All the evidence

The combination of molecular biology, zoology and botany in forensic science comes as a great help to crime investigators

Forensic science has recently gained a high profile worldwide, owing in part to publicity surrounding criminal cases in which advanced methods have been used to determine guilt or innocence, sometimes even overturning previous verdicts. In particular, advances in DNA sampling and testing have spawned powerful methods that police investigators increasingly rely on in serious crime cases. As DNA testing is not always sufficient—or relevant—to solve a crime, there has been equally impressive progress in other fields of forensic biology, notably entomology and palynology—pollen analysis.

As a result, criminal investigation and prosecution are being transformed. There is now so much confidence in forensic science that opponents of the death penalty in the USA had hoped to use DNA testing to demonstrate that an executed murderer was wrongly convicted, thus proving wrong the system of capital punishment. The case in question involved coal miner Roger Coleman, convicted and sentenced to death in 1982 for the murder of his wife's sister, Wanda McCoy. His articulate pleas of innocence while on death row sustained a vigorous worldwide campaign to clear him or at least to commute his sentence to life imprisonment.

In 1990, DNA testing was deemed to have reached the point where it could settle the matter, and a private laboratory, Forensic Science Associates (Richmond, CA, USA), was commissioned to analyse semen samples preserved from the crime scene. Polymerase chain reaction was used to target and amplify the DQA1 region in the human leukocyte antigen class II gene. This region has six alleles, making 21 possible genotypes that occur with varying probability in the human male population. The laboratory found that the DNA sample had the

same profile as Roger Coleman's DNA and that this was shared by 2% of the male population. This, combined with the existing evidence and Coleman's failure to pass a lie-detector test, was considered sufficient to confirm his guilt. Coleman was executed on 20 May 1992.

But with 2% of males sharing Coleman's DQA1 genotype, the DNA test was not sufficient to prove the case beyond all reasonable doubt, and over time the campaign mounted to re-test the sample with higher-precision techniques. Virginia Governor Mark R. Warner conceded to the pressure late in 2005 and ordered new tests, which were conducted by the Centre of Forensic Sciences in Toronto, Canada. The tests found a one in 19 million probability that the DNA sample came from an individual unrelated to Coleman, establishing his guilt even to the satisfaction of his supporters.

Today, forensic DNA analysis uses polymerase chain reaction to target highly polymorphic short tandem repeats (STRs) distributed throughout the genome, rather than singling out a particular region as was first done in Coleman's case. As these regions are independent of each other and the number of repeats varies between individuals, the probability of two individuals sharing the same profile of repeats decreases geometrically with the number of loci investigated.

If the STR analysis shows that a suspect's profile is clearly different from the profile of the sample, that person can be eliminated from the enquiry. But if not, the forensic scientist must calculate the probability that a random person would have an identical profile, using the rules of population genetics and simple statistics. Using the frequency in the general population of each allele found in the suspect's DNA, the Hardy–Weinberg

equation (Stern, 1943) determines the likelihood that a randomly selected person would share that genotype for that particular locus. The probability that any given individual would share the combined genotype of all STR loci—nine in the Coleman case—can be calculated from the product of all of the individual frequencies determined from the Hardy–Weinberg equation.

In the Coleman case, final tests found a one in 19 million chance of a random individual sharing the DNA profile, compared with one in 50 in some of the earlier tests. "This then is the weight that would be applied to the failure to exclude Roger Coleman as a source of the main donor swab from Wanda McCoy," said Ray Prime, Director of the Centre of Forensic Sciences. "Either he is the source of the semen or an extremely unlikely coincidence has occurred."

However, there remain legitimate concerns that human error could still lead to wrong convictions in cases where pivotal evidence comes from DNA profiling. Errors can result from contamination or degradation of the sample, which are problems because crime scenes do not provide ideal laboratory conditions. Modern techniques and procedures mitigate both of these concerns, according to Prime. "Degradation can result in a reduced amount of DNA being available for analysis and in some circumstances being undetectable," he said. "However, the sensitivity of modern techniques, combined with the robustness of the DNA molecule if stored correctly, means that older cases can be considered for re-examination."

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To deal with contamination, leading laboratories use strict quality-control protocols—such as the use of gloves, masks and gowns by staff—and design their environmental systems appropriately, similar to the clean-room techniques that are common practice in the biotechnology and micro-electronics industries. But additional measures may also be necessary, such as recording the DNA profiles of all personnel who might have access to samples, including police officers who attended the crime scene. Even with such precautions, samples will often comprise profiles from two or more individuals; improved sensitivity helps by weighing the relative strengths of the competing alleles to reconstruct each individual profile. Although this might produce ambiguities, other methods can be used to derive the profiles of the individuals confidently enough for comparisons to be made—providing enough STR loci are analysed.

procedures and the legal framework, rather than as an isolated scientific procedure. Benecke cited a German murder case, involving a mother and child found dead in the living room of their house in Cologne on 30 January 2001, in which both of these integrative dimensions featured prominently (Benecke & Barksdale, 2003). One legal requirement was the need to know which of the victims died first, to establish rights of inheritance. The defence lawyer also wanted proof that his client had stabbed the child with brutal force, which would indicate a loss of mental faculties.

DNA typing was first used to establish that several bloodstains in the house originated from the two victims. Attention then focused on a bloodstained lamp hanging from the living-room ceiling. The investigators used blood-spatter analysis to determine whether blood on the lamp resulted directly from the murder, or was carried there by flies

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when working as a forensic consultant for the city of New York. He bought meat from local butchers to study how long it took insect larvae to develop and grow—experiments that did not make him popular with his colleagues.

However, recent developments have proven Benecke right. The power and scope of entomological analysis has increased significantly beyond its traditional role in assessing the time of death, according to Lee Goff, Chair of the Forensic Science Program at Chaminade University of Honolulu (HI, USA). "We have used insects, not only for

Despite its increased power, DNA profiling is often not enough. "Wrongful convictions can only be made if DNA is looked upon as the only evidence," noted Mark Benecke, one of Europe's leading consultant forensic biologists, based in Cologne, Germany. According to Benecke, the integration of different sources of forensic evidence and their combination with investigative and legal procedures are even more significant than progress in any single field, such as DNA testing.

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First, different sources of forensic evidence can be combined. This happens frequently with DNA profiling and entomology, with the latter often used to ascertain the time of death. Second, forensic techniques must operate in the context of investigative

feeding on blood around the victims. DNA profiling showed that some of the stains on the lamp did contain blood from the child but not the mother, while the entomologist considered that, as it was winter, it was improbable that flies had found their way to the scene that quickly. Furthermore, the spots were distributed evenly across the lamp. This suggested that it had been spinning during the struggle and that the blood had struck it as the offender extracted the knife from the child's vertebrae.

According to Benecke, such cases highlight an eternal maxim of criminal investigation, namely to collect as much evidence as possible while it is still fresh. In future cases involving violence or death, it should become routine not only to assess possible DNA evidence, but also to look for insects in the vicinity and consider contacting a forensic entomologist. In fact, after noting that entomology was largely neglected in forensic science, Benecke trained himself in the field, first while studying at the University of Cologne and later

the estimation of a minimum post-mortem interval, but also to provide clues to post-mortem movement of a body, assessment of wounds, and cases of abuse and/or neglect of children and the elderly," he said.

Insects are an alternative source of human DNA, if they feed on corpses or blood. Another emerging role has been in toxicological analysis. In one recent case, two distinct classes of maggot were found in a dead body, with the more mature of the two indicating a post-mortem interval long enough to exonerate a suspect. But those specimens had been obtained from the nose, where high levels of cocaine had accelerated their growth; the less mature specimens from elsewhere in the body gave a more reliable estimate. Goff emphasized that the analysis of insects is not an exact science, as their development depends on environmental conditions. Nevertheless, entomology remains under-exploited and has unexplored potential, particularly in combination with DNA analysis, according to Allan Barton, Associate Professor of Chemistry at Murdoch University in Western Australia,

which has a course in forensic biology and toxicology. Forensic entomology is potentially useful in cases of child neglect (Benecke & Lessig, 2001) and neglect of the elderly (Benecke *et al*, 2004), in addition to cases of fraud.

Similarly, palynology, the analysis of pollen and spores in criminal investigations, can complement forensic DNA by either proving or disproving that people or objects were in a particular place in a certain time-frame. In some cases, pollen evidence can link a person with a precise location, although more often it may be a broad region covering many square kilometres. Although it is reported to have been used as early as 1959, palynology first came to public prominence by its absence in the double-murder trial of O.J. Simpson in 1995. Testimony suggested that the murderer probably hid in the bushes outside the Simpson home, in which case pollen from nearby flowers could have brushed off on the assailant's clothing. If this had been discovered and tested, a pollen fingerprint might have helped to establish Simpson's innocence or guilt. He was acquitted in 1995, although he was later found liable in a civil trial.

Palynology was used in another infamous case involving a boy—christened Adam by UK police—whose torso was found in the Thames River in London in September 2001. Although the boy was found in a body bag without head, arms or legs, his African origin suggested that he might have been the victim of a ritual killing. The first clues came from analysing the pollen contents of the boy's digestive tract. Spores from plants like alder—common in the UK—were found in the lower intestine, suggesting that Adam had been in the country for at least three days. This started a large-scale investigation, and subsequent analysis of Adam's mitochondrial DNA and the mineral content of his bones led police towards his origins in Nigeria. So far, his killer has not been identified.

Similar to entomology, forensic pollen analysis involves carefully sifting through evidence, as the nature of the pollen and its method of dispersal are important factors. One particular strength of palynology is that it can associate objects and people with places. It has been used, for example, to identify fake paintings. Dirt and dust trapped between a picture frame and canvas contain pollen and spores that accumulate while the picture is being painted and indicate where this took place. If this is a location where the

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artist was known to not have been at the time, it suggests the work is a fake.

At present, forensic entomology and palynology are mainly confined to serious crimes in which death has occurred. In the case of DNA analysis, cost and lengthy testing times have also confined its application to serious crimes. But for DNA this could change soon. "These techniques are likely to shift down to general property crime," said Barton, assuming that the police want to investigate such crimes thoroughly.

This requires more people trained in forensic science. Although there has been a recent boom in the number of both forensic-science undergraduate courses and students, doubts persist whether these courses produce people with the combination of scientific, legal and investigative skills required by police forces and testing laboratories, or to become a consultant. "These graduates are often trained as chemists with forensic science as an attractive and popular alibi," said Pierre Margot, director of the School of Criminal Sciences at the University of Lausanne, Switzerland. He contends that it is counterproductive to dress chemistry up in trendy clothes to attract young people into science. Instead, forensic courses should be

multidisciplinary, albeit with chemistry and biology having an important role.

At Murdoch University, students are encouraged to take double or even triple degrees combining two science majors, such as biomedical science and molecular biology with a minor in criminology, Barton explained. According to Olivia Corcoran, senior lecturer in forensics at the University of East London, UK, good forensic-science graduates will find a growing range of job opportunities outside pure science: "With good analytical skills, graduates can apply to pharmaceuticals, food industry labs, consumer watchdog associations, and so on." Although the allure of high-profile criminal cases makes forensic-science courses attractive, the bulk of the field will lie in the realm of less serious crimes or other analytical applications.

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Bioethics for the world

UNESCO's Universal Declaration on Bioethics and Human Rights has far-reaching goals, and has met with widespread opposition

In 2003, the member states of the United Nations Educational, Scientific and Cultural Organization (UNESCO; Paris, France), which bills itself as a 'laboratory of ideas' and a 'standard-setter', decided to develop a global statement on bioethics. After only two years of negotiations, the participating committees presented the final Universal Declaration on Bioethics and Human Rights (UDBHR) to UNESCO's General Assembly for approval (UNESCO, 2005). The first such document to set global standards in biological and

medical ethics, the Declaration has met with opposition and displeasure, particularly as it merges bioethics with human rights—topics that some would prefer to consider separately.

Many ethicists, particularly from southern-hemisphere countries, consider the UDBHR to be an important document that will upgrade the quality of research globally and promote high ethical standards in many nations where no standards exist at present. But many critics think that the Declaration is at best a toothless