug related crimes because it allows for the detection, identification and interpretation of toxic agents found in biological samples. Forensic toxicology can help with criminal investigations, judicial proceedings and the proper reconstruction of criminal events, including impaired driving, accidental poisonings and drug-facilitated crimes, by providing objective evidence through scientifically validated analytical methods.[2]

Forensic Toxicology is an interdisciplinary field of science that combines analytical chemistry, pharmacology, toxicology, biochemistry and forensic medicine to study drugs, alcohol, poisons and other xenobiotics to determine their presence and effects in biological and non-biological materials. The discipline's scope goes beyond the detection of toxic compounds and covers their pharmacokinetics, pharmacodynamics, metabolism, concentration and potential physiological effects as part of the investigated incident. The analytical sensitivity, specificity and reliability of toxicological analysis have significantly advanced with the introduction of gas chromatography – mass spectrometry (GC–MS), liquid chromatography – tandem mass spectrometry (LC–MS/MS) and high resolution mass spectrometry (HRMS) which are capable of detecting trace levels of conventional drugs and emerging novel psychoactive substances (NPS).[3]

Drug-facilitated crime (DFC) is one of the most difficult types of forensic toxicology investigations, in which psychoactive drugs are intentionally used to subdue a victim and make them vulnerable to other people's actions, thereby allowing the perpetrator to commit a crime. Robbery, physical assault, financial exploitation, kidnapping and homicide are only a few of the offences that fall under the category of DFC. One specific group of cases is drug-facilitated sexual assault (DFSA), in which sexual assault victims are incapacitated to give informed

[2] K. Skov, S. S. Johansen, K. Linnet, and M. K. K. Nielsen, "A review on the forensic toxicology of global drug-facilitated sexual assaults," Eur. Rev. Med. Pharmacol. Sci., pp. 183–197, 2022.

[3] S. Shukla, S. Khanna, T. ul Gani Mir, J. Dalal, D. Sankhyan, and K. Khanna, "Emerging global trends and development in forensic toxicology: A review," J. Forensic Leg. Med., vol. 103, p. 102675, 2024, doi: https://doi.org/10.1016/j.jflm.2024.102675.

consent and to accurately remember the assault by use of alcohol, sedatives, hypnotics, dissociative anesthetics or other CNS depressants. The evidence and aftermath of DFC and DFSA is a forensic and legal challenge due to the fact that many of the substances causing these conditions can have a very short detection window and symptoms of intoxication can be confused with voluntary intoxication.[4]

Over the last few years, prescription drug misuse, illicit synthetic drugs and novel psychoactive substances have become more common, making the toxicology investigations of these drugs more complex around the globe. Thus, forensic toxicology is an important instrument in the modern criminal justice system that helps to evidence-based investigations, guides medico-legal decision making, corroborate victim testimonies, and contributes to a scientifically sound toxicological evidence for the fair administration of justice. Forensic toxicology is a critical component in the identification of drug-facilitated crimes and in providing scientifically valid evidence in modern investigations and prosecutions, as the analysis methods continue to advance.

2 Pharmacological Agents Commonly Implicated in Drug-Facilitated Crimes

Drug-facilitated crimes (DFCs) are crimes that are committed after someone is psychologically or physically incapacitated by a psychoactive substance or drug to make informed decisions, remember events, or exercise their judgment. The pharmacologic agents used in these crimes vary in their mechanism of action, duration of effect and toxicological profile, but most of them are sedating, disinhibitory, confusional or amnesic. Their quick onset and some may not be detectable for long in investigations make them very difficult to deal with. Therefore, knowledge of the pharmacological properties of these substances is critical to the toxicological interpretation, evidence gathering and reconstruction of a criminal incident.[5]

i. **Alcohol:** Alcohol is the most common substance found in DFC investigations. It is a central nervous system (CNS) depressant, which affects judgment, coordination, reaction time and memory and increases the sedative effects of other drugs, making victims very susceptible.

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[4] A.-S. Lemaire-Hurtel and J.-C. Alvarez, "Chapter 3 - Drugs Involved in Drug-Facilitated Crime—Pharmacological Aspects," P. B. T.-T. A. of D.-F. C. Kintz, Ed., Oxford: Academic Press, 2014, pp. 47–91. doi: https://doi.org/10.1016/B978-0-12-416748-3.00003-7.

[5] S. Anegg et al., "A ten-year analysis of drug-facilitated crimes: Prevalence and characteristics at a tertiary hospital victim protection center," Forensic Sci. Int., vol. 374, pp. 0–2, 2025, doi: https://doi.org/10.1016/j.forsciint.2025.112552.

ii. **Benzodiazepines and γ-Hydroxybutyrate (GHB):** Diazepam and alprazolam are members of a class of drugs called benzodiazepines, which enhance the activity of the neurotransmitter γ-aminobutyric acid (GABA) and cause sedation, muscle relaxation, and anterograde amnesia. GHB is a powerful CNS depressant that has a very short elimination half-life and rapid onset of action, often leading to unconsciousness and amnesia, which can make it difficult to detect forensically.[6]

iii. **Ketamine and Opioids:** Ketamine is also an N-methyl-D-aspartate (NMDA) receptor antagonist that causes dissociation, hallucinations, analgesia, and loss of awareness. When combined with other depressants like alcohol, opioids, such as fentanyl or morphine, act on the μ-opioid receptors to cause extreme sedation, breathing problems, and loss of consciousness.[7]

iv. **Cannabinoids, Stimulants, and Antihistamines:** Cannabinoids affect concentration, awareness, motor coordination and short-term memory; stimulants like cocaine, methamphetamine, and other stimulants change behavior, make people more impulsive and can be used to manipulate victims. Sedatives such as antihistamines (e.g., diphenhydramine, promethazine) have been associated on occasion due to their significant sedative and cognitive effects.

v. **Emerging Novel Psychoactive Substances (NPS):** Novel psychoactive substances (NPS) such as synthetic cannabinoids, designer benzodiazepines, synthetic opioids, and synthetic cathinones are becoming more frequently found in DFC cases. It is their high potency, diversity of structure, and restricted toxicological reference data that make their routine detection in the laboratory a challenge, and the need for the use of advanced analytical techniques and continuous forensic surveillance.

3 Biological Evidence and Analytical Techniques in Forensic Toxicology

Forensic toxicology can be very reliable if the biological evidence is good and the analytical techniques employed are accurate in the detection and quantification of toxic substances. However, in the case of drug-facilitated crime (DFC) investigations, it is crucial that biological specimens are promptly collected and properly preserved since many drugs metabolize and exit the body quickly. Choosing an appropriate specimen and using analytical techniques that are

[6] H. I. Thalib, A. A. Damanhory, A. H. Shaikh, S. Haidar, and S. Khan, "Forensic toxicology of benzodiazepines: neuropharmacological effects, analytical challenges, and emerging detection strategies," Front. Toxicol., pp. 1–11, 2025, doi: 10.3389/ftox.2025.1639890.

[7] J. L. Jones, C. F. Mateus, R. J. Malcolm, K. T. Brady, and S. E. Back, "Efficacy of Ketamine in the Treatment of Substance Use Disorders: A Systematic Review," Front. Psychiatry, vol. 9, 2018, doi: 10.3389/fpsyt.2018.00277.

sensitive to drugs allows forensic toxicologists to identify the specific drugs, their levels, and the significance of the drug in a criminal situation.[8]

A. Biological Evidence in Forensic Toxicology

The main source of toxicological evidence is in biological samples. Blood is the preferred specimen for the measurement of drug or alcohol levels at or close to the time of the incident as it reflects what has happened most recently in the body. Urine is also commonly used for screening because drug and metabolites will be present in the urine for a longer time than in the blood, but the concentration of the drugs in urine does not directly correlate with impairment. Hair contains a chronic history of drug exposure over a time span of weeks to months and is especially useful when samples are not collected immediately. Oral fluid (saliva) provides an alternative that is non-invasive, reflective of recent drug use, and is becoming more popular in roadside and workplace testing. Extra samples such as gastric contents, vitreous humour, nails and tissues can also be analysed in post mortem investigations or where conventional samples are not available. To preserve evidence and provide a chain of custody, it is important to collect, label, preserve and maintain specimens properly.[9]

B. Analytical Techniques for Drug Detection

A mix of screening and confirmatory analytical procedures are used in forensic laboratories. Immunoassays are frequently used for preliminary screening due to the ability to detect the presence of broad classes of drugs in high throughput but require confirmatory testing due to cross-reactivity and false positive rates. The gas chromatography–mass spectrometry (GC–MS) method is considered the reference method for identification of volatile and thermally stable compounds due to its high sensitivity and specificity. For thermally unstable, polar, and high molecular weight drugs, for which it is difficult to achieve extensive sample derivatization, liquid chromatography–tandem mass spectrometry (LC–MS/MS) is the method of choice for detection. Novel psychoactive substances (NPS), unknown metabolites and complex drug mixtures can be comprehensively targeted and untargeted screened using more recent high-resolution mass spectrometry (HRMS). Combined these advanced analytical techniques provide

[8] M. L. Soria, "The improvements in forensic toxicology and its role in the forensic process. The interpretation of results (II)," Spanish J. Leg. Med., vol. 50, pp. 62–75, 2024, doi: https://doi.org/10.1016/j.remle.2024.05.002.

[9] K. B. N. De Silva, K. S. Dharmasiri, M. P. A. A. Buddhadasa, and K. G. N. U. Ranaweera, "Criminal Investigation: A Brief Review of Importance of Biological Evidence," Eur. Sch. J., vol. 2, no. 8, pp. 8–12, 2021.

solid, reliable, and legally admissible toxicological data that is essential in today's forensic investigations.[10]

4 Interpretation of Toxicological Findings in Drug-Facilitated Crime Investigations

One of the most challenging issues of forensic investigation in drug-facilitated crimes (DFCs) is the interpretation of the toxicological results. The presence of a drug in a biological specimen is not sufficient to prove its involvement in the suspected crime – toxicological results should be analyzed alongside the pharmacological properties, the time at which the specimen was taken, the clinical history of the victim and the witnesses, and the other forensic evidence. Analytical results may be significantly affected by factors such as drug metabolism, elimination, post mortem changes and co-exposures. So, forensic toxicologists are required to use scientific expertise and information that is specific to the case to decide if the substances found are consistent with impairment, incapacitation or intoxication at the time of the alleged crime.

A. Toxicokinetics and Detection Windows

Toxicokinetics is the process of absorption, distribution, metabolism, and elimination of drugs in the human body. These processes play a role in the concentration of a drug in a biological specimen, and in its detectability over time. Urine provides a longer detection window for drugs than does blood, as it contains metabolites. Oral fluid can be used to see if someone has recently used, and hair to see if they have used in the past over a period of weeks or months. Delayed specimen collection may lead to lower levels of many drugs that are implicated in DFCs, including γ-hydroxybutyrate (GHB), as these drugs are quickly metabolized and eliminated, which increases the risk of false-negative results.

B. Postmortem Redistribution and Metabolite Interpretation

Post mortem redistribution is a major problem in fatal poisoning or suspicious death investigations. Drug levels following death could be very different from pre-death levels because drugs may diffuse from organs where their concentrations are high into the blood. Therefore, the toxicologist must consider the type of specimen and sampling site when interpreting the results of a postmortem. An equal amount of importance is placed on metabolite interpretation, since many drugs are extensively metabolised prior to excretion. The identification of characteristic metabolites confirms drug exposure, enables identification of parent compounds from

[10] F. Tariq, I. I. Iffi, K. Naheed, F. Sultana, and K. Mahmood, "Detection and Analysis of Common Substances Used in Drug-Facilitated Sexual Assault (DFSA). A Forensic Laboratory-Based Study," PJMHS, vol. 17, no. 6, pp. 569–572, 2023, doi: https://doi.org/10.53350/pjmhs2023176569.

degradation products, and provides information about the time of drug administration and the extent of drug exposure.[11]

C. Polydrug Exposure and Analytical Challenges

Often, a crime involving a drug involves taking more than one drug, such as taking alcohol with a prescription drug, illegal drugs, or novel psychoactive substances. The effects of these drugs when used together can be more sedative, respiratory depressed, cognitively impaired and can cause anterograde amnesia than any single drug individually. The interpretation of toxicological results is complicated by these pharmacodynamic interactions and low concentration of either of the drugs may lead to high degree of incapacitation. In addition, there is the fact that the number of designer drugs and synthetic analogues is constantly changing and that a wide range of drugs and metabolites need to be identified.[12]

D. Challenges in Evidential Interpretation

Timing and quality of specimen collection are important to toxicologic findings, as are the evidential values. Due to confusion, unconsciousness, or memory impairment, victims of DFC often don't report the incident until several hours or days later, when quickly expelled substances may have left the body. Result interpretation is further complicated by specimen degradation, inappropriate storage, contamination, individual metabolic variability, underlying medical condition and drug tolerance. Consequently, toxicological findings should never be evaluated in isolation but must be integrated with clinical records, investigative information, witness testimony, and other forensic evidence to provide scientifically sound and legally defensible conclusions regarding drug-facilitated criminal activity.

5 Forensic, Legal, and Ethical Challenges in Drug-Facilitated Crime Cases

Drug facilitated crime (DFCs) especially drug facilitated sexual assault (DFSA) involve various forensic, legal and ethical issues that are not limited to the laboratory. Case investigation and prosecution in India necessitates the proper application of scientific evidence and existing legal protocols along with ethics in medical practice. Forensic toxicology requires careful management of evidence, legally acceptable analytical methods and victim-focused

[11] G. M. M. Abdelaal, N. I. Hegazy, R. L. Etewa, and G. E. A. Elmesallamy, “Postmortem redistribution of drugs: a literature review,” Forensic Sci. Med. Pathol., vol. 20, no. 4, pp. 1483–1490, 2024, doi: 10.1007/s12024-023-00709-z.

[12] H. Manjón-prado, E. S. Santos, and E. Osuna, “Patterns of Polydrug Use in Patients Presenting at the Emergency Department with Acute Intoxication,” Toxics, pp. 1–13, 2025, doi: https://doi.org/10.3390/ toxics13050380.

investigative protocols, given that many drugs that can incapacitate an individual are metabolized quickly and victims may have memory loss or delayed reporting. Credibility of toxicological evidence will rely on the maintenance of scientific integrity and the protection of the rights, dignity and privacy of the person(s) involved.

A. Forensic Challenges

The primary forensics problem in DFC cases is the collection and preservation of biological evidence in a timely fashion. Samples must be obtained from blood, urine, oral fluid, and hair as early as possible, be properly labeled, sealed and preserved to ensure that they don't degrade or become contaminated. Evidence must be collected and maintained in an unbroken chain of custody to establish the authenticity and integrity of every piece of evidence from collection to analysis in the lab to presentation in court. The proper implementation of standard forensic procedures from the accredited forensic science laboratories and investigatory agencies is essential in India to meet the court's requirements to ensure that toxicological results will be accepted in court. Victim's failure to report, improper sample collection and the limited detection period for drugs like γ-hydroxybutyrate (GHB) often makes it hard to determine the presence of the causative drug, making forensic interpretation difficult.[13]

B. Legal Challenges

The scientific validity of the analytical method, the quality assurance and the expertise required to interpret the results are necessary for the legal admissibility of toxicological evidence. Forensic experts are called upon by Indian courts to delineate the pharmacological effects of the detected substances, limitations of the analysis and the relevance of the toxicological evidence to the alleged offence. The role of the expert witness in the case is then a critical one in assisting the court to understand the complex scientific evidence. The results of the toxicology test are not, however, sufficient to prove criminal liability and should be confirmed by medical evidence, witness statements, digital evidence or other circumstances. The Indian Evidence Act, 1872, the Bharatiya Sakshya Adhiniyam, 2023, and the procedural requirements under the Bharatiya Nagarik Suraksha Sanhita, 2023 highlight the significance of legally obtained, proper documentation and scientifically reliable evidence for prosecuting successfully.[14]

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[13] H. I. Thalib, A. A. Damanhory, A. H. Shaikh, S. Haidar, and S. Khan, “Forensic toxicology of benzodiazepines: neuropharmacological effects, analytical challenges, and emerging detection strategies,” Front. Toxicol., pp. 1–11, 2025, doi: 10.3389/ftox.2025.1639890.

[14] Mumtaj and R. D. Varma, “Cyber-Facilitated Drug Trafficking and Legal Challenges under Indian Law,” Int. J. Res. Publ. Rev., vol. 6, no. 11, pp. 1305–1319, 2025, doi: https://doi.org/10.55248/gengpi.06.1125.3860.

C. Ethical Challenges

Throughout the DFC process, there are ethical challenges that need to be considered, as victims may be physically and psychologically vulnerable. Informed consent of the victim must be obtained for collection of biological samples, while providing medical treatment for the victim is never deferred, if the victim can give consent. Confidentiality and protection of personal information is critical to ensure the victim's privacy and dignity, especially with respect to sexual offences. It is also important to avoid secondary victimization by conducting sensitive interviews and avoiding unnecessary repetition of questioning by investigators and healthcare providers. Moreover, there should be no speculation in medico-legal documentation, maintaining it to be objective, unbiased and evidence-based, reporting scientific findings accurately. Enhancing the co-ordination of multidisciplinary teams (MDTs) of forensic toxicologists, clinicians, police and judiciary is crucial in optimizing the quality of investigations and ensuring proper utilization of the forensic evidence in India for effective participation in the fair dispensation of justice.[15]

6 Emerging Trends and Future Directions in Forensic Toxicology

The rise in the complexity of drug-facilitated crimes (DFCs) has been fueled by the appearance of new psychoactive substances (NPSs), designer drugs and complex polydrug exposure, which has worked to advance forensic toxicology. Traditional targeted analysis is still essential, but contemporary forensic laboratories are now employing massively parallel analytical platforms that can detect known and new chemicals. To advance the investigation and prosecution of DFC cases in India, there is a need to develop the forensic toxicology scene technologically, by establishing standardized protocols and increasing the capacity of the laboratories.

A. Advances in Analytical Technologies

Recent advances in untargeted toxicological screening by untargeted high-resolution mass spectrometry (HRMS) have made it possible to detect hundreds of drugs, metabolites, and emerging psychoactive substances (EPASS) at once without a need for predefined target lists. To complement these efforts, metabolomics can be used to help identify endogenous metabolic changes that occur as a result of drug exposure, providing new opportunities to detect rapidly eliminated drug metabolites and better interpretation of toxicological data. As the illicit drug market evolves, expanding toxicology testing panels is becoming more critical, with an

[15] M. H. ANDREAE et al., "An ethical exploration of barriers to research on controlled drugs," HHS Public Access, vol. 16, no. 4, pp. 36–47, 2017, doi: 10.1080/15265161.2016.1145282.

increasing number of synthetic opioids, designer benzodiazepines, synthetic cannabinoids, and other NPS.[16]

B. Artificial Intelligence and Portable Technologies

Artificial intelligence (AI) and machine learning are becoming powerful tools to analyse complex toxicological data, discover unknown compounds, foresee metabolic pathways and help forensic scientists in interpreting analytical findings. Meanwhile, mobile analytical instruments such as handheld Raman and infrared spectrometers and portable mass spectrometers are improving in the field for drug analysis, and now allow for preliminary analysis at crime scenes. These technologies can complement laboratory testing but can also help to speed up investigative decision making and evidence gathering.[17]

C. Future Directions in the Indian Context

The future of forensic toxicology in India will rely on the development of the analytical capability of the forensic science laboratories, standardisation of the testing protocols at a national level, and strengthening of interaction between forensic toxicologist, doctors, police and judiciary. Continuous updating of toxicological databases, ongoing professional development, accreditation of laboratories, and investment in state-of-the-art analytical instrumentation are all critical components to respond to new threats from drugs. Furthermore, the scientific quality of toxicological evidence through integration of analytical platforms assisted by artificial intelligence with full toxicology screening will be improved, leading to better investigation, prosecution and prevention of drug facilitated crime in the country through multidisciplinary research.[18]

7 Conclusion

The role of forensic toxicology in the modern era of criminal investigations is an indispensable part of science as it aids in the identification and interpretation of toxic substances in a way that is scientifically sound and reliable. The development of analytical methods such as GC–MS,

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[16] N. G. S. Mogollon, C. D. Quiroz-moreno, P. S. Prata, J. R. De Almeida, A. Sof, and F. Augusto, "New Advances in Toxicological Forensic Analysis Using Mass Spectrometry Techniques," Hindawi J. Anal. Methods Chem., 2018, doi: https://doi.org/10.1155/2018/4142527.

[17] D. P. Dahiya, S. Bharti, C. Kumari, S. Sharma, and A. Sharma, "Recent Advancement in Pharmaceutical Analytical Techniques," Int. J. Creat. Res. Thoughts, vol. 12, no. 4, pp. 341–348, 2024.

[18] I. Parmar and Y. A. Patel, "Recent Method Development by Analytical Techniques of New FDA Approved Drugs in 2021," Int. J. Curr. Pharm. Res., vol. 14, no. 3, 2022, doi: https://dx.doi.org/10.22159/ijcpr.2022v14i3.1975.

LC–MS/MS, and HRMS has greatly contributed to the identification of conventional drugs, metabolites and novel psychoactive substances, thereby increasing the accuracy of forensic investigations. However, problems of fast drug clearance, late reporting, poly-drug exposure and the changing drug scene of synthetic drugs remain to be a source of difficulty in toxicological interpretation. Proper evidence collection, using a chain of custody, multidisciplinary collaboration, and legal and ethical standards are all important issues that must be addressed for effective investigation of DFCs. In India, enhancing forensic infrastructure, expanding toxicology screening panels, standardizing analytical procedures, and incorporating new technologies like AI and metabolomics will enhance the credibility and acceptance of toxicology evidence. Further research, professional training and technological development are needed to improve forensic toxicology and facilitate the effective investigation, prosecution and prevention of drug-facilitated crimes in the current complex forensic environment.

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