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Jeremy Travis, Director

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Highlights

DNA testing has become an established part of criminal justice procedure, and the admissibility of the test results in court has become routine. Although DNA testing has accomplished a great deal in opening up new sources of forensic evidence, its full potential to identify perpetrators and exonerate people falsely convicted has yet to be realized. For this to be done requires further advances in testing technology and in systems to collect and process the evidence. These advances are now under way.

- The development of forensic DNA testing has expanded the types of useful biological evidence. In addition to semen and blood, such substances as saliva, teeth, and bones can be sources of DNA. These sources are expanding still further, as researchers explore the potential of other biological substances, such as hair, skin cells, and fingerprints.

- Even though the sources are multiplying, the use of DNA evidence is currently limited because much of what could be tested remains unrecovered and unanalyzed. The numbers are increasing, but of all sexual assault convictions for which DNA collection is legislatively mandated, samples were obtained from less than half the individuals, and of the cumulative number of DNA samples obtained, only 20 percent have been processed.

continued…

The Unrealized Potential of DNA Testing

by Victor Walter Weedn and John W. Hicks

Since before the turn of the century, at a time when Sir Arthur Conan Doyle was spinning his tales of Sherlock Holmes, objective scientific evidence has been routinely used to investigate crime. Today, although most crimes continue to be solved through confessions and eyewitness accounts, forensic evidence—most often drugs, fingerprints, firearms, blood, and semen—has come increasingly to be used to establish the truth. In the past few years alone, major technological advances have been made in fingerprinting, the development of computerized fingerprint databases, and, perhaps most familiar because of recent sensational criminal cases, DNA testing.

Advances in technology have helped DNA testing to become an established part of criminal justice procedure. Despite early controversies and challenges by defense attorneys, the admissibility of DNA test results in the courtroom has become routine. More than 200 published court opinions support this use, and DNA testing standards have been developed and promulgated. Last year there were more than 17,000 cases involving forensic DNA in this country alone. Questions about the validity and reliability of forensic DNA test methods have essentially been addressed.

DNA's promise of using evidence invisible to the naked eye to positively identify the perpetrator or exonerate the innocent suspect is being fulfilled. Thanks to DNA, biological evidence is now used in new ways, and many more sources of evidence are available than in the past. Yet the potential of DNA may be greater than its accomplishments thus far. Realizing that potential means first overcoming a number of limitations—in procedures for testing DNA evidence and systems to collect and access DNA information.

An enhanced role for biological evidence

As a result of the development of DNA testing, biological evidence—evidence commonly recovered from crime scenes in the form of blood or other body fluid—has taken on new significance. Traditional blood and saliva testing have been rendered obsolete. DNA is found in these substances and in fact in all body tissues and fluids. Because DNA testing is more sensitive than traditional serologic methods and DNA is able to withstand far harsher environmental insults, DNA testing may be successful when traditional testing is not.

Highlights

continued…

• The reasons for the lag in evidence recovery and processing are scarcity of law enforcement resources, lab backlogs caused by insufficient funding, and time-consuming and costly testing methods. Given the deadlines imposed by the courts, it is not possible to analyze all the potential evidentiary specimens submitted.

• More rapid processing of DNA evidence should make it possible to overcome these obstacles within the next few years as a result of improvements in technology. The turnaround time of RFLP (restriction fragment length polymorphism) analysis has recently been reduced. More promising is the anticipated replacement of RFLP by PCR (polymerase chain reaction)-based technology, which takes only days to perform.

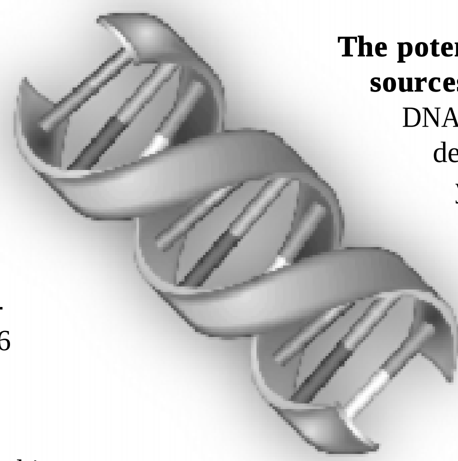
• The development of DNA databases and networks can substantially augment DNA profiling. In the United States, the concept of DNA databanking is still rudimentary, especially compared to the United Kingdom. The U.S. situation is improving, however, because of the FBI-developed CODIS (COmbined DNA Index System) and Federal support for State DNA databanking and compatible testing systems.

• Initial collection of evidence is improving as a result of the establishment in many jurisdictions of more structured crime-scene teams and more formalized evidence collection procedures.

Because the DNA molecule is long lived, it is likely to be detectable for many years in bones or body fluid stains from older criminal cases in which questions of identity remain unresolved. The result is that DNA testing applies to a vastly wider array of specimens than conventional testing and is much more powerful in analyzing biological evidence than any previous technology.

Expanding the range of evidence

Virtually all biological evidence found at crime scenes can be subjected to DNA testing. At most crime scenes, there are many kinds of biological evidence: not only blood and hair but also botanical, zoological, and other types of substances.[1] Blood evidence was revealed in one study to be found in 60 percent of murders and in a similar percentage of assaults and batteries. Hair was found at the scene of 10 percent of robberies and 6 percent of residential burglaries.[2]



Multiple sources. In this country DNA testing has been conducted primarily in cases of sexual assaults from vaginal swabs and semen stains. By contrast, in England the majority of DNA database matches involve burglaries, with the evidence tested consisting of blood found at sites of forced entry. Saliva, skin cells, bone, teeth, tissue, urine, feces, and a host of other biological specimens, all of which may be found at crime scenes, are also sources of DNA. Saliva may be found in chewing gum and on cigarette butts, envelopes, and possibly drinking cups. Fingernail scrapings from an assault victim or a broken fingernail left at the scene by the perpetrator may also be useful DNA evidentiary specimens. Even hatbands and other articles of clothing may yield DNA. DNA testing of urine is becoming common to establish whether a particular individual is truly the source of the specimen in which illegal drugs have been identified.

The array of evidence that can be found at crime scenes and subjected to DNA testing suggests its unrealized potential. For despite the abundance of evidence, and despite the advantages of DNA testing, little of this evidence is recovered from crime scenes, less is submitted to crime labs, and still less is analyzed. (See "Sexual Assault Cases: Need for More DNA Processing.")

The potential for more sources. For certain kinds of DNA-laden biologic evidence, the potential has yet to be fully explored. Hair cells are an example. During a violent confrontation, hair may be transferred between the victim and the perpetrator. Traditionally, forensic scientists have been able to identify the source of this evidence on the basis of its general appearance and structural features, but rarely has it been possible to determine the source definitively. Because an individual's DNA may be detectable in his or her hair, DNA testing technology is likely to change substantially the significance and use of hair evidence.

The superficial skin cells that an individual sheds in the hundreds of thousands every hour may be prevalent at crime scenes. Their presence raises the possibility of subjecting such trace biological material to DNA testing.

Recently researchers have reported that DNA can be recovered from fingerprints, which are therefore another possible source of trace specimens that may be valuable as evidence.[3]

Back to the future

The longevity of the DNA molecule means its power extends not just to the present and future but also to the past. Specimens that in many cases are years or even decades old—dating to the time when DNA testing technology was not yet available—can be tested, resulting in overturned convictions and release of the innocent.

The exoneration of Kirk Bloodsworth is an example of how the past was revisited with DNA evidence. In this case a Baltimore court, using an anonymous tip, identification from a police artist's sketch, eyewitness

Sexual Assault Cases: Need for More DNA Processing*

Case processing of rapes could be improved if, in more instances, the DNA evidence were submitted to laboratories and tested. Currently, in only a relatively small proportion of all rape victimizations is DNA recovered and tested. For DNA databasing of people convicted of sexual assaults, the situation is similar: Samples are not collected, and many of those that are collected are not tested.

A recent FBI survey revealed that of all rapes, less than half were solved by the police and less than 10 percent were sent to crime laboratories. And because crime laboratories are not able to work all cases submitted, in only 6 percent of the 250,000 rape cases was the recovered DNA tested, leaving a backlog of several thousand cases awaiting processing (see below).

Of all convictions for sexual assaults (whether felonies or misdemeanors) from which DNA collection is legislatively mandated for database matching purposes, DNA was obtained from less than half the individuals, and in less than one-third were the samples DNA typed (see below). This proportion is an improvement over the past; however, of the overall, cumulative number of DNA samples collected (452,000 in the 35 States participating in the COmbined DNA Index System [CODIS]), only 20 percent have been typed. Exacerbating this limited databasing is that the mismatch between DNA typing systems prevents comparison searches; for example, most casework is now performed using PCR (polymerase chain reaction) analysis, while RFLP (restriction fragment length polymorphism) typing is performed on the vast majority of collected DNA database samples.

Fortunately, the situation is improving for rape cases: These low DNA utilization rates represent a substantial increase in DNA testing over the previous year (19 percent for DNA typing casework and 30 percent for DNA databasing). However, for nonsexual assault crimes, DNA testing is limited or in some cases even nonexistent.

Rapes	Number	%
Victimizations	250,000	(100)
Investigated by Police	100,000	40
DNA Submitted to Crime Labs	22,000†	9
DNA Processed by Labs	16,000	6
Backlog in Labs	6,000	—

DNA Databasing (Sexual Assaults)	Number	%
Convictions	165,000	(100)
DNA Collected	80,000	48
DNA Typed	45,000	27
DNA Not Typed	35,000	73

† Of the remaining 78,000 rape cases in which DNA was not submitted, 48,000 remained unsolved. The rest (30,000) were solved without the use of DNA evidence.

Note

*These data were presented by Stephen Niezgoda, CODIS Program Manager, FBI, at the American Society of Crime Laboratory Directors' 25th Annual Symposium on Crime Laboratory Development, San Antonio, Texas, September 18, 1997. Data on number of rapes are from the Bureau of Justice Statistics National Crime Victimization Survey; the other data are from the FBI's forthcoming *1997 CODIS Survey of DNA Laboratories.* The survey used information from the States for the period January 1996 through June 1997, and projected data to the end of fiscal year 1998.

statements, and other evidence, found Mr. Bloodsworth guilty of sexually assaulting and murdering a young girl. Later he was retried and again found guilty. But in 1993, more than 8 years after his arrest, prosecutors compared DNA evidence from the victim's clothing to Mr. Bloodsworth's and found the two did not match. He was subsequently released and then pardoned.

As of this writing, dozens of other inmates have been released on the basis of similar evidence. A number of examples of cases in which DNA testing furnished new evidence that resulted in the release of people wrongly convicted have been published.[4]

Limitations to overcome

The fact that much forensic biologic evidence remains unrecovered and unanalyzed is only one obstacle to realizing the full potential of DNA testing. Other limitations stem from lack of sufficient laboratory funding, time-consuming testing methods, inability to test in the field, and the challenges of automating DNA evidence databases. These problems are serious, but new developments suggest they can be overcome.

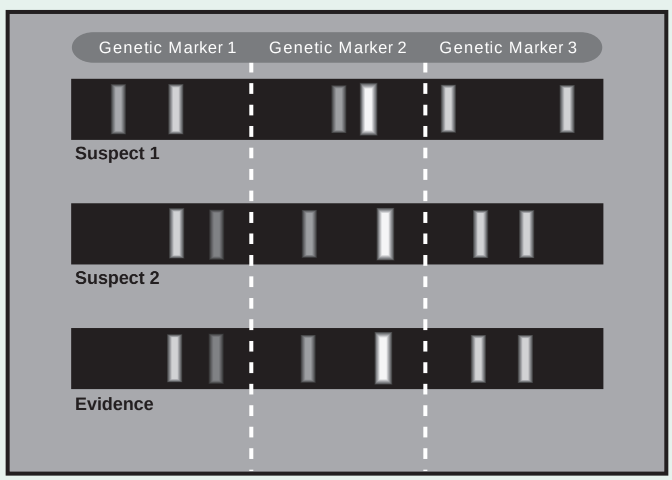
Laboratory testing—funding low, processing slow. For the full potential of DNA evidence to be realized, forensic laboratories must have resources sufficient to test the evidence submitted to them. But laboratories are notoriously underfunded, and many already face heavy backlogs of work. Law enforcement agencies are often forced to distribute scarce resources among a range of pressing needs, and the labs vie for funding in this highly competitive environment.

Exacerbating this difficulty, and explaining why limited testing is done, are the slow, costly testing methods currently used. Because they are so time consuming, crime laboratories must prioritize cases to be processed and specimens to test. It is not possible, given the deadlines imposed by the needs of the courts, to analyze all potential evidentiary specimens submitted. Thanks to the development of new methods of analysis, however, crime laboratories' ability to process DNA evidence within a reasonable time is expected to improve substantially within the next few years. (See "In the Pipeline: New and Improved Testing Technologies.")

Field testing—being tested. Investigatory leads often grow cold within a very short time after a crime is committed. Suspects vanish, witnesses disperse, and potential physical evidence may persist for only a limited time or may be disturbed in some way, even by normal activities. Although faster processing in the laboratory is important, in many cases the ability to secure critical information by field testing at the crime scene might significantly enhance the likelihood of a successful resolution.

Field testing should not replace laboratory testing; instead it may powerfully augment investigations conducted at crime scenes. It could be used to screen potential DNA evidence specimens for those most likely to produce results and, through preliminary analysis conducted at the scene, to help develop investigative leads. Oral swabs could be used to collect DNA samples from those willing to submit to the procedure. Of course, more powerful, confirmatory testing in the controlled environment of the laboratory should continue to be conducted to ensure absolute confidence in the results. The role of preliminary analysis in the field would be to eliminate

Method of Matching DNA Patterns Using STRs



STR (short tandem repeat) genetic markers run simultaneously on known and questioned DNA samples. Each person will have a maximum of two traits for each marker examined. The analyst identifies the traits for each of the three markers and determines whether the traits for the evidence match the traits from the samples of the suspects' DNA. In this case, the pattern of the evidence specimen matches that of suspect 2.

certain individuals as suspects, arguably always a more important role for DNA evidence than incrimination.[5]

Steps are now under way to realize the potential of field testing DNA evidence. Recently, a truly portable microchip-based prototype field-testing instrument has been developed.[6] The instrument, which produces findings within 30 minutes, is currently being upgraded and made available commercially. The National Institute of Justice is sponsoring the development of other types of portable field instruments.

DNA databases—in their infancy. Without computerized searching and without suspects, evidentiary testing, no matter how powerful, can do little more than link crimes together and is of little use in solving them. In the same way that fingerprint registries and then automated fingerprint identification systems each dramatically enhanced the utility of fingerprint evidence, the development of DNA databases and networks can substantially augment DNA profiling.

Information in the database, which consists of DNA test results from individuals convicted of certain categories of crime and DNA from the scenes of unsolved crimes, can be compared to results of evidence obtained at recent crime scenes to find associations. This creates DNA databasing's greatest advantage: its use as an investigative tool in cases where there are no suspects. However, jurisdictions must process suspectless cases to produce "cold hits" (matches lacking previous leads). Databanking in the United States is still limited, but as with testing technologies, it continues to evolve.

The status of databanking

In the United States. Today almost all States have legislation related to DNA databanking, most of it focusing on collecting and testing DNA from individuals convicted of sexual assaults and often homicides. In some cases the legislation requires collection from all convicted felons. Although DNA databanking was proposed almost 10 years ago, and although databanking has been almost universally adopted at the State level, the concept of its development in this country is still rudimentary.

The limitations are partly due to the definition of offender categories in the legislation. For example, rapists who plead to a lesser offense not covered by a particular State databanking law are therefore not subject to it. Similarly, in some States DNA collection laws are inapplicable to juveniles involved in the criminal justice system. In other instances DNA is not collected until an offender is released, instead of at intake, making it impossible to match the offender's DNA to that in a case opened during incarceration. Other problems stem from lack of funding and the incompatibility

In the Pipeline: New and Improved Testing Technologies

More rapid processing of DNA evidence should be possible within the next few years as a result of improvements in testing technology now under way.

The first widespread use of DNA tests in the criminal justice community involved RFLP (restriction fragment length polymorphism) analysis, which was informationally rich but took a long time—about 6 weeks. Recent nonradioisotopic methods have considerably reduced the turnaround time of RFLP. Nonetheless, it is anticipated that RFLP testing will eventually be supplanted by PCR (polymerase chain reaction)-based technology.

It takes only days to perform PCR-based dot/blots and, more recently, STRs (short tandem repeats). Moreover, current STR marker sets produce as much information as RFLP tests and can be used with extremely small and degraded DNA specimens. STRs have only recently become commercially available, but already they are anticipated to supersede less informative dot/blot systems.

Developments that will further automate DNA analysis are being developed as an outgrowth of the Human Genome Project.* These include robots, microchip-based instrumentation, and mass spectrometry. The run time of such instruments may be only minutes or even seconds. Performance of 100 STR analyses within an hour using an automated mass spectrometer has been demonstrated in a research setting.

Support for development of microchip and mass spectrometric work in forensic DNA testing is being provided by the National Institute of Justice. Today the resulting systems are in operation in only a few research centers, but are likely to become commercially available in the next few years.

*The Human Genome Project (HGP) is an international, 15-year effort, begun in 1990, to discover all the genes in the human body's DNA and determine the complete sequence of DNA. A major focus of HGP is development of automated technology for the sequencing process.

of the States' genetic testing systems. Of the 47 States that have passed legislation, the program is operational in only 36, and of that number most programs are severely backlogged.

In the United Kingdom. Compared to the United States, the United Kingdom has moved far more aggressively to establish a national DNA criminal database. Specimens are collected from a wider range of offense categories than the sexual assault category targeted by most State programs in the United States. The number of DNA profiles entered thus far in the United Kingdom is now nearly 200,000,[7] with an expected increase to more than 5 million specimens in the next decade.

The United Kingdom has taken other steps to increase the utility of its database. Specimens are taken upon arrest rather than, as in virtually all the States in the United States, on conviction. Databank staff tell police investigators the chances are about 1 in 2 of finding the perpetrator through a DNA match.

In testing technology, the United Kingdom has switched completely to automated STR, which is able to discriminate among every man, woman, and child in the country. By contrast, most databasing in the United States uses RFLP results. (For an explanation of RFLP and related terms, see "A Primer of DNA Testing Technology.") Laboratory processes in the United Kingdom have been streamlined and automated and therefore are generally more efficient than those at the U.S. State level.

The most important distinction between the two countries is that the United Kingdom views databanking as a primary investigative tool. It is used, for example, for "mass screens" or "intelligence-led screens," in which targeted canvassing is conducted in a certain area or among a certain pool of suspects. The approach has been used with great success: Since 1995 at least 17 high-profile cases have been solved in this fashion.

Officials in the United Kingdom believe that their DNA testing program has actually reduced overall law enforcement costs by eliminating extensive traditional police investigations in some cases.

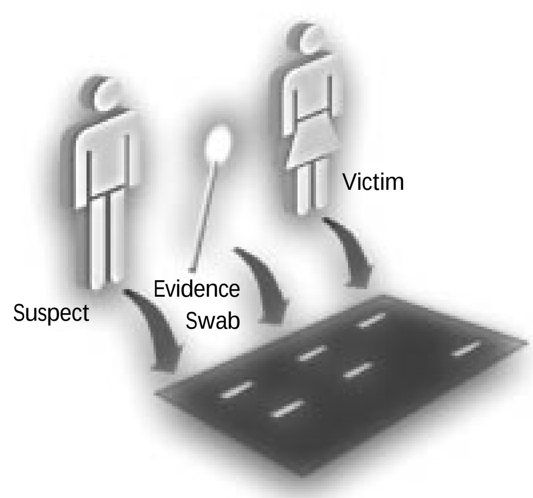
Toward a national system?

Because the United Kingdom databanking system is based nationally, it is central and uniform, not an aggregate of many different, incompatible State systems. Our "patchwork" system is improving, however, because of systems developed by the FBI, Federal support for State DNA databanking, and the convergence of DNA typing methods.

The CODIS system (COmbined DNA Index System) is a national investigative support database. Developed by the FBI, it is used in the national (NDIS), State (SDIS), and local (LDIS) DNA Index System networks to link the typing results from unsolved crime cases in multiple jurisdictions or to those convicted of offenses specified in the DNA databanking laws passed in 47 States. By alerting investigators to similarities among unsolved crimes, CODIS can aid in apprehending perpetrators who commit a series of crimes and in this way prevent other offenses by the same person. The 77 laboratories in the 36 States participating in CODIS have produced 126 case-to-case "hits" and 76 case-to-offender "hits."

For CODIS to work efficiently, all forensic laboratories must use reliable and compatible DNA test systems so that data can be compared. To that end the Violent Crime Control and Law Enforcement Act of 1994 promotes uniform standards for forensic DNA testing and provides Federal support to State and local law enforcement agencies to improve their DNA testing capabilities so they can participate in CODIS.[8] Also, to establish minimal

Method of Matching DNA Patterns Using RFLP



The DNA pattern of the suspect matches the pattern produced from the vaginal swab of the rape victim.

compatibility among laboratories, the FBI has promulgated a core set of RFLP genetic loci (specific places in DNA) and will promulgate a core set of STR loci.

On the horizon

Improved testing technologies are ensuring more efficient and effective DNA evidence processing, advances in technology and databanking promise to widen the use of DNA evidence as an investigational tool, and new sources of biologic evidence are being explored. Nevertheless, we are still far from full realization of the potential of DNA testing. As laboratories improve

A Primer of DNA Testing Technology

DNA is the chemical deoxyribonucleic acid, which stores the genetic code of the human body—the hereditary blueprint imparted to us by our parents. DNA is useful in forensics because it is present in all cells, is the same throughout the body, and does not change in the course of a person's life. Perhaps most important, for each individual (except identical twins) the DNA sequence (the order of the DNA building blocks) is different, making each person's DNA unique.

RFLP

The first type of forensic DNA test to be widely used by crime laboratories was restriction fragment length polymorphism (RFLP), based on the variation among individuals in the length of the DNA fragments. In the RFLP method, DNA is extracted and cut by an enzyme into restriction fragments, which are suspended in a gel, divided up by size, and transferred from the gel by blotting onto a membrane. In order for the examiner to see the fragments, they are identified by radioactively labeled probes, and the membrane is placed over an x-ray film. The radiation from the probe exposes the film and produces a picture of the DNA fragments, called an "autoradiogram."

A match is made when the patterns produced by DNA from an evidence stain and those from a suspect's sample DNA are found to be the same. An estimate of the statistical probability that this evidence is from the suspect rather than someone selected at random is then calculated. RFLP is powerful but is relatively insensitive, cannot be applied to degraded specimens, and is tedious and time consuming, taking about 6 weeks. More recently, to avoid the precautions needed to handle radioactive samples and to speed processing time, other labeling systems have been adopted, including chemiluminescent and fluorescent methods.

PCR

If a forensic sample is too small for RFLP testing or if the DNA is degraded, polymerase chain reaction (PCR) testing may be used to obtain a DNA typing result. PCR is a method of preparing samples in which the targeted DNA is copied many times (amplified). Two DNA molecules are produced from the original molecule; the procedure is repeated many times with a doubling of DNA fragments every time. Eventually millions of copies of a DNA sequence are produced. Although PCR is very sensitive, permitting analysis of as little as a single copy of DNA, this sensitivity also makes the sample susceptible to contamination. NIJ has provided support for the development of PCR as well as RFLP testing standards.[a]

Reverse dot/blots

The original application of PCR to DNA testing involved what is called dot/blot analysis. In a given region of DNA, there is a finite number of possible sequences ("alleles") between individuals, and a probe can be developed to determine the alleles present. In reverse dot/blot analysis, used by some forensic laboratories, amplified DNA binds to probes attached to a membrane. Membrane strips produce a blue dot in the presence of the bound, amplified DNA. Although these tests may be useful in many circumstances, their discriminatory power is low compared to other DNA typing methods, and one specimen may be contaminated with DNA from another person.

STRs

It is possible to amplify regions of the DNA molecule that show variation in DNA fragment length between individuals rather than using the RFLP method of isolating and cutting out these regions. The forensic community has found that smaller sets of fragments, called short tandem repeats (STRs), are preferable for several technical reasons. The technique of using STRs is easier and faster than RFLP, and the analysis can be performed with a number of different automated and semiautomated methods, such as capillary electrophoresis,[b] which is particularly rapid and highly automated.

Notes

a. In cooperation with the Office of Law Enforcement Standards of the National Institute of Standards and Technology, NIJ has initiated development of standards for the RFLP and PCR testing methods.

b. NIJ provided support for applying capillary electrophoresis to forensics.

their ability to process DNA evidence quickly, and as the courts' expectations of the use of DNA test results increase, there will be greater emphasis on initial collection of evidence at the crime scene.

Initial collection of evidence is a key link in the chain of events leading to successful testing, but it is also a vulnerable link. Currently the groundwork is being prepared to strengthen specimen collection and preservation, with more structured crime-scene teams and more formalized evidence collection procedures being established in many jurisdictions. The aim of these teams is to ensure that all potential evidence is recovered and properly preserved for testing, and especially to minimize the possibility of contamination.

Today much evidence is not retrieved, submitted to the lab, or analyzed. Crime labs are neither adequately funded nor fully supported. Database registries are not comprehensive and not fully utilized. People still get away with murder. But if the potential of DNA testing can be fully realized, their chances are likely to be greatly reduced.

Notes

1. Parker, B., and J. Peterson, "Physical Evidence Utilization in The Administration of Criminal Justice," in *Law Enforcement, Science, and Technology III*, ed. S.I. Cohn and W.B. McMahon, Chicago, Illinois: IIT Research Institute, 1970: 513–524. This is the only comprehensive study of physical evidence from crime scenes.

2. Ibid.

3. Van Oorschot, R.A.H., and M.K. Jones, "DNA Fingerprints From Fingerprints," *Nature* 387 (1997): 767.

4. Connors, Edward, Thomas Lundregan, Neal Miller, and Tom McEwen, *Convicted by Juries, Exonerated by Science: Case Studies in the Use of DNA Evidence to Establish Innocence After Trial*, Research Report, Washington, DC: U.S. Department of Justice, National Institute of Justice, June 1996, NCJ 161258.

5. According to statistics from the FBI, the States, and crime laboratories from other countries, DNA testing has excluded the named subject as the source of the suspect DNA in about one-third of the cases received for testing.

6. Belgrader, Phillip, Jonathan K. Smith, Victor W. Weedn, and M. Allen Northrup, "Rapid PCR for Identity Testing Using a Battery-Powered Miniature Thermal Cycler," *Journal of Forensic Sciences* 43 (1998): 315–319; and Ibrahim, M.S., et al., "Real–Time Microchip PCR for Detecting Single Base Differences in Viral and Human DNA," *Analytical Chemistry* 70 (May 1998): 2013–2017.

7. Personal communication with Lyn Fereday of the U. K.'s Forensic Science Service, Reading, England, July 15, 1997.

8. The aim of the DNA Identification Act of 1994, Title XXI of the Violent Crime Control and Law Enforcement Act of 1994 (the Crime Act), is to increase the capabilities and capacity of State and local forensic laboratories to conduct DNA testing. In the first year, NIJ awarded $8.75 million to 31 States, $8 million of which was provided from the FBI.

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