Anything you touch may be used against you

Technical improvements in forensic biology make it increasingly hard for criminals to elude prosecution

Philip Hunter

The perfect crime is increasingly hard to commit; almost any crime that involves physical contact inevitably leaves traces from which forensic laboratories can gather information. The jackpot for law enforcers is biological material, such as hairs or cells, that forensic scientists use to establish the DNA profile of the suspect. Once a high-tech tool used mainly in serious criminal investigations, recent technological improvements and decreasing costs now make DNA profiling possible for offences less serious than murder or sexual assault. The same is true for forensic science involving entomology. Knowledge of insect behaviour and life cycles is now used in an increasing range of criminal investigations, including child abuse and neglect or murder, where entomology can help to identify the time of death.

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But it is the use of DNA profiling that raises the greatest public concern in regard to its accuracy, ethical use and impact on privacy. It is increasingly possible to obtain DNA profiles from ever-smaller samples such as fingerprints on glass or on clothing—essentially, anything that contains a few epidermal cells. Yet, this increasing utility also stokes fears about errors that could lead to wrongful convictions—after all, DNA profiling was adopted because it was supposed to provide more reliable links between

suspects and crime scenes than other forms of evidence.

There are hints that the use of DNA evidence might be reined in, albeit temporarily. Some experts believe that it is now time to take stock and ensure that DNA profiling meets the fundamental rule for evidence used to convict criminals—that it is correct beyond all reasonable doubt—before further extending its use. In fact, the field faces a test case later this year when the Australian High Court hears the appeal of Benjamin Forbes against his conviction for sexual assault, which was based on DNA evidence as the victim was unable to identify her attacker. The appeal was inspired partly by an earlier Australian case, when a 22-year-old man was eventually freed in December 2009. It turned out that he had been wrongly convicted of rape in 2006 based on DNA evidence that turned out to be seriously flawed. This led Forbes' council to argue that conviction based on DNA evidence alone was unsafe for various reasons, such as incorrect procedures being followed or the prospect that future improvements in technology would shed a different light on it.

The Forbes appeal coincided with a paper published by the Australian Institute of Criminology, which stated that DNA evidence made convictions 33 times more likely in sexual assault cases (Australian Institute of Criminology, 2010). The paper also found that jurors were generally more likely to convict based on DNA evidence even though they often did not understand the science involved. The authors even suggested that the safety of these verdicts might be compromised by widespread misconceptions about the infallibility of DNA evidence by jurors who are "overawed by

the scientific garb in which the evidence is presented and attach greater weight to it than it is capable of bearing." If successful, Forbes' appeal could have a profound impact on the use of DNA evidence in court if jurors lose confidence in its infallibility. But the setback is likely to be only temporary, and might lead to greater discrimination in the application of DNA evidence.

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The controversy has arisen partly out of confusion between the use of DNA profiling as an investigative tool and as evidence in court. Its power as an investigative tool continues to increase, but its reliability as evidence will always vary depending on the exact nature of the DNA profile obtained and the state of the sample from which it was derived. The very fact that it is possible to obtain DNA profiles from degraded samples means that there are borderline cases in which the accuracy of DNA profiles is doubtful.

Forensic DNA profiling dates back to 1984, when Alec Jeffreys reported the potential to exploit individual variations in the number of copies of short tandem repeats (STRs) typically found inside the noncoding regions within genes (Jeffreys *et al*, 1984). Today, DNA profiles are usually obtained from STRs between 3 and 5 bases long that exhibit great individual variation.

The polymorphism at each individual loci is usually quite common, occurring in 5–20% of individuals, but the assumption is made that they are independent of each other. Therefore the probability of two individuals sharing multiple polymorphisms is small.

Many countries have since established forensic databases of DNA profiles from convicted criminals and suspects, with varying rules over collection and retention. There are also differences in the STR loci used: the North American Combined DNA Index System (CODIS) uses 13 loci, while the European Network of Forensic Science Institutes (ENFSI) initially decided on a European Standard Set of seven loci. However, there are some common loci used across most if not all DNA profiles around the world, along with initiatives to increase the number used and to establish standards for international cooperation to fight terrorism and global crime.

Having more loci increases the statistical power of DNA matching as a tool and decreases the chance of suspects being falsely identified. But other factors play a role too, notably the state of the sample. The older and more degraded the biological material is, the less loci can be amplified and the higher the risk of laboratory error. In such cases, the actual probability of a match between the partial DNA profile and an entry in a DNA database is a matter of intelligent guesswork; in fact this is the reason why the Forbes case was appealed.

There is also considerable risk arising from basic laboratory errors, as the hunt for the elusive ‘phantom of Heilbronn’ demonstrated. For years, German, French and Austrian police investigators pursued a female suspect who, according to DNA evidence, had committed dozens of crimes and several murders over the course of 14 years including shooting two police officers in Heilbronn in 2007. Eventually, however, they discovered that the DNA profile retrieved from 40 crime scenes in three countries actually came from an employee of the Austrian company that produced the swabs police used to take samples at the crime scenes.

When it comes to detective work, improvements in protocols combined with the ability to obtain partial profiles from small and degraded samples are having a huge impact, according to Reinhard Schmid, head of Biometric Identification at the Austrian Federal

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Ministry of the Interior. Particular progress has been made with previously unsolvable ‘cold cases’ in which DNA samples now provide clues to the suspect’s identity that can be followed up by traditional detective work. “The cold case hit rate obtained with DNA has reached 93%,” Schmid said. “That means that without using DNA analyses and the DNA database, 93% of those cold

crimes could not have been solved because there was no link to a possible offender after the crime had been committed. In each case DNA analyses provided objective evidence—often leading to [the] release of innocent suspects.”

But care must be taken, cautioned Ate Kloosterman, Professor of Biometrics at the University of Amsterdam and senior forensic scientist at the Netherlands Forensic Institute. The DNA samples used to thaw cold cases are derived from samples taken at the time, often not based on the latest protocols to collect evidence without contamination from crime scenes. This increases the risk of contamination with DNA of innocent parties, such as investigators at the crime

scene. Moreover, it is not only old cases that are reopened, but DNA profiles are increasingly used for less serious offences where no other evidence is available. "We use DNA analyses more and more also to solve 'low-threshold' crimes," Schmid said.

This extension of the use of DNA forensics to less serious crimes has been made possible by the development of faster automated techniques for deriving DNA profiles from samples, which is helpful for investigating crimes such as car thefts and burglaries. "In these high volume crime cases, you get lots of matches in the DNA databases, so robotic techniques are essential," Kloosterman explained.

The ability to extract DNA profiles from microscopic samples is also increasing detection rates for some crimes that do not involve breaking or entering, such as skimming—reading the magnetic strips of bank cards. Skimming is happening increasingly at automated cash machines through a combination of an electronic device attached to the card reader and a pinhole camera to read the Personal Identification Number (PIN). DNA matches obtained from microscopic samples left by the criminals at the machines are now leading to successful convictions, despite the difficulty in differentiating their profiles from those of legitimate users of the machines. "It is difficult to separate the profile of the criminal, but when you link profiles from many machines together it can stand out," Kloosterman said. Either the criminal might leave traces on several machines, or the profile would be held on a DNA database if that person had previously offended while the profiles of innocent users would not be held on the database.

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In fact, although governments and law enforcement agencies might like to have DNA profiles of the whole population on databases, this would actually complicate the process of finding significant matches that lead to arrest and the ultimate conviction of suspects, according to Kloosterman.

There would just be too many false positives, with almost every sample leading to a match in the database. "DNA databases are most efficient when they include just people who have committed crimes," said Kloosterman, who also argued that storing profiles of the whole population would increase the risk of innocent people being arrested or caught up in terrorist investigations.

Although DNA databases are no use for catching first-time criminals, DNA samples still have great potential to yield other information about the criminal, for example ethnicity and appearance. This potential has been explored in recent research that identified key genes whose alleles play a major role in determining physical traits such as eye, skin and hair colour (Valenzuela *et al*, 2010). The researchers showed that allelic values can be combined to generate visual profiles of suspects that could be used in the same way as "identikit" images produced from the descriptions given by witnesses. "Our results show that it is possible to predict what a person looks like from a DNA sample. This will be a useful investigational tool in the absence of a CODIS (North American DNA database) match," commented Murray Brilliant, corresponding author of the study, now at the Center for Human Genetics at the Marshfield Clinic Research Foundation (Wisconsin, USA).

Of course, this sort of use would raise legal, ethical and logistical obstacles. There is also the risk that DNA profiles would be used to generate images from innocent parties who happened to have left traces at the scene of the crime. For this reason the approach is unlikely to be adopted at present, according to Schmid: "We won't be following this up at present [in Austria], because the possible lines of enquiry would be too uncertain for secure investigative work."

Meanwhile, there is further scope for tackling organized crime and terrorism through greater international cooperation between and integration of national DNA databases. Interpol has already established an international database, and various European countries have linked their own databases within the so-called Prüm Treaty. This agreement was initially signed in May 2005 by Belgium, Germany, Spain, France, Luxembourg, the Netherlands and Austria—and has since been adopted by the EU's 27 member states—to open their police databases for cross-border access. However,

this is not unfettered access: while the treaty gives each state the ability to determine whether another's DNA database contains a match for a given sample, it does not automatically allow the details of this match to be divulged. Full access is therefore agreed either on an individual case basis or through bilateral agreements between countries. But already such agreements are enabling many more crimes involving international activity to be solved, according to Kloosterman.

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The growing application of DNA profiling is also creating the need for additional skills and knowledge across the spectrum of criminal investigation, from judges and juries to the laboratories themselves. But the impact is felt most at the scene of the crime itself, where a moment's carelessness can jeopardize this vital source of evidence. "It is crucial not just to have contamination free laboratories and procedures, but it all starts at the beginning with the police first on the scene taking the samples," Kloosterman explained. "They have to be even more careful than ever with DNA now that it only takes a few cells to obtain a profile."

The other major application of biology to forensic science is entomology, which has long been regarded as a completely separate field of study. However, recent developments have put it on a more molecular footing, further increasing its scope as a tool for forensic investigation. "Recently, molecular research in the field has expanded beyond species identification," commented Jeffery Tomberlin, an assistant professor at the Texas A&M University in College Station, USA. "Population genetic analyses of blow fly species are appearing in the literature. This sort of information will be extremely useful as there is also mounting evidence that different blow fly populations develop at different rates. Further, there are some research projects devoted to understanding the use of molecular markers of development to improve the precision of PMI (Post Mortem Interval) estimates with blow flies."

Forensic entomology has different applications from DNA profiling, but can complement it in murder investigations. The former might help identify the suspect, while the latter can be used to identify the time of death based on the developmental stage of, for example, blow fly maggots. Similarly to DNA profiling, forensic entomology is now being applied across an increasing range of cases, including neglect, where it can establish that wounds have not been cared for by analysing the remains of insects in the wound area.

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In turn, forensic applications are having a growing impact on the course of entomological research, according to Mark Benecke, an independent forensic consultant in Cologne, Germany. "There are much improved mathematical models now, and tons of experiments carried out by students that give us much better insight into the diversity of habitats, so that in court we can give much better replies to questions about possible errors in the evidence for example," Benecke said. "Also, in my case, I find the police seem to like the stuff, and there is just a generally heightened interest in sending in entomological evidence from the crime scene, even if it is just a wing."

While DNA profiling largely dominates the headlines, forensic entomology has made some notable achievements too, according to Adriana Oliva from the Laboratorio de Entomología forense, Museo Argentino de Ciencias Naturales, in Buenos Aires, Argentina. "In 1994 there was a resonant case where a conscript was killed and the Army tried to hush the thing up," he said. "My expertise showed that the death had occurred much earlier than they claimed. Public indignation resulting from this case led eventually to the abolition of compulsive military service in Argentina."

Yet, while forensic entomology and DNA profiling can be combined in single investigations, they have radically different skills bases. "Forensic biology and forensic entomology are very different," said Gail Anderson, director of undergraduate programmes at the School

of Criminology at Simon Fraser University in Vancouver, Canada. "In today's forensic world, forensic biology really means DNA, and you just need a BSc honours in molecular biology or biochemistry to be taken on by a lab and then trained there. There are then a good number of jobs, but a million kids who want them. Almost all forensic entomologists, however, are not solely [forensic scientists], but [are] also university professors who do these cases on the side as police consultants. There are presently 16 of us Board certified in North America, including two in Canada, so there are very few jobs there."

Nevertheless, there is a growing sense that forensic skills in general are seeing wider applicability, as they involve the judgement and evaluation of different and conflicting sources of evidence, according to Tomberlin. "We are finding our graduates

can apply forensic skills anywhere from the courtroom to the boardroom," he said. "We teach critical thinking skills and how to evaluate information as presented, which can be applied to making processes more efficient, or developing a product, as well as to solving crimes."

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Philip Hunter is a freelance journalist in London, UK.

EMBO reports (2010) **11**, 424–427.
 doi:10.1038/embo.2010.68

History in a single hair

Museums are treasure troves of ancient DNA. Modern extraction and sequencing technology is key to putting the secrets of genetic history to use

Howard Wolinsky

When strolling through museums, his own included, Kristofer Helgen, curator of mammals at the Smithsonian's National Museum of Natural History (Washington, DC, USA), said he is often shocked by the state of some specimens. "I see glaring holes or really major pieces sawn out of bones over the last 10 or 15 years by scientists who were trying to extract DNA out of bone," said the mammalogist, who oversees one of the world's largest collections comprising about 600,000 specimens of skins, skulls and skeletons from extinct animals.

However, new sequencing technologies and new techniques for collecting DNA from ancient specimens now mean that far less material is needed—only a few milligrams or less. "As curator, part of my job is to protect our specimens. Another part is making our collection available for research," Helgen said. "With the changes in methods, we're getting more out of less. Although this type of sampling is called 'destructive,' it doesn't

have to be very destructive at all." Destructive or not, the convergence of new sequencing and sampling technologies and the availability of more samples from museums have advanced palaeontology and the emerging field of palaeogenomics. The knowledge of ancient genes is helping researchers to understand the fate of extinct animals and to analyse the function of specific genes and their evolution over time. Some scientists are already speculating about putting together the genome of extinct species as a first step to reviving animals such as the mammoth or the Tasmanian tiger.

One of the biggest breakthroughs in recent years has been the discovery that hair samples, once considered useless in terms of DNA, are in fact a rich source of mitochondrial DNA (mtDNA). Stephan Schuster, Professor of Biochemistry and Molecular Biology at Pennsylvania State University (USA) and Eske Willerslev's group at the Centre of Excellence in GeoGenetics