بسم الله الرحمن الرحیم

Modern Forensic Medicine: From Classical Toxicology to Genomic Precision

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Forensic medicine has long been at the intersection of science and ambiguity. A body is examined, samples are collected, chemicals are measured, and ultimately, conclusions must be drawn from all the data obtained. For decades, this process, based on autopsy findings and analytical toxicology, has formed the backbone of forensic research. However, many of the questions facing forensic scientists today go beyond what chemical detection alone can explain.

Toxicological emergencies continue to be a staple of forensic cases. Alcohols, pesticides, rodenticides, synthetic drugs, and emerging compounds continue to challenge forensic laboratories. Advances in high-resolution mass spectrometry and modern chromatography systems have greatly improved the ability to detect substances at very low concentrations (1). However, analytical sensitivity is no longer the primary limitation. Interpretation is.

Why does one individual die at a concentration considered “therapeutic,” while another is exposed to a higher concentration? Why do toxicological findings sometimes fail to fully explain the physiological collapse observed in one case? These discrepancies suggest that toxicological interpretation must consider more than chemical measurements.

Molecular detection offers an important step in this direction. Genetic variation in drug-metabolizing enzymes, ion channels, and other biological pathways can significantly influence individual responses to toxicant exposure. The integration of molecular information in forensic toxicology allows chemical findings to be interpreted within the biological context of the individual, rather than as discrete numerical values.

Next-generation sequencing (NGS) has accelerated this change. Beyond traditional STR profiling, NGS enables broader genomic analysis even when samples are limited or degraded (2, 3). This technology enhances the identification and interpretation of human admixture while also creating new opportunities to investigate the biological mechanisms underlying unexplained deaths.

A notable example is molecular autopsy. In cases of sudden unexplained death with inconclusive autopsy findings, genomic sequencing may identify inherited cardiac or metabolic disorders that would otherwise remain unknown (4). In such situations, the cause of death may not be observable during examination but may be encoded in the genome.

The integration of genomic technologies into forensic science requires rigorous validation, standardized analytical workflows, and responsible interpretation of complex data (5). However, these approaches are steadily expanding the interpretive power of forensic research.

As toxicological challenges become more complex, forensic science must move beyond diagnosis to a deeper biological understanding. The convergence of toxicology, molecular diagnostics, and genomic sequencing is gradually shaping a more precise and integrated future for forensic science.

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