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When Science Takes the Witness Stand

In courts of law, forensic testimony often goes unchallenged by a scientifically naive legal community. Forensic methods must be screened with greater care if justice is to be served

by Peter J. Neufeld and Neville Colman

In the early evening of November 21, 1974, powerful bombs ripped through two pubs in the industrial city of Birmingham, England, leaving 21 dead and 162 injured. The government immediately blamed the Irish Republican Army for the attacks and mounted a massive search for the perpetrators. After a railroad clerk reported that six Irishmen had boarded a train in Birmingham minutes before the first bomb blast, police intercepted the men as they disembarked at the port of Heysham. The six men were taken to the police station, and there, their hands were swabbed with chemicals that would reveal the presence of any nitrites, which would be consistent with the recent handling of explosives. The forensic scientist who performed this procedure, known as the Greiss test, reported positive findings on the right hands of two of the six suspects. That evidence became the linchpin of the government's successful prosecution of the "Birmingham Six."

Now, 16 years later, the six men may be released. The Greiss test, on which their convictions had been largely based, has proved unreliable. It turns out that a variety of common substances such as old playing cards, cigarette packages, lacquer and aerosol spray will, along with explosives, yield a positive result. As it happened, the six men had spent most of their train ride to Heysham playing cards and smoking cigarettes.

The Birmingham case raises troubling issues about the application of forensic technology to criminal investigations. Since the discovery of fingerprinting at the turn of this century, science has assumed an increasingly powerful role in the execution of justice. Indeed, scientific testimony is often the deciding factor for the judicial resolution of civil and criminal cases. The scientific analysis of fingerprints, blood, semen, shreds of clothing, hair, weapons, tire treads and other physical evidence left at the scene of a crime can seem more compelling to a jury than the testimony of eyewitnesses. As one juror put it after a recent trial in Queens, N.Y., "You can't argue with science."

Scientists generally welcome this trend. Because the scientific community polices scientific research, subjecting new theories and findings to peer review and independent verification, it is often assumed the same standards prevail when science is applied to the fact-finding process in a judicial trial. But in reality such controls are absent in a court of law. Instead nonscientists—lawyers, judges and jurors—are called on to evaluate critically the competence of a scientific witness. Frequently lawyers are oblivious of potential flaws in a scientific method or argument and so fail to challenge it. At other times, the adversaries in a case will present opposing expert opinions, leaving it up to a jury of laypersons to decide the merits of the scientific arguments.

The disjunction between scientific and judicial standards of evidence has allowed novel forensic methods to be used in criminal trials prematurely or without verification. The problem has become painfully apparent in the case of forensic DNA profiling, a recent technique that in theory can identify an individual from his or her DNA with a high degree of certainty. Although

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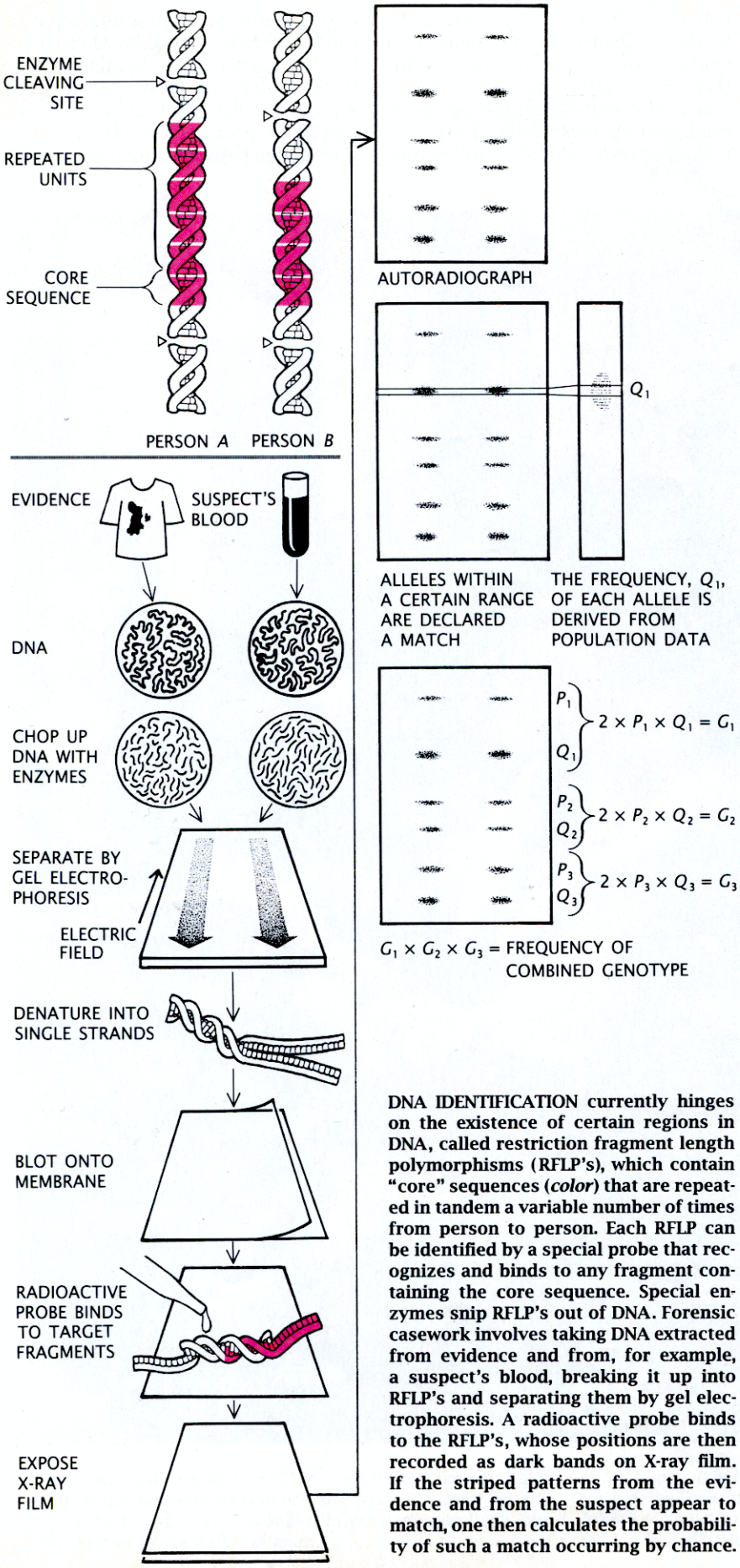
many aspects of forensic DNA identification have not been adequately examined by the scientific community, police and prosecutors have carried out DNA analysis in more than 1,000 criminal investigations in the U.S. since 1987. Few of these cases reached trial. In most instances, defendants pleaded guilty on advice of counsel after a presumably infallible DNA test declared a match.

Several recent cases have raised serious reservations about the claims made for DNA evidence. Last spring, during a pretrial hearing in *People v. Castro* in New York City, Michael L. Baird of Lifecodes Corporation in Valhalla, N.Y., one of the two major commercial forensic DNA laboratories in the U.S., reported the odds of a random match between a bloodstain and

EXPERT WITNESS Lorraine Flaherty, a molecular geneticist at the New York State Department of Health, testifies on DNA analysis during last year's pretrial hearing of *People v. Castro.* Bronx County Supreme Court Justice Gerald Sheindlin later ruled against admitting key DNA evidence into the double-murder trial. The case was the first to examine thoroughly—and challenge successfully—DNA tests, which had already been used to obtain convictions in hundreds of earlier trials.



DNA IDENTIFICATION currently hinges on the existence of certain regions in DNA, called restriction fragment length polymorphisms (RFLP's), which contain "core" sequences (*color*) that are repeated in tandem a variable number of times from person to person. Each RFLP can be identified by a special probe that recognizes and binds to any fragment containing the core sequence. Special enzymes snip RFLP's out of DNA. Forensic casework involves taking DNA extracted from evidence and from, for example, a suspect's blood, breaking it up into RFLP's and separating them by gel electrophoresis. A radioactive probe binds to the RFLP's, whose positions are then recorded as dark bands on X-ray film. If the striped patterns from the evidence and from the suspect appear to match, one then calculates the probability of such a match occurring by chance.

the suspect at one in 100 million. Eric S. Lander of Harvard University and the Massachusetts Institute of Technology examined the same data and arrived at odds of one in 24. Ultimately, several proponents of DNA testing denounced Lifecodes' data in the case as scientifically unreliable. Some of Lifecodes' key methods were repudiated, casting doubt on the integrity of hundreds of earlier criminal convictions. The ongoing debate over DNA testing underscores the need to deal more effectively with the difficulties that arise whenever complex scientific technology is introduced as evidence in a court of law.

A trial is ideally a search for truth. To help juries in their quest, the law allows qualified experts to testify and express opinions on matters in which they are professionally trained. Yet the esoteric nature of an expert's opinions, together with the jargon and the expert's scholarly credentials, may cast an aura of infallibility over his or her testimony. Hence, to prevent juries from being influenced by questionable evidence or expert testimony, U.S. courts usually review the material in a pretrial hearing or outside the presence of the jury.

To be admitted as evidence, a forensic test should, as a matter of common sense, satisfy three criteria: the underlying scientific theory must be considered valid by the scientific community; the technique itself must be known to be reliable; and the technique must be shown to have been properly applied in the particular case.

The expression of common sense in a court of law, however, is at times elusive. A majority of U.S. courts decide on the admissibility of scientific evidence based on guidelines established in 1923 by *Frye v. U.S.*, in which the Court of Appeals for the District of Columbia affirmed a lower court's decision to exclude evidence derived from a precursor of the polygraph. "Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define," the court declared in *Frye*. "Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs."

Judges, scientists, lawyers and legal

scholars have all criticized the *Frye* standard. Some say it is too vague. Some argue that it is unduly restrictive. Still others complain that it is not restrictive enough. Should "general acceptance," for example, require a consensus or a simple majority of scientists? Also, what is it that must be generally accepted? In the case of DNA profiling, is it the theory that no two individuals, except for identical twins, have the same DNA? Is it the various techniques employed in the test, such as Southern blotting and gel electrophoresis? Or is it the specific application of DNA profiling to dried blood and semen samples recovered from the scene of a crime?

Furthermore, what is the appropriate "particular field" in which a technique must be accepted? Does a test for DNA profiling have to be accepted only by forensic serologists, or must it also be recognized by the broader community of human geneticists, hematologists and biochemists? In a recent California case, DNA evidence analyzed by means of the polymerase chain reaction (PCR) was excluded because that method was not generally accepted by forensic scientists. Yet several months earlier a Texas court that was evaluating the identical PCR method looked more broadly to the opinions of molecular biologists and human geneticists and reached the opposite conclusion.

For many applications of science to forensics, the underlying theory is well established, and legal debate rages mainly over whether one must prove only that a technique is generally accepted for scientific research or, more strictly, that the technique is reliable when applied to forensics.

Why the distinction between nonforensic and forensic applications? Scientists commonly accept that when any technology is tried in a different application, such as forensics, it must be tested thoroughly to ensure an empirical understanding of the technique's usefulness and limitations. Indeed, many a technique that has proved reliable for research—polygraphy, for example—has turned out to be of questionable reliability when applied to forensic casework.

Clearly, in order for the courts to evaluate forensic evidence, judges and lawyers must be able to appreciate the scientific issues at hand. Regrettably, lawyers rarely do more than review the qualifications of the expert (typically based on perfunctory queries about institutional affiliation and publications) and verify the facts on which the expert's conclusions are based. The reason for this limited inquiry is simple: most lawyers and judges lack the adequate scientific background to argue or decide the admissibility of expert testimony. Often judges think—mistakenly, in our opinion—that justice is best served by admitting expert testimony into evidence and deferring to the jury for the determination of its weight.

The problem of scientific illiteracy is compounded by the tendency of judges to refuse to reconsider the validity of a particular kind of scientific evidence once it has been accepted by another judge in an earlier case. This practice is founded on the well-recognized need to respect precedent in order to ensure the uniform administration of justice. But in the case of forensic tests, the frequent failure of courts to take a fresh look at the underlying science has been responsible for many a miscarriage of justice.

Perhaps the most notorious example of the problem is the so-called paraffin test (a cousin of the Greiss test employed in the Birmingham Six investigation), which was used by crime laboratories throughout the U.S. to detect nitrite and nitrate residues, presumably from gunpowder, on suspects' hands to show that they had recently fired a gun. The test was first admitted as scientific evidence in a 1936 trial in Pennsylvania. Other states then simply adopted that decision without independently scrutinizing the research.

For the next 25 years innumerable people were convicted with the help of this test. It was not until the mid-1960's that a comprehensive scientific study revealed damning flaws in the paraffin test. In particular, the test gave an unacceptably high number of false positives: substances other than gunpowder that gave a positive reading included urine, tobacco, tobacco ash, fertilizer and colored fingernail polish. In this instance the legal process failed, allowing people accused of crimes to be convicted on evidence that later proved to be worthless.

More recently the debate over scientific courtroom evidence has centered on two applications of biotechnology: protein-marker analysis and DNA identification. Both techniques employ gel electrophoresis to reveal genetic differences, called polymorphisms, in blood proteins and DNA. These two techniques can potentially match blood, semen or other such evidence found at a crime scene to a suspect or victim.

In the late 1960's crime laboratories became interested in protein polymorphisms in populations. The techniques for studying protein polymorphisms were originally developed as tools for population geneticists and were experimentally tested, published in refereed journals and independently verified. The techniques were then modified by and for law-enforcement personnel in order to cope with problems unique to forensic samples, such as their often limited quantity, their unknown age and the presence of unidentified contaminants. These modifications were rarely published in the scientific literature or validated by independent workers.

For example, molecular geneticists study polymorphic proteins in red blood cells and serum by using fresh, liquid blood and analyzing it under controlled laboratory conditions, all subject to scientific peer review. These techniques were then adapted for use on forensic samples of dried blood by the introduction of various modifications, few of which were subjected to comparable scientific scrutiny. No one ever adequately explored the effects of environmental insults to samples, such as heat, humidity, temperature and light. Neither did anyone verify the claim that forensic samples would not be affected significantly by microbes and unknown substances typically found on streets or in carpets.

One of the major modifications made by forensic laboratories was the "multisystem" test. In the original version of this test, three different polymorphic proteins were identified in a single procedure; the purpose was to derive as much information as possible from a small sample. The three-marker multisystem test was further modified by the addition of a fourth protein marker in 1980 by the New York City Medical Examiner's serology laboratory.

By 1987 evidence derived from the "four-in-one" multisystem had been introduced in several hundred criminal prosecutions in New York State. In that year, however, during a pretrial hearing in *People v. Seda,* the director of the New York City laboratory admitted under cross-examination that only one article had been published about that system—and that the article had recommended the test be used only to screen out obvious mismatches because of a flaw that tended to obscure the results.

In *People v. Seda,* the judge ruled that the four-in-one multisystem did not satisfy the *Frye* standard of general acceptance by the scientific commu-

nity and so could not be introduced into evidence. Unfortunately, *Seda* was the first case involving the test in which the defense went to the effort of calling witnesses to challenge the technology. Consequently, the integrity of hundreds of earlier convictions stands in doubt.

In the past two years DNA profiling has all but eclipsed protein markers in forensic identification. The technique is based on a method originally developed to study the inheritance of diseases, both to identify the disease-causing genes in families known to harbor an inherited disease and to predict individual susceptibility when the gene is known.

Crime investigators have embraced the new technique because it offers two significant advantages over conventional protein markers. First, DNA typing can be conducted on much smaller and older samples. And second, DNA typing was reported to offer from three to 10 orders of magnitude greater certainty of a match. Promotional literature distributed by Lifecodes asserts that its test "has the power to identify one individual in the world's population." Not to be outdone, Cellmark Diagnostics in Germantown, Md.—Lifecodes' main competitor—claims that with its method, "the chance that any two people will have the same DNA print is one in 30 billion." Yet, as testimony in the *Castro* case showed, such claims can be dubious.

The hype over DNA typing spreads the impression that a DNA profile identifies the "genetic code" unique to an individual and indeed is as unique as a fingerprint. Actually, because 99 percent of the three billion base pairs in human DNA are identical among all individuals, forensic scientists look for ways to isolate the relatively few variable regions. These regions can be cut out of DNA by restriction enzymes and are called restriction fragment length polymorphisms (RFLP's).

For DNA identification, one wants RFLP's that are highly polymorphic—that is, those that have the greatest number of variants, or alleles, in the population. It turns out that certain regions of human DNA contain "core" sequences that are repeated in tandem, like freight cars of a train. The number of these repeated sequences tends to vary considerably from person to person; one person might have 13 repeated units at that locus, whereas another might have 29. Special restriction enzymes cut DNA into millions of pieces, including fragments that contain the repeated segments. Because the number of repeated segments varies among individuals, so too does the overall length of these fragments vary.

How can these variable fragments be picked out of the haystack of irrelevant DNA segments? The answer lies in "probes" that bind only to fragments containing the core sequence. If the core sequence occurs at only one DNA locus, the probe is called a single-locus probe. If the core sequence occurs at many different loci, the probe is called a multilocus probe. Forensic laboratories currently make use of three different methods of DNA typing: single-locus RFLP, multilocus RFLP and the polymerase chain reaction. Because the single-locus system is the one most widely employed in forensic DNA identification, we will describe it in some detail.

For forensic DNA identification by single-locus RFLP analysis, DNA from various sources is digested with restriction enzymes, placed in separate lanes on an electrophoretic gel and subjected to an electric field. The field pulls fragments down the lane, with smaller fragments traveling faster than larger ones. The fragments, now sorted by size, are denatured into single strands and transferred from the gel onto a nitrocellulose or nylon membrane, which fixes the fragments in place. (Incidentally, anyone who handles nitrocellulose might test positive on the Greiss test!)

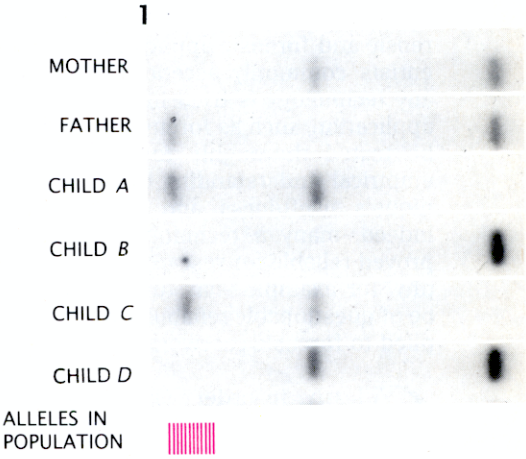
At this point, a radioactive probe is applied, which hybridizes, or binds, to the polymorphic fragments. The mesh is then laid on a sheet of X-ray film to produce an autoradiograph. The radioactively labeled fragments are thereby revealed as a series of bands resembling a railroad track with irregularly spaced ties; the position of the bands is a measure of the size of the polymorphic fragments. The probe can be rinsed away, and a new probe can be applied to identify a different set of alleles.

The autoradiograph resulting from a single-locus probe will ordinarily show alleles of two distinct sizes, one inherited from each parent; such a pattern indicates that the person is heterozygous for that locus. If the probe reveals only one distinct allele, it is assumed that the person inherited the same-size allele from both parents and that the person is homozygous for the locus. Forensic DNA-testing laboratories typically employ several single-locus probes, each of which binds to a different site.

To determine whether two samples of DNA come from a single source, one examines the bands identified by a particular probe on the autoradiograph and decides whether they match. One then refers to data from population-genetics studies to find out how often that particular allele size occurs. A typical allele might be found in 10 percent of the population, making it not all that unlikely that two random people will carry the same allele. But if one looks at alleles at three or four different sites, it becomes increasingly unlikely that two individuals will have the same alleles for all the sites. It is this hypothesis that gives DNA profiling its persuasive power.

How well does forensic DNA profiling stand up under the *Frye* standard? Certainly the underlying theory—that no two people, except for identical twins, have the identical DNA—is unquestioned, and so DNA identification is possible in theory. But is that theory being applied to give a reliable forensic test? And if so, is that test being carried out properly?

In scientific and medical research, DNA typing is most often employed to trace the inheritance of disease-causing alleles within a family. In this diagnostic application, however, one can assume that one allele was inherited from the mother and the other from the father. Because each parent has only two alleles for that gene, barring a mutation, the pattern observed in the child is limited at most to four possible combinations. In addition, if the results are ambiguous, one can rerun the experiment with fresh blood sam-



FORENSIC DNA TYPING is fraught with uncertainty. If the autoradiographs in group 1 are assumed to be from one family, then the alleles of the children must be derived from the parents, even though one of the bands for child *C* is visibly

ples or refer to the alleles of other family members.

In forensic DNA typing, however, it is much more difficult to determine whether an allele from one sample is identical to an allele from another. In the RFLP systems employed in forensics, the number of alleles can run into the hundreds—in contrast to the four from which one must choose when identifying the alleles of a child whose parents are known. Indeed, forensic RFLP systems produce so many different alleles that they virtually form a continuum. In some RFLP's the most common alleles can be crowded into a quarter-inch span on a 13-inch lane. Gel electrophoresis can resolve only a limited number of alleles, however—perhaps between 30 and 100 depending on the particular RFLP—and so alleles that are similar, but not the same, in size may be declared identical. Hence, it can become difficult indeed to declare with confidence that one band matches another. What is worse, forensic samples are often limited in amount and so cannot be retested if ambiguities arise.

These inherent difficulties are further complicated by a problem called band shifting. This phenomenon occurs when DNA fragments migrate at different speeds through separate lanes on a single gel. It has been attributed to a number of factors, involving variables such as the preparation of gels, the concentrations of sample DNA, the amount of salt in the DNA solution and contamination. Band shifting can occur even if the various lanes contain DNA from the same person. Because allele sizes in forensic RFLP systems are closely spaced, it is difficult to know whether the relative positions of bands arise purely from the size of allele fragments or whether band shifting might play a part.

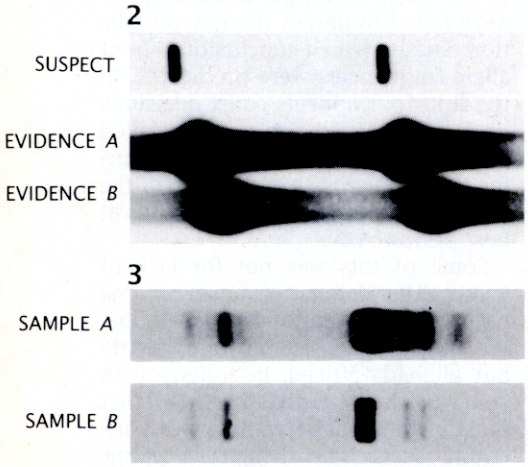
The courts' handling of band shifting is an excellent illustration of the problems that arise when courts, rather than the scientific peer-review process, take on the task of determining whether a method is reliable. Two years ago, when DNA evidence was first introduced in U.S. courtrooms, most forensic DNA scientists rejected the existence of band shifting. But now some experts think band shifting occurs in perhaps 30 percent of forensic DNA tests. There are now many theories about the cause, but as of this writing not one refereed article on the subject has been published.

Forensic DNA laboratories are rushing to develop special probes that bind to monomorphic loci—restriction-enzyme fragments that are the same size in every person—as a possible way to control for band shifting. In theory, if the monomorphic regions are displaced, one would know that band shifting had occurred and could then calculate a correction factor. The difficulty again is that neither this method, nor any other possible solution, has been peer reviewed.

Yet in a rape case tried last December in Maine, *State v. McLeod*, the laboratory director who had supervised the DNA tests for the prosecution testified that a correction factor derived from a monomorphic probe allowed him to declare a match between the suspect's blood and the semen recovered from the victim, even though the bands were visibly shifted. When evidence then came to light that a second monomorphic probe indicated a smaller correction factor, which did not account for the disparity between the bands, he acknowledged that monomorphic probes may yield inconsistent correction factors; nevertheless, he argued that the first correction was appropriate to the bands in question. The prosecutor, though, recognized the folly of defending this argument in the absence of published supporting data and withdrew the DNA evidence. In dozens of other cases, however, judges have been persuaded by the same types of arguments, even though there is no body of research to guide the court. As a matter of common sense, the proper place to first address such issues is in scientific journals, not the courtroom.

Another major problem that arises in forensic DNA typing is contamination. More often than not, crime-scene specimens are contaminated or degraded. The presence of bacteria, organic material or degradation raises the risk of both false positives and false negatives. For example, contamination can degrade DNA so that the larger fragments are destroyed. In such instances a probe that should yield two bands may yield only one (the smaller band).

Research laboratories employ internal controls to avoid the misinterpretation that can result from such artifacts. But such controls may not be suitable for forensic casework. For example, one suggested control for band shifting is to run a mixing experiment: sample *A* is run in lane one, sample *B* in lane two and *A* and *B* in lane three. If



shifted. But if that same lane were of a person whose parentage is unknown, then the band could correspond to one of the other alleles (*color bands*) observed in the population. In group 2, the band patterns from the suspect and from evidence *A* and *B* appear to be displaced relative to one another, which may indicate a band shift. In group 3, sample *A* contains all of the bands from sample *B*, along with extra bands, possibly from contaminants. In group 4, a suspect has two bands, whereas the forensic evidence has only one; the "missing" band may have resulted because degradation of the DNA destroyed the larger fragments. On the other hand, all of these cases could also indicate a real genetic difference.

both samples are from the same person, then ideally lane three would produce one set of bands, whereas if they are from different people, it would show two sets of bands. Unfortunately, in forensic casework there is often not enough material to run a mixing experiment. What is more, recent unpublished studies indicate that certain contaminants, such as dyes, can bind to DNA and alter its mobility in a gel, so that a mixing experiment using samples from the same person can produce two sets of bands.

The power of forensic DNA typing arises from its ability not only to demonstrate that two samples exhibit the same pattern but also to suggest that the pattern is extremely rare. The validity of the data and assumptions on which forensic laboratories have been relying to estimate the rarity are currently being debated within the scientific community.

There are two particularly important criticisms. First, because it is difficult to discriminate accurately among the dozens of alleles at a particular locus, the task of calculating the frequency with which each allele appears in the population is inherently compromised. Second, the statistical equations for calculating the frequency of a particular pattern of alleles apply only to a population that has resulted from random mating—a condition that is called Hardy-Weinberg equilibrium.

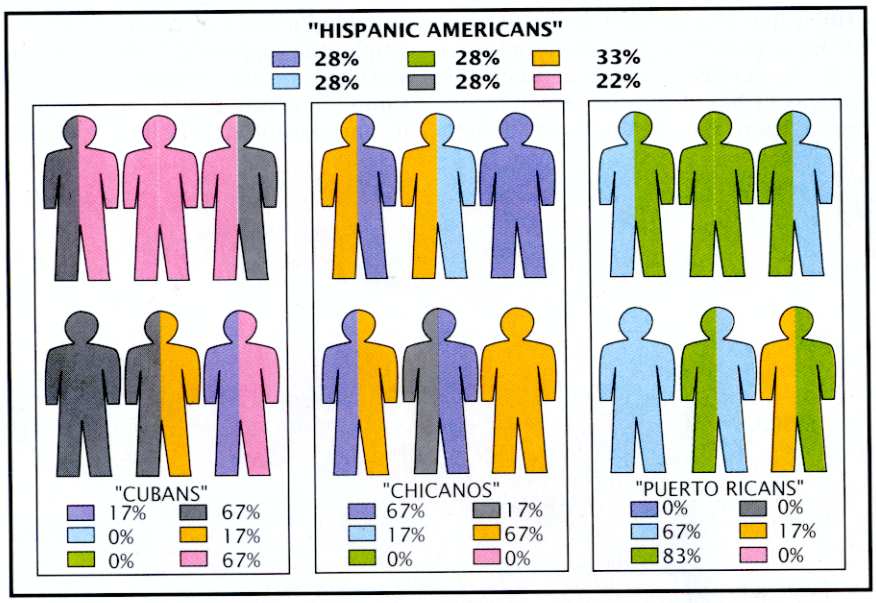
If a population is in Hardy-Weinberg equilibrium, one can assume allele types are shuffled at random. The occurrence of one allele is then independent of the occurrence of a second allele. One can therefore calculate the frequency of the "genotype," or a particular pair of alleles, for a specific locus by multiplying the frequency of each allele and doubling it (because one has the same probability of inheriting each allele from both parents). The frequency of a genotype for a combination of loci is then obtained simply by multiplying the frequency of the genotype for each individual locus. For example, if the genotypes at loci *A*, *B*, *C* and *D* each occur in 10 percent of the population, then the probability that a person would have these genotypes at all four loci is .1 multiplied by itself four times: .0001.

Forensic DNA laboratories carry out these calculations based on data they have assembled themselves. Most of the data have not been published in peer-review journals or independently validated. One problem is that none of the major laboratories employs the same RFLP system. And even if the laboratories decide to adopt uniform probes and enzymes, the results may still differ significantly unless they all also adopt identical protocols. Commercial DNA-testing laboratories are reluctant to do so, however, because each considers its RFLP system to be proprietary, and the probes and enzymes are sold or licensed to crime laboratories around the country.

Another serious issue is that some populations may not be in equilibrium, in which case neither the alleles nor the various loci may be independent. For such a population, there is as yet no consensus on how to calculate the frequency of a genotype (given the limited data bases of the forensic DNA laboratories). As matters stand, population geneticists are debating whether various racial and ethnic communities exhibit significant population substructures so as to preclude the use of current data bases for the highly polymorphic systems employed in forensic DNA identification. For example, do Hispanics in the U.S. constitute a single mixed population? Or is there nonrandom mating, with Cubans more likely to mate with other Cubans and Chicanos more likely to mate with other Chicanos? Should there be a separate data base on allele frequencies within each of these subpopulations? To find out, population geneticists will need to gather more data.

More than 1,000 criminal investigations in the U.S. have now involved DNA evidence, but in only a few dozen cases has DNA evidence been challenged in a pretrial hearing. According to our own study of these hearings, until the *Castro* case in New York, not one of these hearings addressed the problems of forensic DNA typing that distinguish it from diagnostic DNA typing. In all but two of the early hearings, defense attorneys failed to obtain the raw population data on which conclusions about allele frequencies were predicated. In the first four appeals-court decisions on DNA evidence, the defense failed to present any expert witnesses during trial, and cross-examination of the prosecution's expert witnesses was at best perfunctory.

Some of this was not for lack of trying. The defense counsel in one case explained that he had asked dozens of molecular biologists to testify but all had refused. Interviews with some of the scientists revealed that most of them, being familiar with scientific research involving DNA typing, assumed the forensic application of the technique would be equally reliable. Some who were aware of possible problems were reluctant to criticize the technology publicly for fear that this would be misconstrued as a gen-



POPULATION DATA may not yet be reliable enough to calculate the frequency of a genotype accurately. In the hypothetical Hispanic-American population depicted here, a particular DNA site has six distinct alleles, each represented by its own color. Heterozygous individuals are shaded with two colors to represent the two alleles inherited from the parents; homozygous individuals, who have inherited the same allele from both parents, are shaded with one color. Allele frequencies for the entire population differ markedly from allele frequencies for the subgroups shown here.

eral attack on the underlying science.

Another troubling fact is that defense attorneys are often not able to spend the time or funds required to deal with the complexities of the issues. Novel scientific evidence is most often used to solve violent crimes, and defendants in such cases come predominantly from the less affluent sectors of society. Consequently, most of them must rely on court-appointed counsel selected from public-defender offices, legal-aid societies or the financially less successful members of the private bar. Many of these advocates are exceptionally skillful, but they often lack the time and resources to mount a serious challenge to scientific evidence. And frankly, there are also many less-than-adequate attorneys who are simply overwhelmed by the complexity of the subject.

What is more, in most states a court-appointed lawyer may not retain an expert witness without the approval of the trial judge. In recent DNA cases in Oklahoma and Alabama, for example, the defense did not retain any experts, because the presiding judge had refused to authorize funds. In the *Castro* case, a critical factor in the defense's successful challenge was the participation of several leading scientific experts—most of whom agreed to testify without a fee.

Because defendants are seldom able to challenge novel scientific evidence, we feel that independent overseeing of forensic methods is the only way to ensure justice. Specifically, national standards must be set before a scientific technique can be transferred from the research laboratory to the courtroom, and there must be laws to ensure that these standards are enforced.

The regulation of forensic laboratories has an excellent model: the Clinical Laboratories Improvement Act of 1967 (which was amended in 1988). The act established a system of accreditation and proficiency testing for clinical laboratories that service the medical profession. The law was enacted to ensure that such service laboratories, which are not subject to the same peer scrutiny as research laboratories, would nonetheless provide reliable products and services.

In contrast, no private or public crime laboratory today is regulated by any government agency. Nor is there any mandatory accreditation of forensic laboratories or requirement that they submit to independent proficiency testing. It is also troubling that there are no formally enforced, objective criteria for interpreting forensic data. Four fifths of the forensic laboratories in North America are within police or prosecutor agencies, and so there is an enormous potential for bias because technicians may be aware of the facts of the case. In short, there is more regulation of clinical laboratories that determine whether one has mononucleosis than there is of forensic laboratories able to produce DNA test results that can help send a person to the electric chair.

Accreditation and proficiency testing will work only if implemented with care. National standards for forensic testing must serve the interests of justice, not of parties who have vested interests in the technology. This is not an imaginary danger: from 1988 to 1989 a committee of the American Association of Blood Banks set out to develop national standards for forensic DNA typing and brought in two scientists to provide expertise in molecular genetics; these two happened to be the senior scientists at Lifecodes and Cellmark, the two companies that perform virtually all commercial forensic DNA identification in the U.S.

Some observers suggest delegating the task of setting national standards for forensic DNA identification to the Federal Bureau of Investigation. But there is reason to be wary of this approach. Last year the FBI began to perform forensic DNA identification without first publishing its methodology in refereed journals. In the few pretrial hearings that have challenged DNA tests conducted by the FBI, the bureau has been reluctant to supply the raw data on which it based its criteria, citing its "privilege against self-criticism"—a concept that, incidentally, has little precedent in law. The FBI also opposes independent proficiency testing, arguing that no outsider is qualified to evaluate the bureau's performance. In addition, at a recent FBI-sponsored symposium on DNA typing that attracted 300 forensic scientists from around the country, FBI personnel were alone in opposing proposals requiring laboratories to explain in writing the basis for their conclusions and to have their reports signed by the scientists and technicians who conducted the test.

The FBI's stance on these issues flies against norms established elsewhere in the scientific community. For example, if the author of a scientific article refused to divulge his or her raw data to peer review, the article would be rejected. There is also a clear consensus in favor of independent proficiency tests. If a clinical laboratory refused to comply with any reasonable public request to examine the results of proficiency tests, it would risk losing its accreditation. And it would be unthinkable for a diagnostic laboratory to deliver to the obstetrician of a pregnant woman an unsigned report with only the word "abort" appearing on the page.

Independent scientists are finally beginning to awaken to the urgency of these issues. Last fall the New York State Forensic DNA Analysis Panel proposed detailed requirements for certifying, licensing and accrediting forensic DNA laboratories. The Congressional Office of Technology Assessment is expected to issue a report on the regulation of DNA typing by the time this article appears. The National Academy of Sciences has appointed a committee to study appropriate standards for DNA typing and is expected to issue a report early next year.

It is regrettable that these measures were set in motion only after flaws in current DNA typing came to light in the courtroom. We hope the anticipated reforms will enhance the interests of justice in the future, although this may be small solace to defendants who were wrongfully convicted or to crime victims who saw the true culprit set free. It is our hope that, with appropriate national standards and regulation of forensic laboratories, powerful new forensic techniques such as DNA typing will serve an important and beneficial role in criminal justice. When all is said and done, there should be no better test for identifying a criminal—or for exonerating an innocent suspect.

FURTHER READING

Paul C. Giannelli, THE ADMISSIBILITY OF NOVEL SCIENTIFIC EVIDENCE: *FRYE V. UNITED STATES*, A HALF CENTURY LATER. 80 *Columbia Law Review*, pages 1197–1250; 1980.

Randolph N. Jonakait, WILL BLOOD TELL? GENETIC MARKERS IN CRIMINAL CASES. 31 *Emory Law Journal*, pages 833–912; Fall, 1982.

Black, A UNIFIED THEORY OF SCIENTIFIC EVIDENCE. 56 *Fordham Law Review*, pages 595–695; 1988.

THE CLINICAL LABORATORY IMPROVEMENT AMENDMENTS OF 1988. 42 U.S. Code, Section 263a, 1988.

DNA FINGERPRINTING ON TRIAL. Eric S. Lander in *Nature*, Vol. 339, No. 6225, pages 501–505; June 15, 1989.

DNA TECHNOLOGY AND FORENSIC SCIENCE. Banbury Report 32. George Sensabaugh and Jan Witkowski. Cold Spring Harbor Laboratory, 1989.

DNA goes to court

Caitlin Smith, Stephen Strauss & Laura DeFrancesco

DNA profiling is playing a growing role in solving crimes, identifying victims of natural and unnatural disasters and even tracking diplomats. Some forensic experts are looking to advances in genome technologies to gain further ground against criminals.

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DNA forensics has not been a field where innovation proceeds by leaps and bounds. Profiles of individuals in forensic databases worldwide are based on a standard set of 13 short tandem repeats (STRs) in human genomes that have been in use for over two decades. Recently, DNA assays for eye color determination have also been added to law enforcement's genomic arsenal, and reports also suggest tests for hair are undergoing validation. The IrisPLEX assay, pioneered by a group of Dutch researchers, is legal for use in The Netherlands and takes only six genes to differentiate among 40 shades of blue or brown eye color (**Fig. 1**); in August, the group announced that they have added an assay for hair color (HIrisPLEX). Manfred Kayser, professor of forensic molecular biology at Erasmus University Medical Centre Rotterdam and leader of the VisiGen Consortium—an academic consortium dedicated to mapping the genes for human appearance—sees a future where facial features and even age can be read off DNA[1]. "That's, of course, a kind of policeman's dream, where you take a blood sample, you put it in a machine and on the computer screen you get a facial image," Kayser told a radio audience on Australia's Radio National Law Report last year.

Although commercial applications of human genomics have been focused mostly on biomedical research and have increasingly been developed for the clinic, some flagship companies are now also looking for ways to serve the law enforcement community—witness a recently announced collaboration between Illumina and the Department of Forensic and Investigative Genetics at the University of North Texas Health Science Center (Dallas)[2]—and niche companies are providing more specialized tools (**Table 1**). But the application of sequence-based testing and other high-throughput genomic assays to forensics isn't going to happen overnight. "We're not going to go from STR to sequencing in one leap," says Laurence Rubin, CEO of Identitas, a New York company with a single-nucleotide polymorphism (SNP) chips for forensic use.

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The DNA shall set you free. The individual shown, one of hundreds exonerated using DNA evidence, spent 25 years in prison after being wrongly convicted of rape. (Source: AP/Tony Gutierrez)

Citizen DNA

Of the 3 billion base pairs of information in the human genome, most are untouched by the current methods used to create DNA profiles for forensic use. Profiles stored in the US Federal Bureau of Investigation's (FBI's) Combined DNA Index System (CODIS), the United States' national storehouse of profiles created by federal, state and local crime laboratories, comprises a set of 13 short tandem repeats (STRs), 4 or 5 base pairs long, distributed across the genome (**Fig. 2**). Each STR can have several repeats (from 6 to 21) and because every person has two alleles of each STR, a profile consists of just 26 numbers representing the number of repeats at each allele. The FBI chose the individual loci based on their noncoding status, so as not to reveal personal information (personal information on subjects is held at the location where the sample was collected.) Using all 13 loci in a profile harnesses the power of statistics; the likelihood that any two individuals (except identical twins) will have the same DNA profile of all 13 loci is believed to be one in several billion (http://www.ornl.gov/sci/techresources/Human_Genome/elsi/forensics.shtml). Partial profiles of less than 13

Figure 1 Forty shades of blue. Of 40 different blue eye colors, only the three colors in the red box couldn't be determined by IrisPlex DNA-based eye color detection system. (Reprinted with permission[3].)

loci can be useful, but do not carry the same statistical power.

As in so many things criminal, the United States now leads the world with over 10 million DNA profiles in its National DNA Index, although the United Kingdom, which was the first to create a national collection of DNA profiles, has a greater proportion of its population represented, with close to 6 million profiles (http://www.fbi.gov/about-us/lab/codis/ndis-statistics/). Under pressure from citizens' groups, the UK's Parliament passed a law last May requiring that the profiles of innocent people be removed from the database, which is expected to reduce the size of the database by more than a million profiles.

In the United States, today's collections are a combination of offender profiles and forensic profiles, or material collected at crime scenes, but in addition, several states (upward of 25) are now collecting DNA from arrestees, swelling the databases and putting stress on the local crime laboratories. That was not the intent of the US DNA Identification Act of 1994, which set up a system for collecting DNA profiles for tracking violent criminals (**Box 1** and **Fig. 3**). In addition, in some locations, DNA sweeps have been done, in which entire populations (usually of men) from prescribed areas were profiled, where law enforcement was certain of the perpetrator's location but failed to get a match in the local database. (A match can occur only if the person's DNA has been previously collected, which used to mean that he or she had already been convicted of a violent crime.) A few countries (e.g., Portugal and Denmark) have contemplated profiling their entire population; indeed, the United Arab Emirates may actually be doing it, according to GeneWatch, a UK nonprofit that monitors genetic research (**Fig. 4**).

The FBI has statistics showing that the US National DNA Index has assisted in over 200,000 criminal cases nationally. What's more, DNA profiling has been involved in exonerating over 200 prisoners, according to the Innocence Project (New York), which champions efforts to help those wrongly accused. Even so, at least two types of forensic samples yield inconclusive results with STR profiling alone: compromised DNA and mixed DNA samples. Mixtures of DNA in forensic samples occur commonly, according to the US National Institute of Standards and Technology's (NIST's) Applied Genetics Group, which assesses technologies and develops standards for forensic DNA testing. In reviewing over 5,000 DNA samples from 14 laboratories, they found that 34% of samples contained DNA from two people, and 11% contained DNA from three or four people.

Adding SNPs to the analysis enables forensic laboratories to distinguish between the genetic profiles of two individuals in a mixed sample or to make matches with compromised samples that give only partial profiles. "By simultane-

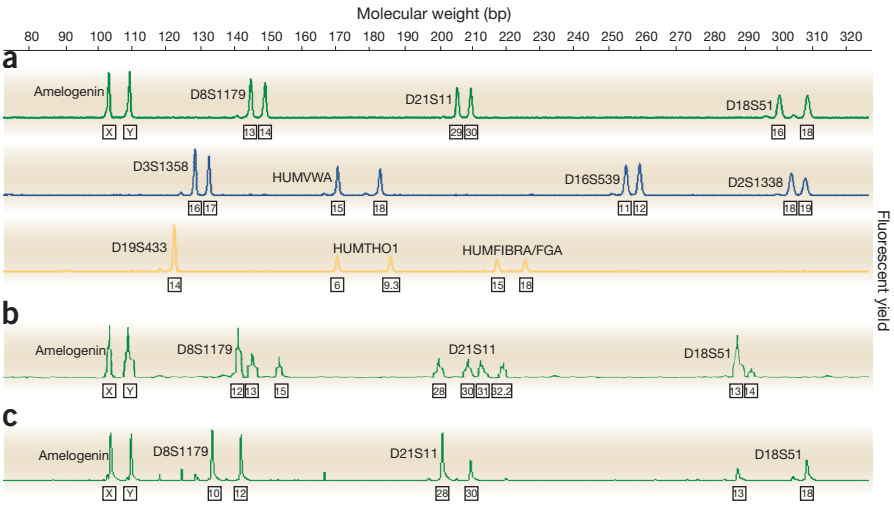

Figure 2 STR profiles. (**a**) Electropherogram of a single individual with equally balanced alleles. Numbers below the peaks indicate the number of repeats. (**b**) Mixture of two individuals in equal proportions. (**c**). Low copy number testing, where additional PCR cycles were used to overcome small sample size, leading to imbalance in alleles due to stochastic nature of PCR. (Reprinted with permission[4].)

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Box 1 Mind your DNA

With DNA detection technologies becoming ever more sensitive, and DNA databases expanding their reach, the right of individuals to keep their genetic information private is being threatened. As databases increase in size, so too does the probability that an innocent person will be wrongly incriminated, a fact largely unappreciated by state legislatures and the public who believe DNA is infallible, according to William Thompson, professor in the Department of Criminology, Law and Society at the University of California, Irvine. Thompson says the possibility of error is real. DNA profiling can go off the rails in numerous ways, from contamination and mislabeling, to investigator bias, which can happen when well-intentioned people are driven by their desire to nail a person they believe is guilty[5].

Twenty-six states have enacted laws expanding their databases; among the most aggressive is California where anyone arrested for a felony must submit DNA, often under threat of further charges if they fail to provide the sample. Many of those arrested are never charged or are found innocent. Meanwhile, the California database grows by some 11,000 profiles each month. That includes people like Lily Haskell, an anti-war protester who had to give a cheek swab for a DNA test after the police arrested her for a felony. The charges were dropped, but her DNA remains in the database. With the help of the American Civil Liberties Union, she is attempting to get the law reversed[6] (*L. Haskell v. K. Harris*).

The justifications for collecting profiles simply don't hold up for people falsely accused or guilty of a lesser crime, according to Thompson. Convicted criminals forfeit some of their rights by virtue of having committed a crime, and there is a strong governmental interest in having them in a database as they are likely to commit more crimes, argues Thompson. "Neither of those rationales applies very well to people who have been arrested for some minor offense," he says.

Another potential threat to innocents is the facility with which DNA fragments can be made to order. Separately, two groups, one in Australia and the other in Israel, have produced amplicons containing CODIS fragments, using various techniques—PCR amplification from collected DNA, whole genome amplification or cloning. The Australian researchers showed that synthesized amplicons planted in a simulated crime scene, along with blood, were detectable and indistinguishable from native DNA. The Israelis, from the Tel Aviv–based company Nucleix, assembled a library of 425 CODIS fragments, sufficient to generate any profile, which also is indistinguishable from native DNA when planted at mock crime scenes. However, Nucleix has provided some solutions; their researchers showed that synthetic DNA can be distinguished from native DNA by looking for methylated bases, present only on native DNA. Whereas present-day technology for detecting methylation (bisulfite sequencing) may not be readily adaptable by forensic laboratories, they also pointed out that the presence of an unusually large number of stutters, which occur during amplification, may be another indicator of synthetic DNA, as the synthesis requires additional amplification steps.

Figure 3 Blue marks the criminal. DNA sprays can identify intruders weeks after a crime is committed. (Source: SelectaDNA, Auckland, New Zealand).

The concept of misdirecting law enforcement is not new, and there are simpler ways to do it, says Bruce Budowle. "Why go through all that, when you can just follow them around and pick up a coke can or cigarette butt?" But, argues Harvard's George Church, "those 'simpler ways' are not that much simpler, and anyway people tend to try many different ways, hoping that they can get ahead of the game. Putting anthrax spores into envelopes or ramming planes into buildings may not have seemed 'simple', but someone did it."

Turning this scenario on its head is the Kent, UK, company Selectamark Security Systems, which markets a DNA-based property marking system. Once applied to a computer or other piece of property, it cannot be completely removed, thus making it possible to identify an item as stolen and trace it back to its owner. SelectMark also offers a DNA spray for connecting intruders to a crime scene. Motion-activated devices mounted on entryways spray a solution of unique DNA on anyone entering the premises. The DNA remains visible on skin or clothing by a simple UV light for weeks (**Fig. 3**), allowing law enforcement to link a criminal to a particular crime scene. According to news reports, McDonald's fast food restaurants in Australia and the Netherlands are testing the system. *LD*

ously interrogating SNPs selected for identification, more information can be obtained from partially degraded samples that are currently deemed 'inconclusive' and thus a dead end for the justice system," says Cydne Holt, senior market manager for applied markets at Illumina and former director of San Francisco's crime laboratory.

Using current technologies to reanalyze old DNA samples that previously had given inconclusive results could have life-altering consequences for the wrongly convicted. In a recent case in Fort Worth, Texas, David Wiggins, a prisoner held since being sentenced to life in 1989 for aggravated assault of a 14-year-old girl, was exonerated when new technologies for isolating sperm cells and interrogating Y-chromosome STRs was applied to a semen stain on the victim's clothing. The Innocence Project took on Wiggins' case in 2007, but it wasn't until this year that they finally got the evidence they needed to exonerate him. "Advances in DNA technology have come into play in a lot of our cases," says Paul Cates, communications director at the Innocence Project. "It's not unusual for us to have cases where the technology has improved over the years and ultimately helps someone."

Wiggins was fortunate that the evolution of DNA analysis technology was on his side. For many others, DNA samples that might exonerate them are still intractable with today's technology. "There are some cases that we have to close because of inconclusive results, for example, because the sample was too old, degraded or there was not enough DNA to test," says Cates. So whereas advances in DNA technology have been helpful, there's room for improvement. "Nearly one in five of our cases are dropped because of difficulty in analyzing the DNA, so from our perspective, there is room for techniques that could better analyze difficult samples," says Cates.

Another modification to CODIS that has been useful, particularly with degraded samples, are mini-STRs. Researchers at NIST developed a set of mini-STRs for all 13 CODIS loci that require samples be only 100 base pairs long, by designing PCR primers that bind closer to the repeat. (Standard STR analysis requires 400 base pair fragments.) These were

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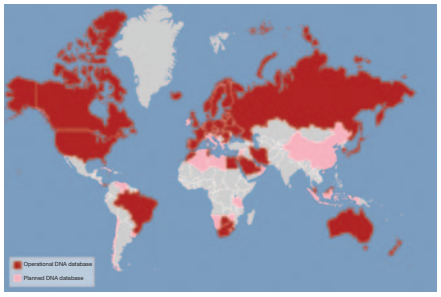

Figure 4 Locations of national DNA databases. Dark shading: pperational DNA database; light shading: planned DNA database. (Source: Council for Responsible Genetics, Cambridge, MA, USA)

particularly helpful during the effort to identify victims of the World Trade Center disaster. Only 655 people of the estimated 2,753 victims could be identified using standard DNA profiling techniques due to the intense heat at the site and contamination with inorganic building material, which left many samples too degraded to analyze by standard methods. Forensic scientists in the New York City Office of Chief Medical Examiner turned to other tools, including SNP analysis, mini-STRs and mitochondrial DNA, bringing the number of 9/11 victims identified by DNA analysis to 1,633 people. Further improvements to isolation methods and analytical tools were contributed by a number of private companies, among them Cybergenetics (Pittsburgh), Orchid Cellmark (Princeton, NJ, USA), a division of Orchid Biosciences, Myriad Genetics (Salt Lake City, UT), Celera Genomics (Alameda, CA, USA) and Bode Technology (Lorton, VA, USA).

Unblocking the backlog

Greater demand, coupled with more evidence being collected by law enforcement, has created a backlog of DNA cases. According to the National Institute of Justice (NIJ), a case becomes backlogged when the sample has not been analyzed 30 days after submission to the laboratory. With increases in throughput available with next generation sequencing (NGS) platforms, backlogs could be reduced or eliminated. Illumina's MiSeq sequencer, which uses as little as 50 ng DNA as input, can analyze all the loci used in forensic laboratories worldwide, plus hundreds more—in a single run. "This includes the core sets of autosomal and Y STRs (as dictated by each nation), many additional STRs, including those on the X chromosome, several categories of SNPs and the mitochondrial DNA genome, as well as other classes of polymorphisms," says Holt. Likewise Life Technologies' (Carlsbad, CA, USA) Ion PGM sequencer, which can use as little as 10 ng input DNA along with the multiplexing capabilities of its Ion AmpliSeq Target Selection Technology, lets you use as many as 1,536 primers in a single tube. "The fact that the library prep method for PGM requires at least 15 times less DNA than other NGS methods is a big advantage," claims John Gerace, head of applied sciences for Life Technologies.

Michael Sheppo, director of the Office of Investigative and Forensic Sciences at the NIJ, acknowledges the benefits that NGS could bring to forensics but recognizes that challenges remain. "The potential advantage for performing highly multiplexed sequencing reactions that could produce information from several marker systems simultaneously presents a strong argument for replacing current methods with NGS systems." But, two major concerns with the technology are data quality and the length of the reads. "The quality of the sequence has direct relevance to the confidence that the data generated can be used in court, and the length of the read has direct relationship to what kinds of markers can be analyzed with the method," he says.

Monte Miller, president of the consulting firm Forensic DNA Experts (Riverside, CA, USA), feels that speed, cost and precision are at issue. "If you could sequence the 13 loci more quickly and efficiently, and you got the same power of statistics, that's more likely to happen first—so that they don't have to change CODIS right off the bat," he says. He also notes that for each allele used by CODIS, the frequencies in the general population, and various subpopulations, are known. This is required to estimate the likelihood that a DNA sample came from a particular person. These statistics would have to be gathered anew if the profiling system were changed drastically.

As technology for DNA detection devices matures, law enforcement may someday be able to process crime scenes on the spot (**Box 2**). But what forensics really needs is a technology that is not dependent on PCR, according to Rotterdam's Kayser. "The real breakthrough will come when PCR can be avoided in NGS—all current studies use PCR-based NGS—as slippage artifacts occurring during PCR can cause problems [because] it cannot necessarily be known whether a small PCR [capillary electrophoresis] peak comes from a real allele (that is, an additional contributor) or from slippage artifacts," he says.

CODIS and beyond

There's no disputing the benefit that DNA profiling has provided law enforcement. "CODIS has been a fantastic tool for law enforcement for many years," says David Whelan, an investor and director at Identitas. "However, when you run a sample and you get no match against a known reference sample, that's the end of the line," he says. And that's where some biotechs are placing their bets, with developing technologies to bridge this gap.

Identitas has developed a high-density array based on Illumina's genotyping chip technology that provides information for no-match samples. "We can say they are of a certain

Table 1 Companies developing technologies with forensic applications

Company (location)	Product
Illumina	SNP genotyping sequencing services
Life Technologies	AutoMate Express benchtop DNA extraction system for forensics with AmpliFSTR Identifiler Plus PCR amplification kit
Promega (Madison, WI, USA)	STR systems to amplify CODIS loci, kits for sample preparation and DNA quantification
Qiagen (Hilden, Germany)	QuantiPlex Hyres kit, sample extraction solutions optimized for forensic samples
AI Genetics (Fairfax Identity Laboratories) (Richmond, VA, USA)	Full-service forensic laboratory in addition to other offerings in DTC genomic testing, relationship, and CLIA clinical genetics laboratory
Casework Genetics (Woodbridge, VA, USA)	Ultra high-density SNP arrays using Illumina Human Omni1-Quad Beadchip
Cybergenetics (Pittsburgh)	TrueAllele software package for casework technology, TrueAllele Databank
DNA Diagnostics Center (Fairfield, OH, USA)	DNA testing for forensic, paternity, ancestry, immigration, accredited by the American Society of Crime Laboratory Directors
Gene Codes Forensics (Ann Arbor, MI, USA)	Sequencer software package adapted for forensics work with mitochondrial DNA analysis
Identitas	Developing high-density SNP chip for forensic market
ZyGem (Hamilton, New Zealand and Charlottesville, VA, USA)	Markets *forensicsGEM* high-throughput DNA extraction kit which is compatible with STR profiling kits

DTC, direct to consumer; CLIA, Clinical Laboratory Improvement Amendments.

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Box 2 DNA profiles on demand

Many sequencing companies are racing to be the first to market with a portable, turnkey-type sequencer that can generate DNA profiles at the crime scene. This requires that the system be easy to use, and hardy enough to be transported and used by law enforcement personnel who likely lack scientific training. Instruments that fit the bill are just emerging. For example, IntegenX (Pleasanton, CA, USA) recently released their RapidHIT instrument, which conducts STR-based profiling in fewer than 90 min without a highly trained operator.

Partnering with Key Forensic Services in the United Kingdom for the initial implementation, IntegenX hopes to make RapidHIT accessible to law enforcement personnel. "Key Forensic Services are a perfect partner to both initially use and help implement law enforcement custody suite usage of rapid DNA identity systems, and in future help extend the usage to crime scene stains," says Stevan Jovanovich, president and CEO of IntegenX. Other companies developing rapid DNA sequencing systems for a variety of applications include Lockheed Martin (Bethesda, MD, USA) and ZyGEM (Hamilton, New Zealand), which together are developing a rapid DNA analysis cartridge, QuantuMDx (Tyne and Wear, UK), which has a nanowire-based point-of-care instrument, Q-POC and DNA Electronics (London) and geneOnyx (London), which are combing forces to create a device for on-site analysis for cosmetic purposes. Sandia National Laboratories (Albuquerque, NM, USA), a US government research facility, offer the Battlefield Automated DNA Analysis and Sampling System, a customized, droplet-based, digital microfluidic platform that can be used by soldiers with little scientific experience to analyze DNA samples on the battlefield.

The fierce competition to be first to, and best in, the market for rapid DNA sequencers can only further the overall goal of improving law enforcement. "The main challenge facing law enforcement is timely information," says Jovanovich. "PCR is a technology that enables the analysis of vanishingly small amounts of DNA, but the law enforcement investigator needs information as soon as possible so that the crime scene does not get cold. IntegenX has integrated eight steps, including PCR, to streamline the determination of identity information to help catch bad guys faster." In October, the company released the instrument for sale in the United States. *CS*

ethnic background…are related to somebody else that [we] have another sample for—which is very important—as well as [identify] external, phenotypic traits that can really help [law enforcement] focus," says Whelan. Results of a pilot study of over 3,000 profiles, done in collaboration with the VisiGen Consortium as well as several law enforcement agencies, which provided the samples, will be released shortly. The study looks at gender, first- and third-degree relatedness and geographic ancestry, and builds up a visual profile of the subject. "The agencies that contributed the data were very impressed with the results," says Identitas CEO Rubin.

Others are working to improve the ability to deconvolute mixtures, which can also lead to dead ends. Cybergenetics (Pittsburgh) has developed a software package, TrueAllele, which can take previously unanalyzable samples and give results that can be used with existing law enforcement tools. TrueAllele automates the analysis of raw STR data; using Markov chain modeling, it takes features such as peak height, shape and area, and calculates the probabilities that particular genotypes comprise complex profiles.

Not so fast

Another potential roadblock for incorporation of NGS into forensics involves privacy issues, especially where governments are involved. "Would the generation of additional data from genetic markers that might be linked to medical information result in privacy concerns?" asks Sheppo. Peter de Knijff, professor at the Forensic Laboratory for DNA Research at Leiden University Medical Centre in The Netherlands, whose laboratory is actively involved in advising the Ministry of Safety and Justice in The Netherlands about possible future uses of NGS-based methods, says, "Legislation and ethics issues relating to the unlimited genetic information one could infer from NGS DNA profiles will be a major barrier in many countries."

Table 2 Commercial DNA testing laboratories

Forensics-focused companies[a] (location)	Identity/relationship focused companies[b] (location)
Andergene Labs (Oceanside, CA, USA)	Affiliated Genetics
Anjura Technology (STACSDNA) (Fairfax, VA, USA	BRT Laboratories (Baltimore)
Bode Technology Group	Cellmark DNA Paternity Services (Oxfordshire, UK)
Cybergenetics	DNA Findings (Houston)
DNA Clinics (London)	DNA Heritage (Houston)
DNA Diagnostics Center (Fairfield, OH, USA)	DNA Services of America (multiple sites in the US)
DNA Reference Laboratory (San Antonio, TX, USA)	easyDNA (Elk Grove, CA, USA)
DNA Resource (Washington, DC, USA)	Family Tree DNA (Houston)
DNA Security (Burlington, NC, USA)	Genetrack Biolabs (Vancouver, BC, Canada)
DNA Solutions (multiple global sites)	Genetic Profiles (San Diego)
DNA Testing Solutions (Tampa, FL, USA)	Genetic Testing Laboratories (Las Cruces, NM, USA)
DNA Worldwide (Frome, UK)	GeneTree DNA Testing Center (Salt Lake City, UT, USA)
Fairfax Identity Labs (Richmond, VA, USA)	Identigene (Salt Lake City, UT, USA)
Forensic Bioinformatics (Fairborn, OH, USA)	Identity Genetics (Aurora, SD, USA)
Forensic DNA Experts	LabsDirect (multiple sites in UK)
Forensic Science Associates (Richmond, CA, USA)	Long Beach Genetics Esoterix (Rancho Dominguez, CA, USA)
Future Technologies (Fairfax, VA, USA)	Oxford Ancestors (Oxford, UK)
Gene Codes Forensics	Paternity Testing Corporation (Columbia, MO, USA)
Genetic Technologies (Glenco, MO, USA)	Sorenson Genomics (Salt Lake City, UT, USA)
Mitotyping Technologies (State College, PA, USA)	
Molecular World (Laval, Quebec)	
Myriad Genetic Laboratories	
Orchid Cellmark (multiple global sites)	
QuestGen Forensics (Davis, CA, USA)	
PRO-DNA Diagnostic (Laval, Quebec)	
SoftGenetics (State College, PA, USA)	
Sozer, Niezoda and Associates (Alexandria, VA, USA)	

[a]Provides services to forensic laboratories. [b]Provides services to individuals seeking information on ancestry and paternity.

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Box 3 Unlocking mysterious deaths

In the popular mind, forensic science is associated with the examination of a crime scene and presentation of evidence found there at a trial. But many of forensic scientists' investigations are related to answering a much more basic question. What do you fill in on a death certificate after the words "cause of death"?

In over a little more than a decade, dramatic advances in both the technology of genetic testing and in our understanding of the genetics of certain conditions have given rise to a new way for coroners, medical examiners and pathologists to explain what have traditionally been the most troubling of deaths—so-called autopsy-negative sudden unexplained deaths (SUDs). SUDS are the incidences where seemingly healthy and symptomless people, largely between the ages of 1 and 35, keel over and die. When traditional physical, toxicological, metabolic screens are done, no physical obvious cause of death can be found. Conducting what have come to be called 'molecular autopsies'—largely tests for genes related to heart disease carried by the dead person—forensic scientists have been able to associate many previously mysterious deaths with heart arrhythmias that are known to strike and kill without any previous warning. But equally important, because there often are ways to prevent the heart attacks, molecular autopsies are being used as a pretext to test close relatives of the dead person for the deadly mutation and physical manifestations of the disease.

A mark of the speed of molecular autopsies application is that in 1999 Mayo Clinic pediatric cardiologist Michael Ackerman and his colleagues in Rochester, Minnesota, reported conducting the world's first such autopsy on a 19-year-old woman and then linking her death to a gene mutation that her sister also carried. They predicted that their discovery "holds potentially great importance for forensic science"[7].

The blooming of that potential appeared in June when Ackerman and his colleagues reported that they had looked at samples of SUD cases sent to them over a 12-year period by medical examiners. When a molecular autopsy was conducted, mutations previously identified as pathogenic were identified in 26% of cases[8].

Equally significant from a biotech perspective, genetic testing companies and laboratories—GeneDx, Partners Healthcare Center, Transgenomics and others—have over the past five to seven years begun to offer post-mortem tests both to detect deleterious mutations and to promote this testing. "We regularly go to medical examiners' meetings," remarks Sherri Bale, the managing director of GeneDx in Gaithersburg, Maryland.

Impressed with the promise of the analysis, some medical pathology offices are moving to make a molecular autopsy something like standard operating procedure. The Ontario Forensic Pathology Service has put in place a facility in Toronto to systematically collect, analyze and store tissues taken from SUD victims whose cause of death could not otherwise be determined.

And yet with all of these advances, when you talk to people in the field, whether researchers, genetic testing companies, coroners or medical examiners, there is a sense that the genetic autopsy revolution hoped for since 1999 is still idling in neutral gear. Part of this has to do with the necessity of a fundamental reconfiguration in how medical examiners and coroners conceive of their work and conduct their autopsies.

One issue is preservation of material. "One of the challenges is that the vast majority of tissue samples from autopsies are complete failures in genetic testing," says Heidi Rehm, director of the Harvard-affiliated Laboratory for Molecular Medicine at the Partners Healthcare Center for Personalized Genetic Medicine in Cambridge Massachusetts. The formalin traditionally used to preserve body tissues in autopsies destroys the genetic reliability of the sample.

Equally importantly, a forensic autopsy traditionally is used to rule out a criminal cause of death whereas a genetic explanation for a SUD carries with it an implicit 'duty to warn' responsibility to living family members. This challenges medical examiners and coroners, many of whom have no medical training and in North America are often political appointees, to change into something they have never been before—physicians.

Silvia Priori, professor of medicine at the New York University School of Medicine, has worked closely with the New York City Office of Chief Medical Examiner, which has developed an expertise in genetic testing, as a result of their efforts to identify remains after the 9/11 attacks. She says follow-up testing on family members whom an autopsy indicates could be carrying a lethal mutation is not taking place because medical examiners "aren't organized to do a follow-up."

Not all coroners are equally stuck. In Ontario, provincial forensic pathologist Kris Cunningham says his department has put in place a protocol where close family members will be told if a mutation has been found in a deceased relative that they may carry. And they will also be counseled to go to a doctor for an examination and possibly a genetic test.

Circling about all this comes the issue of who pays for a molecular autopsy which, depending on the test, can cost anywhere between $2,500 and $9,000. In most places around the world, both private medical insurance and government-covered health coverage ceases at death. This means that families wanting to learn if there is genetic explanation for the unexpected death of a loved one usually have to pay themselves.

In response to economic issues coroners and grieving families regularly try to convince research institutions to slip molecular autopsies onto their research budgets even though the testing, "is not really a research question any longer...it is a clinical question," says Ackerman.

And none of this addresses the most confusing question of all. Whereas in some diseases, the link between a mutation and a potentially fatal condition has been strongly made—mutations in three genes explain roughly 75% of all Long QT cases (a rare potentially serious heart condition spotted by irregular EKGs)—in many conditions the linkage between genetics and the course of a genetically inherited disease is extremely amorphous. For example, mutations that can cause death in some arrhythmogenic right ventricular cardiomyopathy carriers are apparently benign in others. But even more troubling are the hundreds and hundreds of "mutations of unknown clinical significance" which regularly are found when general screenings of genes linked to the rare heart conditions are made.

All this has led cardiologists to walk softly when it comes to routinizing molecular autopsies. "In the setting of autopsy-negative SUDS...testing may be considered in an attempt to establish probable cause and manner of death and to facilitate the identification of potentially at-risk relatives," is how a consensus paper by European and North American cardiologists put it last year[9].

So what is the way forward? One answer may be showing that however expensive it is, molecular autopsies are still cheaper than a continual physical testing of living family members who genetically may be at risk for SUDs. It is an analysis that Ackerman is working on based on the 173 cases and he says the results will hopefully be published soon. *SS*

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Others downplay concerns about storing private information that might be used against people. "There is, of course, the worry about genetic information being used by others to stigmatize and discriminate, but that means someone would have to get access to a person's genomic data and so far I don't see that being very easy to do. People already are stigmatized and discriminated against without anyone knowing their genetic information," says Karen Maschke, research scholar at the Hastings Center (Garrison, NY, USA).

Fight on

Identity testing has become a cottage industry, with a host of companies offering genetic testing for various legal reasons—paternity, immigration—whereas others cater to the needs of law enforcement (**Table 2**). "If popular culture and media are the meters by which we measure society's feeling toward a science, it is clear that society is very interested in the forensic sciences," says NIJ's Sheppo. And the benefits go beyond criminal applications. DNA technology has been brought to bear in other areas of forensic sciences, such as solving cases of unexplained deaths (**Box 3**).

But as with most areas of science, levels of funding are linked to technology advancement. It has taken government support in the past to advance major improvements in the forensic sciences. In 2006, the NIJ provided over $107 million to fund a five-year study, which supported the expansion of forensic DNA applications in state and local laboratories, bringing capillary electrophoresis and robotic automation, as well as many additional technological advances to state and local forensic laboratories. NIJ's Sheppo points out, "Without this kind of government support, it is difficult to imagine that forensic DNA laboratories would have been able to expand in the way that they have over the last decade." But there are still areas in need of improvement. According to Bruce Budowle, director of the University of North Texas Health Science Center's Institute of Investigative Genetics, "The limitation with CODIS is [that it is] driving casework rather than casework driving CODIS."

It's not clear where the next set of advances will come. "The early adopters may not be in law enforcement," says Kevin Lothridge, CEO of the National Forensic Science Technology Center (Largo, FL, USA), a nonprofit agency that provides training and technology assessment. "They may be in other arenas that use forensics and biometrics, such as Homeland Security, the Department of Defense or [the] US border patrol."

Harvard's George Church finds that the potential benefits justify the efforts. "The issue is not whether the new forensic technology is perfect, but whether it is better than eyewitness sketches, etc. The same is true for new diagnostics—the issue is not how many people get no medical insight, but rather the number of patients who are helped by the new technology," says Church.

ACKNOWLEDGMENTS
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1. Liu, F. *et al.* A genome-wide association study identifies five loci influencing facial morphology in Europeans. *PLoS Genet.* **8**, e1002932 (2012).
2. Illumina Enters Collaborative Research Agreement with UNTHSC for Next-Generation Sequencing in Forensic DNA Analysis. October 4, 2011, available at: <http://investor.illumina.com/phoenix.zhtml?c=121127&p=irol-newsArticle&ID=1613146&highlight=>
3. Kayser, M. & deKnijff, P. Improving human forensics through advances in genetics, genomics and molecular biology. *Nat. Rev. Genet.* **12**, 179–192 (2011).
4. Jobling, M. & Gill, P. Encoded evidence: DNA in forensic analysis. *Nat. Rev. Genet.* **5**, 739–751 (2004).
5. Thompson, W. The myth of infallibility. in *Genetic Explorations: Sense and Nonsense* (eds. Krimsky, S. & Gruber, J.) 227–255 (Harvard University Press, Cambridge, MA in press).
6. *Haskell v. Harris*, — F.3d — (9th Cir. (Cal) 2012).
7. Ackerman, M.J., Tester, D.J., Porter, J. & Edwards, W. Molecular diagnosis of the inherited Long QT syndrome in a woman who died after near drowning. *N. Engl. J. Med.* **341**, 1121–1125 (1999).
8. Tester, D.J., Medeiros-Domingo, A., Will, M.L., Haglund, C.M. & Ackerman, M.J. Cardiac channel molecular autopsy: insights from 173 consecutive cases of autopsy-negative sudden unexplained death referred for postmortem genetic testing. *Mayo Clin. Proc.* **87**, 524–539 (2012).
9. Akerman, M.J. *et al.* HRS/EHRA expert consensus statement on the state of genetic testing for the channelopathies and cardiomyopathies. *Heart Rhythm* **8**, 1308–1339 (2011).

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U.S.

DNA Analysis Exposes Flaws in an Inexact Forensic Science

MAY 18, 2014

Retro Report

By CLYDE HABERMAN

By now — despite the apparent infallibility of detectives from Sherlock Holmes to Lieutenant Columbo, despite the clinical genius of wizards from Dr. Quincy to Gil Grissom — it should surprise no one that forensic science is not the model of exactitude that popular culture might have us believe. The scientific rigor of entrenched forensic disciplines has been challenged for years. Still, we live in a "C.S.I." world, and television viewers could be forgiven for assuming that laboratory techniques used to catch bad guys are unassailable. In real life, though, the soundness of criminal analysis is being regularly tested, both in America's labs and in its courtrooms.

This week's offering from Retro Report, a series of video documentaries that re-examine major stories from the past, zeros in on microscopic hair analysis, a staple of forensics for generations. It was long accepted as a virtually unerring technique to prove that this suspect — without a doubt, Your Honor — was the criminal. Wasn't a hair found at the scene?

But with the advent of DNA analysis in the late 1980s, apparent matches of hair samples ultimately proved to be not quite as flawless as people had been led to believe. Instances of wrongful imprisonment make that clear. Retro Report focuses on one such case, that of Kirk Odom, a Washington man who was found

guilty of rape in 1981 and spent two decades behind bars. The Federal Bureau of Investigation's vaunted crime lab had asserted that hairs taken from his head were microscopically like — meaning virtually indistinguishable from — one found on the victim's nightgown. In time, however, DNA testing established that Mr. Odom was not the rapist, as he had asserted all along. Unfortunately for him, that official conclusion came late. By then, he had completed his prison sentence, a man done in by discredited forensic testimony.

Other lab techniques have had their reliability in the courtroom called into question. A 2009 report by a committee of the National Academy of Sciences found "serious problems" with an assortment of methods routinely relied on by prosecutors and the police. They included fingerprinting, blood typing, weapons identification, shoe print comparisons, handwriting, bite marks and — yes — hair testing. DNA was the game changer. The 2009 report said that, with the exception of nuclear DNA analysis, "no forensic method has been rigorously shown to have the capacity to consistently, and with a high degree of certainty, demonstrate a connection between evidence and a specific individual or source."

This is not to say that these techniques are no good at all. Indeed, the F.B.I. still affirms its faith in microscopic hair analysis, particularly as a first look. But it now tries to follow that procedure with a deeper and more certain investigation that uses DNA sampling, and it has done so for 18 years. Nonetheless, many forensic methods no longer come wrapped in the shield of invincibility they once widely enjoyed (especially among those prone to take TV shows literally). Fingerprints get blurred, bullets get smashed, blood specimens get tainted, hairs get mischaracterized.

And then there is human frailty. In 1997, the F.B.I.'s inspector general reported that the bureau's crime lab was — not to put too fine a point on it — all too often sloppy. Technicians were found to have exaggerated the reliability of their findings beyond the bounds of science, typically slanting their conclusions in the prosecution's favor. A forensics expert who used to work in the federal lab, Max M. Houck, told Retro Report that there was "absolutely a disconnect between what I could say as a scientist and what the prosecutors, or the defense attorneys, wanted me to say." One lab employee, Michael P. Malone, was accused

in the late 1990s of providing false testimony. (Mr. Malone left the bureau, but said he has since resumed working for it as a contractor, doing background investigations.)

The Innocence Project, a nonprofit group based in New York that uses DNA testing to help clear people wrongly convicted of crimes, has played a notable role in casting doubt on how forensic science is applied. Nationwide over the past 25 years, the project says, 316 people sent to prison have been exonerated through DNA analysis; 18 of them served time on death row. Hair comparisons performed by crime labs were factors in nearly one-fourth of those cases.

Even the F.B.I., while asserting the validity of hair analysis, has effectively acknowledged past problems.

In 2012, in an understanding reached with the Innocence Project and the National Association of Criminal Defense Lawyers, the F.B.I. agreed to a more cautious approach to stay squarely within the confines of known science. No absolutes. The bureau would now say, for example, only that a specific person *could be* included in, or *could be* excluded from, a "pool of people of unknown size" who might be the source of a specific hair sample. There would also be no statements of statistical probability. In addition, the F.B.I. says it is examining more than 2,500 old cases that lacked DNA evidence, to determine if hair analysis, of itself, played a role in guilty verdicts. It is unclear how far along this review is.

Oh, just one more thing, as Lieutenant Columbo would say.

While it is undoubtedly lamentable, even outrageous, that innocent men and women have been put behind bars, it would probably be a mistake to assume that the prisons are filled with thousands upon thousands of inmates who are doing the time without having done the crime. No one pretends that all those imprisoned people are angels. The Innocence Project acknowledges that.

"About half the cases that go to DNA testing," said Paul Cates, a spokesman for the project, "end up confirming guilt."

The video with this article is part of a documentary series presented by The New York Times. The video project was started with a grant from Christopher Buck. Retro Report has a staff of 13 journalists and 10 contributors led by Kyra Darnton, a former "60 Minutes" producer. It is a nonprofit video news organization that aims to provide a thoughtful counterweight to today's 24/7 news cycle. Previous Retro Report videos can be found here, and articles here.

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WORLD VIEW *A personal take on events*

ERIN NELIS

Forensic DNA evidence is not infallible

As DNA analysis techniques become more sensitive, we must be careful to reassess the probabilities of error, argues **Cynthia M. Cale**.

Earlier this month, the Texas Forensic Science Commission raised concerns about the accuracy of the statistical interpretation of DNA evidence, and it is now checking whether convictions going back more than a decade are safe.

Despite how it is often portrayed, in the media and in courts, the forensic science of DNA is far from infallible. Particularly concerning is that police and prosecutors now frequently talk of 'touch DNA' — genetic profiles of suspects and offenders that have been generated in a laboratory from just a handful of skin cells left behind in a fingerprint.

Research done by me and others at the University of Indianapolis in Indiana has highlighted how unreliable this kind of evidence can be. We have found that it is relatively straightforward for an innocent person's DNA to be inadvertently transferred to surfaces that he or she has never come into contact with. This could place people at crime scenes that they had never visited or link them to weapons they had never handled.

Such transfer could also dilute the statistics generated from DNA evidence, and thereby render strong genetic evidence almost insignificant. (The issue of statistics is reportedly the focus of the Texas investigation.)

We urgently need to review how DNA evidence is assessed, viewed and described. Everyone in the medico-legal community — forensic scientists and technicians, DNA analysts, potential jurors, judges and lawyers for both the prosecution and defence— must know and understand the potential for mistakes.

The term 'touch DNA' conveys to a courtroom that biological material found on an object is the result of direct contact. In fact, forensic scientists have no way of knowing whether the DNA was left behind through such primary, direct transfer. It could also have been deposited by secondary transfer, through an intermediary. (If I shake your hand then I could pass some of your skin cells onto something that I touch next.)

Contamination from secondary DNA transfer was raised as a possible problem in *Nature* in 1997 (R. A. H. van Oorschot and M. K. Jones *Nature* **387,** 767; 1997). It is known to happen, but has largely been dismissed by legal experts as being rare outside the conditions of a laboratory. Experiments done in real-world conditions seemed to support this, and concluded that secondary DNA transfer would have little impact on interpretation of the genetic profile.

It is important to recognize that DNA amplification kits have become much more sensitive than they were in the past. As a result, the types of samples being analysed have expanded. Investigators no longer need to identify and request analysis of body fluids such as blood, semen and saliva. They can swab surfaces for otherwise invisible cells left behind, on the handle of a weapon or on a windowsill, perhaps, and ask labs to generate a DNA profile from them. The new kits can generate a full genetic profile of a suspect from as little as 100 picograms (trillionths of a gram) of DNA.

These subtleties are not usually explained in court. Instead, a jury is told that there is a one-in-a-quadrillion chance that the evidence retrieved from the crime scene did not come from a defendant. Naturally, the jurors assume that the defendant must have been there.

Given the power of modern forensic techniques to pull a DNA profile from a smudge of cells, secondary DNA transfer is no longer a purely theoretical risk. In California in 2013, a man called Lukis Anderson was arrested, held for four months and charged with murder after his DNA was found under the fingernails of a homicide victim.

Anderson had never met the victim and was severely intoxicated and in hospital when the man was killed. The same paramedics who took Anderson to hospital responded to the murder. Most likely, the paramedics were covered in Anderson's DNA, which they then inadvertently transferred. The charges were dropped.

Experiments in our labs, under the supervision of forensic anthropologist Krista Latham, show how easily DNA can be transferred to an object.

We asked pairs of people to shake hands for two minutes and then each individual handled a separate knife. In 85% of cases, the DNA of the other person was transferred to the knife and profiled. In one-fifth of the samples, the DNA analysis identified this other person as the main or only contributor of DNA to the 'weapon' (C. M. Cale *et al. J. Forensic Sci.* http://doi.org/8j2; 2015).

How significant is the result of a single study? Other analyses have shown that DNA transfer can be unpredictable and can depend on environmental conditions. We need more research on when and how secondary transfer can occur.

At the very least, the results highlight again that samples at crime scenes must be gathered with great care. DNA can persist on latex gloves, so they must be changed — or bleached — before and after handling evidence.

Even apparently rigorous evidence such as DNA profiles can be interpreted in multiple ways, some of which will be incorrect. As the technology to generate these profiles continues to accelerate, so must our efforts to sift out possible mistakes. ■

WE NEED MORE RESEARCH ON WHEN AND HOW SECONDARY TRANSFER CAN OCCUR.

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Monte Sereno murder case casts doubts on DNA evidence

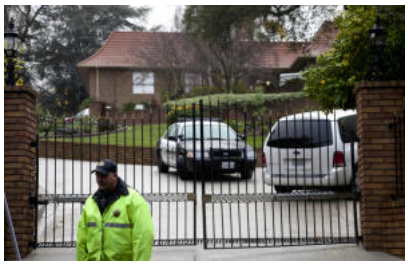
By Tracey Kaplan | tkaplan@mercurynews.com (mailto:tkaplan@mercurynews.com)

POSTED: 06/28/2014 07:27:16 PM PDT | UPDATED: ABOUT A YEAR AGO **19 COMMENTS**

It looked bad for homeless alcoholic Lukis Anderson when DNA evidence tied him to a Silicon Valley millionaire's 2012 murder.

But when Anderson's lawyer proved that paramedics who had treated him on the streets of downtown San Jose inadvertently transferred his DNA to the Monte Sereno murder scene, she didn't just clear him. The case is believed to be the first in California and perhaps the nation in which DNA evidence was shown to have falsely placed an innocent person at the scene of a crime, lending credibility to defense lawyers who struggle to convince jurors to view DNA evidence more skeptically.

"Before, we just had hypotheticals, stuff that DAs would say was smoke and mirrors," said Deputy Public Defender Kelley Kulick, who handled the groundbreaking case. "Now, there is a case to support it."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The scene of the home invasion . in Monte Sereno, Calif., Nov. 30, 2012. (Patrick Tehan/Staff)

Among defendants now pointing to Anderson's case in hope of clearing their own names are former Santa Clara County Supervisor George Shirakawa Jr., whose lawyers are challenging felony criminal charges that he was behind a fraudulent campaign mailer allegedly bearing his DNA on the stamp.

While others accused of a crime -- most famously exchange student Amanda Knox -- have used the so-called transference defense against DNA evidence with some success, those

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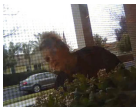


defendants weren't able to prove, as Anderson's attorneys did by establishing his alibi, that the DNA evidence had been compromised.

In the pivotal case, Anderson was arrested on murder charges after his DNA was found under the fingernail of Silicon Valley millionaire Ravi Kumra, who suffocated after thieves bound him during a 2012 home-invasion robbery at his gated Monte Sereno estate.

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- Monte Sereno murder: 'Be quiet if you want to live,' killers told Ravi Kumra's wife before binding and gagging her with tape (http://www.mercurynews.com/crime-courts/ci_22551513/monte-sereno-murder-be-quiet-if-you-want?source=pkg)

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Despite the DNA, nagging concerns about the case persisted. The prosecution saw connections to support the DNA link -- that Anderson had a residential burglary conviction on a criminal rap sheet composed otherwise of nonviolent minor crimes such as being drunk in public, and he had spent time in the same jail dorm with a member of one of the gangs tied to the Kumra killing. But that gang member wasn't implicated in the murder. And while the others accused in the homicide belong to some of Oakland's most violent home-invasion gangs, Anderson didn't seem mentally capable of organized crime. He suffered a brain injury from being hit by a truck and could not even recall his whereabouts that November night.

Kulick pursued every avenue to prove Anderson had nothing to do with the crime, eventually discovering medical records that show on the night Kumra died, Anderson was at Santa Clara Valley Medical Center, where he had been taken by ambulance after passing out drunk in downtown San Jose.

His DNA turned up at the murder scene only because paramedics inadvertently transferred it there, via a simple oxygen-monitoring probe they'd clipped first onto his finger and then onto the dead man's. Prosecutors dropped the charges after examining a dossier Kulick put together, interviewing the paramedics and hospital personnel, and reviewing videotape of the crime scene to make sure the paramedics had really treated both men. Anderson walked out of jail five months later.

With the tacit support of the District Attorney's Office, Kulick plans to petition a judge to wipe the Kumra murder arrest off Anderson's record via a document declaring him factually innocent. It's expected to be granted, paving the way for more defense attorneys to tout the example, using the document, at a time when DNA is playing a key role in an increasing number and variety of cases, not just rape or murder. In the near future, for instance, DNA will be immediately tested at the crime scene, using portable equipment that has already been developed in the lab.

Of course, the Anderson case alone won't be a magic bullet, both in instances where there's plenty of other evidence, and if prosecutors successfully argue the incident is an unlikely chance occurrence. The California District Attorneys Association declined to comment. In a Sacramento baby-killing trial in March, for instance, lawyer Ruth Edelstein tried to sway a

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jury by recounting the case, but the panel came back with a guilty verdict anyway, based in part on evidence of an alleged admission to an acquaintance. Even so, Edelstein still plans to tell other juries about Anderson.

"Because of "CSI" and a lot of other misinformation, there's a belief that if someone's DNA is there, the person was there," Edelstein said, referring to the popular TV crime drama about forensic scientists. "But the presence of DNA doesn't tell you anything about how it got there."

Before the Anderson incident, the transference argument helped defendants get off the hook in at least two high-profile cases. In Italy, an appellate court last year overturned American exchange student Knox's murder conviction in the killing of her British roommate. The defense argued that trace amounts of DNA from both the victim and Knox that were found on a knife in Knox's boyfriend's apartment could have been transferred there by Knox, who lived with the victim and was in constant contact with her. A higher Italian court, however, has reversed that decision, concluding that the slain woman's injuries suggested multiple killers.

In 2012, an English cabdriver charged with killing a prostitute based on the discovery of his DNA under her fingernails was cleared after the defense argued that he had a dry skin condition -- so severe that his nickname was "Flaky." The defense successfully contended that his DNA could have been transferred to change he gave a passenger, who later killed her.

Scientists and cops have long recognized the risk of DNA contamination -- by lab technicians, for instance -- and of transfers from one object or person to the crime scene. Law Enforcement magazine, a trade publication, even warned officers two years ago to "take great care in collecting evidence if you have a sunburn or dandruff because your DNA may fall into the evidence." In the lab, one experiment showed that it only takes 30 seconds of handling something or someone firmly for skin cells containing DNA to be transferred. Another study demonstrated that semen on one garment can contaminate another if they are washed together in the same machine.

But with Anderson, there are actual medical records proving his innocence. In Shirakawa's case, defense attorney Jay Rorty has asked a judge for those records. He's also consulted with San Francisco lawyer Bicka Barlow, who specializes in DNA and is familiar with the Anderson case, according to court documents. Rorty declined to comment.

Exactly how Shirakawa's defense would claim a transfer occurred is unknown, but there are any number of possibilities -- for instance, if Shirakawa shook hands with someone who subsequently stuck the self-adhesive stamp on the mailer.

"You could very innocently come in contact with an object, and days or months later, your DNA shows up at a crime scene you had nothing to do with," said Barlow, speaking in general, not about Shirakawa.

Prosecutors are dead set against releasing Anderson's records to Shirakawa's lawyers. They argue Anderson's DNA records are confidential, "wholly" unrelated to the case and not potentially exculpatory. If the judge agrees, the jury could still hear about the case indirectly via the testimony of an expert defense witness. Prosecutor John Chase said either way he's confident he'll prevail.

But the Anderson episode is shifting the legal landscape by forcing the prosecution in cases that rest heavily on DNA to make doubly sure there's plenty of supporting evidence, Chase said.

"It's an absolute now," Chase said. "You can't make a case solely on contact DNA."

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