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The Advancement of Omics in Forensics Science: Unveiling Real and Current Cases

José L. Capelo[1,2,*]

[1](Bio)Chemistry & Omics, BIOSCOPE Research Group, LAQV-REQUIMTE, Department of Chemistry, NOVA School of Science and Technology, Universidade NOVA de Lisboa, 2829-516, Caparica, Portugal; [2]PROTEOMASS Scientific Society, Madan Parque, Rua dos Inventores, 2825-182 Caparica, Portugal

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In recent years, forensic science has undergone a profound transformation, driven by the integration of **omics sciences** - genomics, proteomics, metabolomics, transcriptomics, and other molecular approaches into the analysis of biological evidence. These advanced technologies are enabling unprecedented precision in identifying individuals, uncovering the circumstances surrounding deaths, and solving complex crimes that were once deemed unsolvable.

The growing application of omics analyses in forensic investigations is reshaping both the justice system and scientific understanding of biological traits. Real-world cases have demonstrated that omics can help to both incriminate the guilty and exonerate the innocent, illustrating its transformative potential.

What Are Omics Sciences?

Omics sciences involve the comprehensive study of biological systems at various molecular levels. **Genomics** focuses on the complete set of genes within an organism, while **proteomics** analyzes the full complement of proteins expressed in a biological sample.
Metabolomics and **transcriptomics** examine metabolites and RNA transcripts, respectively. By providing a multi-dimensional view of biological processes, these fields offer invaluable tools in forensic applications, where conventional methods may be limited or inconclusive.
Forensic omics can generate crucial data from tiny, degraded, or complex biological samples that are often present in crime scenes. For instance, where traditional DNA typing might fail due to sample degradation, newer omics approaches can reveal critical information through **mitochondrial DNA** (mtDNA) or **proteomic profiles**, even from bones or hair that have been damaged or aged [1].

Omics in Action: Real Cases of Justice and Revelation

Several high-profile cases around the world have demonstrated the power of omics in forensic science, both in bringing criminals to justice and in protecting the innocent.

1. The Golden State Killer: Solving a Cold Case with Genomic Genealogy

Perhaps one of the most famous cases showcasing the impact of omics in forensics is that of the **Golden State Killer**, a serial rapist and murderer active in California in the 1970s and 1980s. For decades, investigators were stymied by the lack of leads, even though DNA evidence had been collected from multiple crime scenes. The breakthrough came in 2018, when forensic scientists used **genomic genealogy**, an omics-based technique that compares crime scene DNA with publicly available genetic profiles from ancestry databases. By tracing familial matches through distant relatives, authorities were able to narrow down the search to **Joseph James DeAngelo**, who was subsequently arrested and convicted of multiple murders and assaults [2].

This case exemplifies the intersection of genomics and forensic genealogy, where millions of DNA profiles in

***Corresponding author:** José L. Capelo, jlcapelom@bioscopegrouporg, Tel: +351 919 404 933

ancestry databases can serve as powerful tools for solving crimes. However, it also raises ethical concerns about privacy and consent, given that relatives of suspects often do not consent to their data being used in criminal investigations.

2. Exoneration through DNA: The Case of Kirk Bloodsworth

On the other side of justice, omics technologies have also been instrumental in **exonerating the wrongfully convicted**. One of the first people to be freed from death row through DNA evidence was **Kirk Bloodsworth**, a former U.S. Marine who had been convicted of the 1984 rape and murder of a young girl. After serving nearly nine years in prison, including two on death row, Bloodsworth was exonerated when DNA testing - performed using samples that had been preserved - proved that he was not the perpetrator [3,4,5].

This case highlights the vital role of omics, specifically forensic DNA testing, in ensuring justice for the wrongly accused. It underscores the need for constant review and application of advanced omics methods in cases where evidence is preserved but initial forensic techniques were insufficient.

3. Identifying the Unknown: Proteomics in Historical Cases

In some historical cases, omics approaches like **proteomics** and **metabolomics** are becoming essential tools in identifying human remains. A recent case in the United Kingdom involved the use of **forensic proteomics** to analyze proteins from ancient skeletal remains. By studying the unique protein profiles in the bones, forensic scientists were able to provide key information about the deceased's identity, including age, sex, and even dietary habits, helping to resolve historical mysteries that had baffled investigators for decades [6].

This type of analysis is proving especially valuable in archaeological forensics and cold cases involving skeletonized remains, where traditional DNA extraction may no longer be possible. Proteomics can offer critical insights into post-mortem changes and degradation, supporting both modern and historical forensics.

4. The Death of Alexander Litvinenko: Metabolomics in Action

The high-profile case of **Alexander Litvinenko**, a former Russian spy who was poisoned in London in 2006, demonstrated the power of metabolomics in forensic toxicology. Litvinenko was poisoned with **polonium-210**, a radioactive isotope that is extremely difficult to detect using standard toxicological methods. However, forensic scientists were able to use a combination of metabolomics and radiological analyses to trace the rare isotope in Litvinenko's body and link the assassination to Russian operatives [7].

This case showcases how metabolomics can be employed to detect poisons, drugs, and other toxic substances that are either present in minuscule quantities or metabolized rapidly, eluding conventional testing. By analyzing metabolic changes and breakdown products, metabolomics offers a new dimension of forensic investigation, crucial for cases of poisoning or overdose.

Beyond DNA: Expanding the Forensic Toolkit with Proteomics and Metabolomics

While **DNA analysis** has been the gold standard in forensic science for the last few decades, **proteomics** and **metabolomics** are rapidly emerging as complementary techniques that expand the capabilities of forensic investigators. **Proteomics**, which studies the structure and function of proteins, is especially useful in identifying individuals from bone, hair, or other tissues that may no longer contain viable DNA. For instance, the analysis of keratin proteins from hair samples can provide clues about an individual's identity or history, such as exposure to certain chemicals or environmental factors [8].

Similarly, **metabolomics** - the study of small molecules, or metabolites, within a biological system - has found a niche in forensic toxicology and drug testing. In cases involving complex drug overdoses or poisonings, where traditional toxicology might fail to identify all substances, metabolomics can detect the subtle metabolic changes that result from drug or toxin exposure, helping to pinpoint the cause of death with higher accuracy [9,10].

Ethical Challenges and the Future of Omics in Forensics

Despite the immense potential of omics technologies in forensics, several challenges remain. One of the primary issues is the **complexity of data interpretation**. Omics analyses generate vast amounts of data, and interpreting this data in a legally sound manner can be challenging. Forensic omics results must not only be scientifically accurate but also clear enough to be understood in courtrooms by judges and juries who may lack a technical background.

Moreover, the **ethical implications** of using large genetic databases in criminal investigations cannot be ignored. The use of public genealogical data, as seen in the Golden State Killer case, raises concerns about **privacy** and **consent**. While the utility of these databases in solving crimes is undeniable, regulators and society at large must balance this with individuals' rights to privacy and protection from misuse of their genetic information [2].

Conclusion

Omics at the Forefront of Forensic Science

The integration of omics sciences - ranging from genomics to proteomics and metabolomics - into forensic science is revolutionizing the way we investigate crimes and deliver justice. From identifying individuals and uncovering hidden toxic substances to solving decades - old cold cases and exonerating the wrongfully accused, these technologies are pushing the boundaries of what is possible. However, as forensic omics continues to evolve, ethical and interpretative challenges must be carefully navigated to ensure that these powerful tools are used responsibly and effectively.

As the field advances, omics will likely become an indispensable component of forensic science, offering new insights and greater accuracy in the pursuit of truth. With ongoing technological innovations and interdisciplinary collaborations, forensic omics has the potential to solve some of the most challenging questions facing the justice system today.

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