

MORE THAN JUST A PROFILE: THE RISE OF EPIGENETICS IN MODERN FORENSICS

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Background: Recent advances in molecular biology have expanded the scope of forensic science far beyond traditional DNA profiling methods such as short tandem repeat analysis. One of the most important developments is the use of epigenetic biomarkers – particularly DNA methylation – which provides information that complements and extends classic genetic identification. DNA methylation refers to the addition of methyl groups to cytosine residues at CpG sites, and these patterns vary with age, lifestyle or tissue type making them highly informative in forensic contexts.

A major application is the identification of body fluids using tissue specific methylation signatures. These markers can also assist in interpreting mixed biological samples, which are often challenging for standard genetic approaches. DNA methylation analysis further enables the differentiation of monozygotic twins, who share identical DNA sequences but may exhibit distinct epigenetic profiles. Methylation based methods can also be used to determine biological sex from forensic traces.

Another key use is the estimation of epigenetic age, allowing investigators to infer an individual's age from biological material. Methylation patterns may also provide insights into lifestyle factors, phenotypic traits, biogeographical ancestry, and certain health conditions. Additionally, methylation signatures help determine tissue origin and sample age, offering valuable contextual information.

An increasingly important application is sample authentication, where methylation patterns help detect fabricated, contaminated, or altered biological evidence, thereby supporting the integrity of forensic analyses.

DNA methylation analysis is also applicable to ancient DNA. It enables estimation of age at death, reconstruction of past lifestyles, and investigation of evolutionary processes. By comparing methylation profiles across populations, researchers can identify adaptive traits and gain deeper insight into human evolutionary history.

Objective: The aim of this study is to provide a comprehensive review of contemporary applications of DNA methylation in forensic science, including identification, age estimation, tissue origin analysis and its emerging use in ancient DNA research.

Keywords: DNAMAge; Epigenetics; Methylations.