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DNA Identification Tests and the Courts

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DNA IDENTIFICATION TESTS AND THE COURTS*

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On June 30, 1987, a fifty-seven year old woman was raped in Pierce County, Washington. The victim, who suffers from Alzheimer's disease, was incapable of identifying her assailant or aiding police in their investigation. The assailant's semen was the sole clue. Police determined that only one man, the bus driver who drove her to day care, had access to the victim. Investigators performed a dramatic new test that identifies individuals by unique patterns of deoxyribonucleic acid ("DNA") contained in their cells. The test implicated the driver, who, when confronted with the results of the test, pled guilty.[1]

DNA technology offers the judicial system a powerful new test for identifying criminal suspects and tracing paternity. Every individual, except an identical twin, possesses a unique genetic "blueprint" known as DNA. This unique pattern enables scientists to use DNA tests to identify individuals, much like fingerprints enable criminologists to identify individuals.

No other blood or serum test rivals DNA's accuracy. DNA tests can match a sample of the suspect's DNA to small amounts of blood, semen, and other biological tissue recovered from a crime scene. Under ideal testing circumstances, the probability of two individuals sharing the same DNA test pattern, and thus of a match due to chance, is less than one in thirty billion. This ability to analyze DNA

1. State v. Haynes, No. 87-1-02309-7 (Pierce County Sup. Ct., Wash., Mar. 28, 1988).

could revolutionize criminal and civil prosecutions in which biological material is present.[2]

Although DNA testing has tremendous potential, the use of its results as evidence in a civil or criminal proceeding is still relatively new.[3] Currently, it is a costly and complicated procedure, performed by a few private labs with competing techniques.[4] Because of these limiting factors and concerns about the reliability of the test,[5] a

2. DNA tests have five major forensic applications. First, in criminal investigations, DNA recovered from the crime scene can link a suspect to the crime. DNA tests are especially applicable to rape cases. In 1986, 90,000 forcible rapes were reported in the United States, with arrests in only 52% of the cases. DEP'T OF JUSTICE & FBI, UNIFORM CRIME REP.: CRIME IN THE U.S. 14 (1987). DNA tests offer the potential to dramatically increase the number of arrests. DNA recovered from sperm links the suspect directly to the alleged rape. Other suspect identification tests, such as fingerprints, link a suspect only circumstantially to a crime scene or weapon but not to the crime itself. The success of DNA tests also may encourage victims of sexual assault to press charges because their testimony will be confirmed by the DNA test.

Second, DNA tests can be used in civil cases involving disputed parentage. Portions of an individual's DNA are transmitted from parent to child. DNA tests can tell courts whether two people are related by comparing their DNA. *See infra* note 61. Similarly, DNA tests can be used to screen immigrants who claim a blood relation with a United States citizen. *See* Jeffreys, Brookfield & Semeonoff, *Positive Identification of an Immigration Test-Case Using Human DNA Fingerprints,* 317 NATURE 818, 818–19 (1985) [hereinafter Jeffreys, *Positive Identification*].

Third, DNA tests can be used to distinguish serial crimes from "copy-cat" crimes. By comparing the DNA recovered from multiple crime scenes, police can determine whether more than one perpetrator is involved.

Fourth, DNA tests can exculpate wrongly accused suspects. In 1986, DNA testing was used in England to exonerate a man of multiple rape and murder charges. Later, it helped police trap the real assailant when the nearly 4000 men living near the victims' homes voluntarily submitted blood samples for DNA analysis. The assailant eventually was caught when police learned that he had sent a friend to give blood under his name. Subsequent DNA analysis linked him to the sperm recovered from the victims, and he was convicted in January 1988. Schmitz, *Murder on Black Pad,* San Francisco Chronicle, Jan. 17, 1988, This World, at 14.

Fifth, DNA tests can identify the remains of victims. *See, e.g.,* Baird, Giusti, Meade, Clyne, Shaler, Benn, Glassberg & Balazs, *The Application of DNA-Print™ for Identification from Forensic Biological Materials,* 2 J. FORENSIC HAEMOGENETICS 396, 398 (1988) [hereinafter Baird, *Forensic Applications*] (tissue found on the grille of victim's car was identified as the victim's by DNA testing and comparison with the DNA of the victim's parents).

3. Only several thousand people have been tested with any of the several DNA tests developed to date. *See infra* note 64.

4. Only three labs in the United States currently offer forensic DNA tests for use in the courts: Lifecodes Corporation in Valhalla, New York, Cellmark Diagnostics in Germantown, Maryland, and Forensic Science Associates in Emeryville, California. Forensic Science Associates performs forensic DNA analysis with significantly different procedures than the procedures used by Lifecodes or Cellmark. Haller, *Can DNA Save Dotson?,* CHICAGO LAW., Feb. 1988, at 1; *see infra* note 70 (discussing the technique used by Forensic Science Associates). Applied Genetics in Seattle, Washington opened in September 1987, and expects its first DNA tests to be introduced as evidence in the fall of 1988. Interview with Carole Jenny, M.D., Medical Director of the Harborview Hospital Sexual Assault Center, Seattle, Washington, and consultant to Applied Genetics (Feb. 3, 1988). A lab in Chicago, Illinois, is scheduled to open in 1988. Haller, *supra,* at 1.

5. *See infra* notes 70–97 and accompanying text.

number of forensic scientists and prosecutors have reacted cautiously, fearing an adverse court decision that could delay judicial acceptance for years.[6] To date, DNA tests have been introduced in only a handful of criminal cases in the United States and abroad.[7] No case has reached the appellate court level.

This Comment assesses the current state of forensic DNA tests and analyzes whether courts should admit the results of these tests as evidence. Section I provides a background discussion of how DNA tests work. This knowledge is essential for attorneys and courts seeking to evaluate expert testimony and analyze important issues concerning the reliability and admissibility of DNA test results. Section I also proposes safeguards and standards to facilitate the judicial acceptance of forensic DNA tests. Section II discusses judicial approaches to the admissibility of novel scientific techniques such as DNA tests, and concludes that courts should admit the results of DNA tests.

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6. For instance, California Attorney General John Van de Kamp thinks it is a "real possibility that we can botch a golden opportunity by rushing too quickly into court." Moss, *DNA—The New Fingerprints*, 74 A.B.A. J. 66, 68 (1988). Similarly, Charles McGowan, commanding officer of the New York City Police Department's scientific research division, states that "[a]n adverse court decision could set the whole thing back . . . . You can't act too precipitously." N.Y. Times, Feb. 7, 1988, at 13, col. 5; *see also Current Reports*, 2 BNA CRIM. PRAC. MANUAL No. 19 (1987) (James Starr, professor of law and forensics at George Washington University, cautions restraint in seeking court approval of DNA tests until further validation of the test).

Forensic crime laboratories that perform non-DNA forensic tests also have reacted cautiously. In a poll of 87 directors of crime laboratories in September 1987, one-third said DNA tests should be used in criminal investigations, one-third said they should not be used, and one-third had no opinion. Moss, *supra*, at 69. Because DNA tests are complicated and may be beyond the capabilities of some crime laboratories, crime directors also may be concerned that their position will be usurped by commercial labs that perform DNA tests. *See infra* note 136 (discussing the error rate of crime laboratories in sophisticated blood analysis).

7. On November 6, 1987, Tommie Lee Andrews became the first person in the United States to be convicted with evidence from a DNA test when DNA in the semen recovered from the rape victim was matched to a sample of DNA from his blood. Judgment at 1, State v. Andrews, Case No. 87-1565 (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Nov. 6, 1987). Andrews plans an appeal challenging the use of the DNA test and the statistical evidence used to estimate the probability that the semen came from Andrews. Telephone interview with Ken Cotter, Andrews's defense attorney (Feb. 8, 1988). Subsequently, DNA testing has been used in a variety of other cases. Lifecodes and Cellmark report that the results of their DNA tests have been admitted in the following cases: State v. McCarthy, No. 87CRS5081 & No. 87CRS5080 (Duplin County, N.C. Mar. 8, 1988) (in a criminal incest case, DNA testing demonstrated that the victim's father had sexual intercourse with her); State v. Reynolds, No. 87F670-2 & No. 87F750 (Henrico County, Va. Feb. 2, 1988) (the court admitted DNA test results in a murder case); United States v. Lake (Mar. 11, 1988) (military court admitted the results of a DNA test; the defendant subsequently pled guilty to rape and attempted murder). In addition, Cellmark's test has been admitted in criminal proceedings in the United Kingdom. *See, e.g.*, Regina v. Melias, Indictment No. 872463 (Bristol Crown Court Nov. 13, 1987) (defendant pled guilty after DNA test results linked him to a rape).

I. SCIENTIFIC BACKGROUND: HOW DNA TESTS WORK

This section is intended to familiarize the reader with DNA, its forensic application, and the labs that perform the tests.

A. The Origins of DNA Tests

DNA tests were developed for use in the field of molecular biology[8] in the search for the chromosomal location of particular genes, such as those that cause inherited diseases.[9] These tests allow physicians to diagnose the predisposition for or presence of an inherited disease at an early stage,[10] and may ultimately aid in the successful treatment of the disease.[11] DNA tests have helped identify the defective DNA associated with Huntington's disease,[12] Duchenne muscular dystrophy,[13] sickle cell disease,[14] cystic fibrosis,[15] and other afflictions.[16]

8. "The use of DNA probes has been so thoroughly assimilated into molecular biology that . . . it is hard to know how we got along without them." DNA PROBES: APPLICATIONS IN GENETIC AND INFECTIOUS DISEASE AND CANCER 1 (L. Lerman ed. 1986).

9. *See* White & Lalouel, *Chromosome Mapping with DNA Markers,* SCI. AM., Feb. 1988, at 40.

10. DNA tests can diagnose an inherited disease before any symptoms are detectable. DNA tests can even diagnose an inherited disease in a fetus. White, Lalouel, Lathrop, Leppert, Nakamura & O'Connell, *Mapping Approaches to Gene Identification in Humans,* 147 W.J. MED. 423, 423 (Oct. 1987) [hereinafter White, *Mapping*].

11. The goal, which has not yet been achieved, is to identify the defective or mutant section of DNA and either repair or replace the section with healthy DNA sequences. *See* Lathrop, Farrall, O'Connell, Wainwright, Leppert, Nakamura, Lench, Kruyer, Dean, Park, Woude, Lalouel, Williamson & White, *Refined Linkage Map of Chromosome 7 in the Region of the Cystic Fibrosis Gene,* 42 AM. J. HUM. GENETICS 38, 38 (1988) [hereinafter Lathrop, *Linkage Map*]; Marx, *Gene Therapy—So Near and Yet So Far Away,* 232 SCI. 824, 824 (1986).

To this end, researchers gradually are mapping the entire human DNA sequence, or genome, to identify the sections of DNA that are associated with disease. It has been estimated that a "map" of the human genome could be generated by six thousand molecular biologists working full time for ten years at a cost of approximately $2.25 billion. Bodmer, *Human Genetics: The Molecular Challenge,* 51 COLD SPRING HARBOR SYMPOSIA ON QUANTITATIVE BIOLOGY: MOLECULAR BIOLOGY OF HOMO SAPIENS 1, 12 (1986). *But cf.* Watson, *Foreword,* 51 COLD SPRING HARBOR SYMPOSIA ON QUANTITATIVE BIOLOGY: MOLECULAR BIOLOGY OF HOMO SAPIENS xv, xv (1986) (the human genome may take hundreds or thousands of years to fully explore).

12. White, *Mapping, supra* note 10, at 423.

13. *Id.*

14. *Id.*

15. Lathrop, *Linkage Map, supra* note 11, at 38.

16. For example, DNA tests are 80% to 90% accurate in diagnosing retinoblastoma, a malignant eye tumor occurring in 1 in 34,000 to 1 in 15,000 children in the United States. This knowledge can be vital in early diagnosis and successful treatment of this cancer. Wiggs, Nordenskjold, Yandell, Rapaport, Grondin, Janson, Werelius, Petersen, Craft, Riedel, Liberfarb, Walton, Wilson & Dryja, *Prediction of the Risk of Hereditary Retinoblastoma, Using DNA Polymorphisms Within the Retinoblastoma Gene,* 318 NEW ENGL. J. MED. 151, 151–57 (Jan. 21, 1988).

The tests also are used in anthropological research to trace human development[17] and migration patterns,[18] as well as in agricultural[19] and zoological[20] research.

The forensic use[21] of DNA tests is a recent development.[22] Increasingly, these tests are being used to identify criminal suspects and link parents to children in cases of disputed parentage. Despite the novelty of forensic DNA tests, the extensive use of the tests in other well respected scientific disciplines may enhance the judicial acceptance of forensic DNA tests. These sciences also provide a ready pool of qualified, yet disinterested, experts to testify about the DNA tests' reliability and general acceptance in the scientific community.[23]

B. How DNA Tests Work—An Overview

Before examining in detail how forensic DNA tests identify individuals, it is helpful to have a general understanding of how the tests work. First, DNA is extracted from the forensic sample, such as semen, blood, or other cellular tissue. Second, the long strands of molecules which make up the DNA are chemically cut into fragments. These fragments are sorted by length. Third, a radioactive "probe" is added. This probe binds with specific portions of the DNA to create a pattern, which varies from individual to individual. Because the probe is radioactive, the pattern can be captured on x-ray film. Fourth, the pattern is compared with the pattern produced by the suspect's DNA. If the patterns match, the forensic sample is linked with a high degree

17. *See, e.g.*, Andrews, *Fossil Evidence on Human Origins and Dispersal*, 51 COLD SPRING HARBOR SYMPOSIA ON QUANTITATIVE BIOLOGY: MOLECULAR BIOLOGY OF HOMO SAPIENS 419 (1986) (comparing human and primate DNA and fossils).

18. *See, e.g.*, Stoneking, Bhatia & Wilson, *Rate of Sequence Divergence Estimated from Restriction Maps of Mitochondrial DNAs from Papua New Guines*, 51 COLD SPRING HARBOR SYMPOSIA ON QUANTITATIVE BIOLOGY: MOLECULAR BIOLOGY OF HOMO SAPIENS 433 (1986) (compared maternal DNA of Papua New Guineans to the DNA of other ethnic groups around the world).

19. *See, e.g.*, Gerlach & Peacock, *Chromosomal Location of Highly Repeated DNA Sequences in Wheat*, 44 HEREDITY 269 (1980); Rimpau, Smith, Flavell, *Sequence Organization in Barley and Oats Chromosomes Revealed by Interspecies DNA/DNA Hybridisation*, 44 HEREDITY 131 (1980).

20. *See, e.g.*, Beckman, Kashi, Hallerman, Nave & Soller, *Restriction Fragment Polymorphism Among Israeli Holstein-Friesian Dairy Bulls*, 17 ANIMAL GENETICS 25 (1986); Wetton, Carter, Parkin & Walters, *Demographic Study of a Wild House Sparrow Population by DNA Fingerprinting*, 327 NATURE 147 (1987).

21. Use in criminal, paternity, and other legal proceedings.

22. Alec Jeffreys of the University of Leicester in England pioneered the forensic use of DNA testing in 1985. Jeffreys, Wilson & Thein, *Hypervariable "Minisatellite" Regions in Human DNA*, 314 NATURE 67 (1985) [hereinafter Jeffreys, *Minisatellite Regions*].

23. *See infra* notes 143–264 and accompanying text (discussing judicial acceptance of DNA tests).

of certainty to the suspect. If they do not match, the forensic sample did not come from the suspect.

C. *The Underlying Scientific Principle of DNA Tests*

Forensic DNA tests can identify individuals because each individual has a unique molecular pattern of DNA.[24] To understand how forensic DNA tests work, one must begin by understanding DNA's function, location within the body, and molecular structure.

1. *DNA's Function*

DNA is the substance that contains the genetic instructions used to assemble and regulate all life forms.[25] The differences we see in each other are the outward manifestations of each person's unique DNA pattern. Everything from eye, hair, and skin color to facial features and shoe sizes is determined by DNA.[26]

2. *DNA's Location and Molecular Structure*

A complete copy of an individual's DNA is located in the nucleus of every cell.[27] Thus, DNA tests can be run with identical results on a

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24. Von Beroldingen & Sensabaugh, *Forensic DNA Analysis,* 12 TIELINE 27 (1987). The only exception is identical twins, who have identical DNA. Hill & Jeffreys, *Use of Minisatellite Probes for Determination of Twin Zygosity at Birth,* LANCET, Dec. 21–28, 1985, at 1394.

25. *See* R. GAENSSLEN, SOURCEBOOK IN FORENSIC SEROLOGY, IMMUNOLOGY, AND BIOCHEMISTRY (1983) (published by the National Institute of Justice); B. LEWIN, GENE (3d ed. 1987).

26. The specific segment of DNA responsible for each inherited characteristic is called a gene. There are approximately 100,000 genes on the 46 chromosomes in a human cell. White & Lalouel, *supra* note 9, at 40. These 46 chromosomes are arranged in 23 pairs, and one chromosome per pair is inherited from each parent. R. GAENSSLEN, *supra* note 25, at 25–27. This combined maternal and paternal genetic pool accounts for the inheritance of recognizable, but not identical, traits from one generation to another, thus allowing DNA tests to determine parentage. The potential for variation between generations is enormous. In meiosis, the creating either of egg or sperm cells, segments of the chromosomes are rearranged in a process known as "cross over." This cross over results in a "patch work of segments from the two chromosomal parents" and explains why siblings do not have identical DNA or characteristics. White & Lalouel, *supra* note 9, at 40.

For a concise description of DNA and its functions, see Kelly, Rankin & Wink, *Method and Applications of DNA Fingerprinting: A Guide for the Non-Scientist,* 1987 CRIM. L. R. 105, 105–106 [hereinafter Kelly]. For a more detailed discussion, see generally B. LEWIN, *supra* note 25.

27. Mature red blood cells are the only cells that do not carry nucleic DNA, but white blood cells and other parts of the blood do. Excerpt of Trial Proceedings at 15, State v. Andrews, No. 87-1400 (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20, 1987) (from testimony of Dr. David Housman, molecular biologist from MIT during the *Frye* admissibility hearing). DNA tests cannot be performed from urine or fecal matter because they do not contain DNA.

variety of biological materials: Semen, bloodstains, hair, bone marrow, and other tissues containing nucleated cells.[28]

Each person has a unique molecular DNA pattern. The molecular structure of the DNA resembles a twisted ladder.[29] The sides of the ladder, called strands, are comprised of alternating molecules of sugar (s) and phosphate (p). The rungs of the ladder are formed by a hydrogen bonding of the bases. There are four bases in DNA, each identified by its first letter: A, T, G, & C.[30] The bonding needed to form a rung can occur only between bases A and T and between C and G (see figure I).

Figure I*

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—s p s p s p s p s p s p s p s p s p s p s p s p s p s p s p s p s—
—T  A  G  C  C  C  T  A  G  A  T  G  G  T  G  A  A  C—
   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
—A  T  C  G  G  G  A  T  C  T  A  C  C  A  C  T  T  G—
—s p s p s p s p s p s p s p s p s p s p s p s p s p s p s p s p s—
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HYPOTHETICAL FRAGMENT OF A DOUBLE STRAND DNA MOLECULE

s = Sugar Molecule
p = Phosphate Molecule
GC/CG = Complementary Base Pairs
AT/TA = Complementary Base Pairs
— = Hydrogen Bonds Between Base Pairs

* The "sp" molecules form the sides of the DNA ladder while the bonding of the base pairs G,C,A,T forms the ladder's numerous rungs.

There are approximately three billion base pairs, or rungs, in every human cell.[31] Every individual's DNA has a distinctive ordering of these base pairs, G-C, C-G, T-A, and A-T.[32] Individuals possess a

28. *See infra* notes 71–77 and accompanying text (discussing the types and sizes of biological material needed for testing).

29. This model of the DNA molecule is known as a double-helix and was first theorized by professors Watson and Crick in 1953. They were later awarded the Nobel Prize for their discovery. R. GAENSSLEN, *supra* note 25, at 22.

30. Adenine (A), Thymine (T), Guanine (G), and Cytosine (C). *Id.* at 21–23; B. LEWIN, *supra* note 25, at 42–44.

31. White & Lalouel, *supra* note 9, at 40. One way to visualize this number of base pairs in the human genome is to imagine this page covered not with text but with continuous combinations of base pairs such as ATGCATCGCGATGCGCTATACG . . . . It would take more than one million of these pages, or a volume over 70 yards thick, to equal the number of base pairs found in just one human cell. Calculation: 6 billion characters (3 billion pairs) divided by 5880 (70 characters per line, 84 lines per double-sided page) = 1 million pages (1,020,408). 1,020,408 pages divided by 400 pages per inch = 2,551 inches = 212.5 feet = 70.7 yards.

32. This "concept of base pairing is central to all [DNA] processes . . ." including forensic DNA testing. B. LEWIN, *supra* note 25, at 57.

tremendous variation in the ordering of their DNA base sequences. DNA tests use these variations in the location of base pair sequences to differentiate between individuals and to trace paternity.[33]

Not all parts of this vast DNA structure vary among individuals. The segments that do vary are known as restriction fragment length polymorphisms ("RFLP").[34]

D. How Forensic DNA Tests Identify Individuals

The previous section reviewed the scientific principles that explain why DNA tests can identify individuals. This section examines how the tests are performed, including test preparation, the administration of the test, and the analysis of the test results.

1. Test Preparation

A number of steps must be taken to prepare DNA samples for testing.[35] First, the DNA is chemically isolated from the sample material.[36] DNA samples have been isolated from blood stains,[37] body

33. The same technique is used to determine the identities of both criminal assailants and putative fathers. Only the analysis of the results is different. *See infra* notes 60–66 and accompanying text.

34. Polymorphisms, or polymorphic sites, are regions along the human DNA chain that vary from person to person. The discovery of these polymorphic sites is credited to A. Wyman and R. White. Jeffreys, *Minisatellite Regions, supra* note 22, at 67.

Molecular biologists have located over 500 polymorphic sites. Schumm, Knowlton, Braman, Barker, Botstein, Akots, Brown, Gravius, Helms, Hsiao, Rediker, Thurston & Donis-Keller, *Identification of More than 500 RFLPs by Screening Random Genomic Clones,* 42 AM. J. HUM. GENETICS 143 (1988); *see infra* note 51. These polymorphic sites are important both for tracing the genetic diseases and for forensic identification. They provide a "rich source of highly informative markers." White, *Mapping, supra* note 10, at 424.

35. The procedures used to perform forensic DNA analysis are nearly identical to those used in medical and other genetic research. Excerpt of Trial Proceeding at 12-14, State v. Andrews, No. 87-1400 (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20, 1987).

36. Depending on the type and condition of the biological sample, DNA is isolated from nuclei with a variety of chemicals and centrifuging techniques. *See, e.g.,* Gill, Lygo, Fowler & Werrett, *An Evaluation of DNA Fingerprinting for Forensic Purposes,* 8 ELECTROPHORESIS 38, 42 (1987) [hereinafter *Evaluation*]; Giusti, Baird, Pasquale, Balazs & Glassberg, *Application of Deoxyribonucleic Acid (DNA) Polymorphisms to the Analysis of DNA from Recovered Sperm,* 31 J. FORENSIC SCI. 409, 410 (1986) [hereinafter Giusti]; Jeffreys, *Minisatellite Regions, supra* note 22, at 67, 69; Kanter, Baird, Shaler & Balazs, *Analysis of Restriction Fragment Length Polymorphisms in Deoxyribonucleic Acid (DNA) Recovered from Dried Blood Stains,* 31 J. FORENSIC SCI. 403, 404 (1986) [hereinafter Kanter].

37. DNA can be recovered from dried or fresh blood. Gill, Jeffreys & Werrett, *Forensic Application of DNA "Fingerprints,"* 318 NATURE 577, 577 (1985) [hereinafter Gill]; Kanter, *supra* note 36, at 403.

tissues,[38] semen stains,[39] hair,[40] and buccal swabs.[41] Second, an enzyme[42] is added that cuts the DNA into fragments at specific points. Third, the resulting fragments, which may total in the millions, are sorted according to their various lengths by electrophoresis.[43]

During electrophoresis, an electrical current is sent through a gel containing the sample DNA fragments.[44] The DNA, which carries a negative charge, is attracted to the positive pole at the other end of the gel.[45] The longer fragments of DNA move more slowly through the gel than do the shorter fragments, resulting in a gel with the DNA sample fragments sorted by size.[46] The DNA fragments range in size from a few hundred to several thousand base pairs.[47] These fragments are measured in thousands of bases, or kilobases ("KB").[48]

In the fourth step of the process, the sorted DNA fragments are "denatured"; the hydrogen bond forming the rungs of the DNA ladder is broken,[49] and the DNA chain is split into two single strands (see

38. Baird, *Forensic Applications, supra* note 2, at 396 (DNA samples can be isolated from kidney, liver, muscle, and brain tissue).

39. *Evaluation, supra* note 36, at 38; Giusti, *supra* note 36, at 409 (DNA samples were recovered from semen stains). Vaginal DNA also has been recovered from penile swabs up to three hours after intercourse. *Evaluation, supra,* at 42.

40. DNA samples were recovered from hair roots, but no DNA was recovered from hair shafts. Gill, *supra* note 37, at 578.

41. *Evaluation, supra* note 36, at 42. Buccal swabs are scrapings of the inner mouth lining. The limited intrusion of this procedure compared to blood tests makes it an ideal source of DNA. Buccal swabs have been used to obtain analyzable samples of DNA, but the resolution of the bands produced is less than those from blood samples. *Id.* In the future, however, it may become a viable method for obtaining a DNA sample.

42. Restriction endonuclease enzymes look for specific base sequences, ranging from four to twelve base pairs in length, and digest or cut the DNA at those sites. These points along the DNA chain are called restriction sites. Von Beroldingen & Sensabaugh, *supra* note 24, at 29; White & Lalouel, *supra* note 9, at 42.

43. *See generally* Kelly, *supra* note 26, at 107: B. LEWIN, *supra* note 25, at 75; Von Beroldingen & Sensabaugh, *supra* note 24, at 29.

44. More sophisticated electrophoresis methods may involve the use of pulse currents (on/off) and alternating the poles (+/−) in order to improve the sorting process, but the underlying principle of electrical attraction still applies. *See, e.g.,* Julier & White, *Detection of a NotI Polymorphism with the pmetH Probe by Pulsed-Field Gel,* 42 J. HUM. GENETICS 45, 47 (1988).

45. B. LEWIN, *supra* note 25, at 47.

46. Sensabaugh, *Forensic Biology—Is Recombinant DNA Technology in its Future?,* 31 J. FORENSIC SCI. 393, 393 (1986).

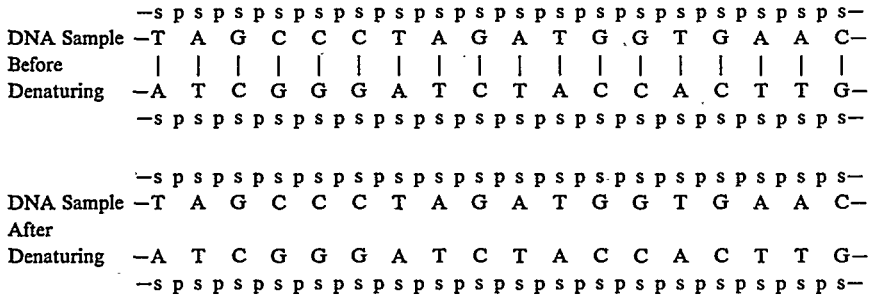
47. The fragment lengths are measured against a control sample of DNA containing standardized fragments of known length. The control DNA is run through the same electrophoresis process on a discrete portion of the same gel. The control is a ruler which measures fragment lengths. B. LEWIN, *supra* note 25, at 75; *see also* Von Beroldingen & Sensabaugh, *supra* note 24, at 27–44.

48. B. LEWIN, *supra* note 25, at 47; Von Beroldingen & Sensabaugh, *supra* note 24, at 27–44.

49. Denaturing is accomplished by either heating or increasing the *p*H level, which causes the two strands to separate. White & Lalouel, *supra* note 9, at 42. The denaturing does not alter the

figure II). The denatured DNA is then transferred from the gel to a more stable medium, typically a nylon membrane.[50]

Figure II



DOUBLE STRAND DNA MOLECULE IS SPLIT FORMING TWO SINGLE STRANDS OF DNA

2. *The Forensic DNA Test*

The sample now is ready to be tested. The RFLP probe,[51] composed of single strands of cloned DNA,[52] is added to the nylon membrane containing the sample DNA. These strands bind to specific

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DNA, which has been sorted by length; it only breaks the bond of the double helix. B. LEWIN, *supra* note 25, at 57–58.

50. This method is called Southern blotting. It is used extensively in DNA research. Southern blotting is also used as a catch-all to describe the entire process from the isolation of DNA to the making of the autoradiograph. *See, e.g.,* White & Lalouel, *supra* note 9, at 42.

51. RFLP probes are used in both forensic and nonforensic DNA tests. The probes used in forensic tests are a unique type of RFLP probe called variable number tandem repeats ("VNTR"). VNTR's detect repeated base sequences (11 to 60 base pairs in length) found throughout the DNA. Nakamura, Leppert, O'Connell, Wolfe, Holm, Culver, Martin, Fujimoto, Hoff, Kumlin & White, *Variable Number of Tandem Repeat (VNTR) Markers for Human Gene Mapping*, 235 SCI. 1616, 1617 (1987). These VNTR sequences are arranged in repeated succession along the DNA. Both Lifecodes and Cellmark Diagnostics use these polymorphic VNTR sequences for DNA analysis. Jeffreys, Wilson & Thein, *Individual-Specific "Fingerprints" of Human DNA*, 316 NATURE 76, 76 (1985) [hereinafter Jeffreys, *DNA Fingerprints*] (Cellmark Diagnostics uses Jeffreys's method of DNA analysis); Von Beroldingen & Sensabaugh, *supra* note 24, at 32–36. Textbooks on molecular biology and peer review journals demonstrate the use and acceptance of RFLP and VNTR probes in genetic research. *See, e.g.,* B. LEWIN, *supra* note 25, at 73–82; 42 AM. J. HUM. GENETICS (1988).

52. Probes are cloned using recombinant DNA methods. First, the DNA probe is isolated in human DNA and spliced into the DNA of a viral phage. Next, the phage is inserted into bacteria, usually *E. Coli,* where the phage uses the bacteria as a host to reproduce. Because the probe was genetically spliced into the phage, the probe is reproduced along with the phage's other DNA. The phages are removed and the probes are isolated. *See generally* J. WATSON, N. HOPKINS, J. ROBERTS, J. STEITZ & A. WEINER, MOLECULAR BIOLOGY OF THE GENE 596–605 (4th ed. 1987) [hereinafter J. WATSON].

segments of the denatured DNA sample and radioactively "mark" the segments, allowing them to be compared to other DNA samples. Because the probe binds to segments of DNA which vary from person to person, the probe creates a unique pattern which can identify an individual.

A probe binds to the sample DNA through a process known as hybridization. The RFLP probe is added to the denatured sample, whose double-strand has been split, and binds with the sample DNA's complementary bases.[53] In figure III, CCTAGATGGT is the probe's complementary base sequence (only A can bind with T and G with C).

Figure III

```
Denatured     —s p s p s p s p s p s p s p s p s p s p s p s p s p s p s p s—
DNA Sample    —T   A   G   C   C   C   T   A   G   A   T   G   G   T   G   A   A   C—
                               |   |   |   |   |   |   |   |   |   |
DNA Probe                      G   G   A   T   C   T   A   C   C   A
```

SINGLE STRAND OF DENATURED DNA AND PROBE BIND TO FORM HYBRIDIZED DNA

Each probe contains thousands of identical, radioactively labeled[54] strands of DNA. Once the probe has bound to all the complementary base sequences on the sample DNA, the excess probe is "washed" off. This process leaves only the probes which have successfully hybridized with the sample DNA.

Next, x-ray film is placed over the membrane. Because the probe is radioactive, it exposes the film with a banding pattern which resembles a bar code from the grocery store (see figure IV).[55] The presence of one or more bands on the film, called an autoradiograph, indicates that the probe has found and hybridized with a segment of the sample DNA.[56] The number of bands depends on the type of probe used, the

53. Depending on the temperature and salinity of the test condition (known as the "stringency condition"), probes can bind with sequences that are not exact complementary base pairs. Tests which use the low stringency conditions are more susceptible to this imperfect matching. Although these tests are reliable and produce more bands than high stringency tests, some problems in interpretation of the results may arise. *See* C. Jenny, H. Coleman, D. Reay & Sweeny, Forensic Applications of DNA Typing: A grant Application to the National Institute of Justice, 11–13 (1987) [hereinafter C. Jenny, Grant] (discussing potential problems of low stringency tests).

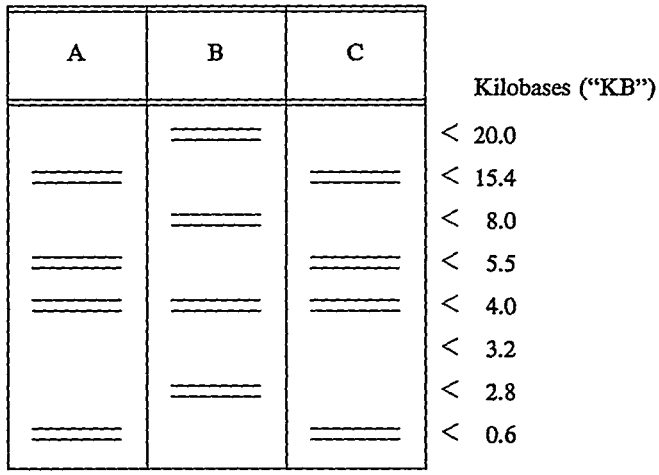
54. The phosphate molecule is marked with a radioactive isotope, usually ^{32}P. Sensabaugh, *supra* note 46, at 393–94.

55. *See, e.g., Evaluation, supra* note 36, at 39–40 (shows numerous reprints of autoradiographs and their banding pattern); Kelly, *supra* note 26, at 108 (discussing the banding pattern).

56. Kelly, *supra* note 26, at 108.

condition of the sample DNA, and the individual's unique genetic pattern.[57]

Figure IV



BANDS FROM THREE HYPOTHETICAL AUTORADIOGRAPHS: A, B, & C

A & C have identical bands indicating that they are from the same person. Even though all three samples have a band at the 4.0 KB length, sample B has other, nonmatching bands indicating that it is from another individual.

The band's location on the autoradiograph indicates the length of the DNA fragment containing the probe.[58] The location of the bands varies among individuals depending on their DNA. For any particular individual, however, the location of the bands on the autoradiograph remains constant throughout that individual's lifetime.[59] Furthermore, the bands produced will be identical regardless of whether the DNA was isolated from the individual's blood, semen, hair, or other nucleated tissue.

57. *See infra* notes 101–09 and accompanying text (discussing the various types of probes and the number of bands they produce).

58. The length is shown because the fragments were sorted according to their various lengths during electrophoresis. The lengths are in kilobases ("KB"), each unit equals one thousand base pairs, and can be read from the DNA control strip on the edge of each sample. *See supra* notes 44–47 and accompanying text on electrophoresis.

59. Mutations within an individual's DNA are very rare, and should not affect the consistency of test results. Mutations, however, may affect the location of bands passed on from parents to their offspring. *See infra* note 93.

3. *Analysis of Test Results*

Bands are "read" by comparing the bands from different samples.[60] In criminal cases, the bands from a suspect are compared with the bands from the DNA sample recovered from the crime scene. In paternity suits, the putative father's bands are compared with the bands from the child's DNA sample.[61] If the bands match, a connection is made between the samples. The number of matching bands is obtained by visually examining the relevant samples and noting the number of matches.[62] For example, samples A and C in figure IV match on all four bands.

The strength of the connection depends on the number of bands matched and the frequency of occurrence of each "matched" band in the general population.[63] The higher the number of matches, the more certain it is that the two samples came from the same individual. To compute the frequency of occurrence, data collected from previous DNA tests is used to determine the probability of a band occurring at

60. Only DNA samples exposed to the same enzyme and probe can be compared (see figure IV).

61. The child inherits roughly one-half of its DNA from each parent. Sample DNA is taken from the child, the mother, and the putative father, and DNA tests are conducted. The child's bands are first compared with the mother's bands. Those bands which match represent the maternal segments of the child's DNA and can be disregarded, unless they overlap with the father's bands. The remaining bands represent the paternal component and are compared with the bands from the putative father to determine parentage. DNA tests are particularly useful when the putative fathers are closely related (brothers/cousins) because other blood typing methods may not be able to differentiate between them. Dodd, *DNA Fingerprinting in Matters of Family and Crime,* 26 MED. SCI. L. 5, 6 (1986); *see* Jeffreys, Wilson, Thein, Weatherall & Ponder, *DNA "Fingerprints" and Segregation Analysis of Multiple Markers in Human Pedigrees,* 39 AM. J. HUM. GENETICS 11, 15 (1986) [hereinafter Jeffreys, *Segregation Analysis*].

62. Visual comparison may not be as clear and obvious as the example in figure IV might indicate, particularly when a probe detects numerous bands. Lifecodes Corporation is using a computer assisted digitizing system to compare samples. Baird, Balazs, Giusti, Miyazaki, Nicholas, Wexler, Kanter, Glassberg, Allen & Rubinstein, *Allele Frequency Distribution of Two Highly Polymorphic DNA Sequences in Three Ethnic Groups and Its Application to the Determination of Paternity,* 39 AM. J. HUM. GENETICS 489, 490 (1986).

63. The frequency of occurrence is the probability that a band will occur at a given location on the autoradiograph from a random sample taken in the relevant population.

Because bands may have different frequencies of occurrence in different population groups, the population base used should be the one to which the suspect belongs: White, black, hispanic, asian, or other ethnic group. Baird, *Forensic Applications, supra* note 2, at 399 (indicates some variation in the frequencies of bands in blacks and whites). The variations between different ethnic groups do not appear to dramatically alter the frequency of occurrence, but further testing should be conducted. *See infra* note 121 and accompanying text (discussing the need for additional testing to increase and diversify the population data). *But cf.* Letter to Authors from Bruce Lehr, Market Development Manager with Cellmark (Mar. 3, 1988) (Cellmark Diagnostics, which uses the probes developed by Jeffreys discussed below, reports no significant racial variation in band locations).

any particular point on the autoradiograph.[64] Each band is an independent variable;[65] that is, the presence of a band at one location on the autoradiograph does not affect the probability of a band occurring at another location. Because the bands are independent variables, the probability of each band's chance occurrence can be multiplied by the probabilities of the other matching bands to calculate the probability that all bands could occur in one individual. This formula is known as the "product rule" and dramatically increases the likelihood that the matching autoradiographs came from a single individual, rather than from a chance occurrence.[66]

Accordingly, when a probe produces a large number of matching bands, or when multiple probes[67] are used to increase the number of matching bands, the likelihood that the two samples matched by chance is extremely low. Under ideal conditions, the probability of two samples matching by chance is estimated to be greater than one in thirty billion,[68] or one in six times the present population of the earth.[69]

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64. Lifecodes had performed DNA analysis on over 2400 people as of May 1988. Telephone interview with Michael Baird, Ph.D., Senior Scientist with Lifecodes (May 4, 1988). Cellmark Diagnostics, along with its parent corporation ICI in the United Kingdom, has performed over 10,000 tests on over 5000 people. This number increases by a few hundred every week. Letter from Bruce Lehr, *supra* note 63.

65. Professor Joseph Felsenstein of the University of Washington's Department of Genetics indicates that the bands might not be strictly independent, but that their occurrence is still statistically independent for calculation purposes. Interview with Professor Joseph Felsenstein (Mar. 2, 1988); *accord,* Jonakait, *When Blood Is Their Argument: Probabilities in Criminal Cases, Genetic Markers, and, Once Again, Bayes' Theorem,* 1983 U. ILL. L. REV. 369, 673 (1983).

66. For example, if the four bands in figure IV each had a frequency of occurrence of .10 (one out of ten people randomly selected would have a band at that location on the autoradiograph), the probability of sample A and C matching on all four bands would be equal to .0001 (.10 × .10 × .10 × .10). *See, e.g.,* C. Jenny, Grant, *supra* note 53, at 12. In other words, the chance of samples A and C matching by chance would be one in ten thousand. The actual frequencies of occurrence may be much less than the one in ten used in the example. *See, e.g.,* Haller, *supra* note 4, at 20 (Lifecodes claims that the chance of each band's occurrence varies from one in one thousand to one in five thousand). For a discussion of dependent and independent variables, see A. AGRESTI & B. FINLAY, STATISTICAL METHOD FOR THE SOCIAL SCIENCES 167 (2d ed. 1986); Kaye, *Is Proof of Statistical Significance Relevant?,* 61 WASH. L. REV. 1333 (1986).

67. DNA samples can be exposed to repeated probing. The nylon membrane can be washed, which clears off the prior probe and allows the sample to be retested with a new probe. Baird, *Forensic Applications, supra* note 2, at 396 (reports six probes from the same sample with no significant loss in sensitivity). A new probe will only bind if the enzymes, which cut the sample DNA, did not destroy the complementary base sequence. *See supra* note 53 and accompanying text.

68. Jeffreys, *DNA Fingerprints, supra* note 51, at 76.

69. L. BROWN, STATE OF THE WORLD 1987 5 (1987) (in 1986, the UN estimated the world population at five billion).

E. Potential Problems with the Forensic Use of DNA Tests

Ideal testing conditions are not always possible with forensic DNA samples. Unlike samples gathered under sterile laboratory conditions, DNA samples recovered during a criminal investigation often are small and suffer from harsh exposure to the environment. These situations potentially may affect the reliability of DNA tests.[70]

1. Amount of DNA Needed for DNA Testing: Size

DNA tests can be performed only if a sufficient amount of DNA is recovered from the biological sample.[71] DNA tests currently require a bloodstain roughly the size of a quarter[72] or a dime-sized semen

70. An alternative to DNA tests, which use RFLP analysis, is polymerase chain reaction ("PCR"). PCR analysis can reproduce portions of insufficient or degraded DNA, amplifying them up to one million times their original size. This process has allowed identification from a single strand of hair and can be performed on any tissue amenable to RFLP probe analysis. Higuchi, Von Beroldingen, Sensabaugh & Erlich, *DNA Typing from Single Hairs,* 322 NATURE 543, 543 (1988). PCR analysis can successfully analyze a DNA sample that is 1000 times smaller than the sample required for RFLP-type analysis, according to Dr. Edward Blake, whose firm, Forensic Science Associates of Emeryville, California, uses the test. Haller, *supra* note 4, at 21. PCR testing is fast, taking only a couple of days to analyze a sample, but presently lacks the discriminatory powers of RFLP DNA tests. Von Beroldingen & Sensabaugh, *supra* note 24, at 40. Nevertheless, PCR analysis can be a powerful and cost-effective tool *to exclude* suspects, and its ability to discriminate between individuals probably will improve with further development. *Id.* at 37–40. Henry Erlich, Director of Human Genetics at Cetus Corporation, Emeryville California, which developed PCR analysis, estimates that it will soon be able to identify an individual with a less than one in a million probability that the samples matched by chance. Barinaga, *DNA Fingerprinting Database to Finger Criminals,* 331 NATURE 203 (1988). Like RFLP testing, PCR amplification is not limited to forensic use. Presently, it is used in prenatal diagnosis of viral infections with quicker results and less risk to the fetus than previous methods. Beardsley, *Supertests,* 258 SCI. AM. 34, 35 (Feb. 1986). Unlike RFLP tests, PCR analysis may not be adversely affected by low molecular weight. Both are susceptible to contamination from foreign DNA and other environmental factors which may alter the sample DNA's molecular pattern. *See infra* notes 90–97.

71. The use of DNA tests in paternity cases should not be affected by the sample size and environmental factors because an ample supply of high quality DNA material is available from all the parties.

72. This amount corresponds to a bloodstain of at least 50 microlitres ("mL"). Sensabaugh, *supra* note 46, at 395.

stain.[73] Other biological samples such as hair[74] and tissue[75] samples have their own threshold amounts below which no test is possible.[76]

The need for sufficient amounts of DNA is crucial. In rape cases, where a semen stain is the only biological evidence, approximately half of all the samples given to one laboratory were untestable.[77] Nevertheless, an insufficient sample does not affect the reliability of DNA tests. If an inadequate sample is tested, the test is unreadable and produces no identification, and thus neither falsely incriminates an innocent suspect nor exculpates a guilty one. Therefore, an inadequate sample size does not affect the reliability of DNA tests because the results are merely inconclusive.

2. *Environmental Contamination: High Molecular Weight*

Environmental factors also may make a sample unsuitable for testing. When a DNA sample is intact, it has a high molecular weight[78] and is suitable for DNA analysis. High molecular weight is needed because DNA tests compare bands found on DNA fragments cut at specific lengths and sorted by size.[79] Exposure to the environment,

73. This amount corresponds to a semen stain of at least 10mL. *Id.* A normal post-rape vaginal swab will yield 100mL of fluid, requiring a ratio of semen to vaginal fluid of at least 1 to 10 to obtain sufficient DNA to analyze. *Id. But cf. Evaluation, supra* note 36, at 43 (reports successful results from as little as 6mL of semen).

74. At least 15 hairs are needed. Von Beroldingen & Sensabaugh, *supra* note 24, at 37.

75. Skin, buccal swabs, organs, muscle tissue, and bone marrow. *See, e.g.*, Baird, *Forensic Application, supra* note 2, at 396; *Evaluation, supra* note 36, at 38. Presently, DNA tests require between 1 to 10 micrograms of isolated DNA to successfully analyze a sample. Sensabaugh, *supra* note 46, at 395.

76. Generally, the smaller the amount of sample DNA, the fewer and fainter the resulting bands will be. Eventually, no bands will be discernible. *See, e.g., Evaluation, supra* note 36, at 43; *see also* Decision and Order at 22, People v. Wesley, Index No. DA 311-87 (Albany County, N.Y. July 15, 1988) (disinterested molecular biologists from the Yale University School of Medicine and the Cold Springs Harbor Laboratory testified that insufficient DNA or improper performance of the DNA test merely results in a "blank" test such that no identificiation is possible).

77. This figure included samples that were contaminated or degraded from environmental conditions. Telephone interview with Michael Baird, Ph.D., *supra* note 64; *see also Evaluation, supra* note 36, at 42 (vaginal swabs taken one to forty-eight hours after sexual intercourse produced a successful analysis 62% of the time, but a lower success rate was predicted under field conditions). Despite this disappointing percentage, advancements in the DNA tests should allow greater success in these marginal cases, according to Professor Sensabaugh of the Department of Biomedical and Environmental Health Sciences, University of California at Berkeley. Sensabaugh, *supra* note 46, at 395.

78. High molecular weight DNA is DNA that has not degraded into small fragments, and is therefore suitable for DNA probe analysis. Kanter, *supra* note 36, at 405.

79. *See supra* notes 42–48 and accompanying text (discussing enzyme cutting and electrophoresis).

however, may degrade or cut the DNA into small random chunks, making it unsuitable for DNA testing.[80]

Currently, scientists are researching the environmental conditions that may affect the molecular weight of DNA samples.[81] These conditions include exposure to light,[82] moisture,[83] heat,[84] radiation,[85] chemical agents,[86] and age.[87] The research has three primary goals: First, to determine through empirical testing the effect of environmental contamination on the DNA; second, to determine if those effects alter the results of the DNA test; and third, to provide insight into optimal retrieval, storage, and analysis conditions.[88]

Although environmental contamination does limit the number of samples which can be successfully tested, it does not affect the reliability of DNA tests. Environmental contamination, like an insufficient

80. Any resulting bands will be compressed together at the end of the autoradiograph containing the smallest fragments of DNA. Because most of the fragments are small, they will be drawn through the gel during the electrophoresis at the same rate. *See* Kelly, *supra* note 26, at 107.

81. Research is being conducted by both criminal and commercial labs including the FBI, which is conducting an evaluation of all the various DNA tests. Telephone interview with Randy Murch, researcher at the FBI's Quantico Laboratory (Feb. 8, 1988); Schmitz, *supra* note 2, at 17 (FBI is conducting an 18-month study on the reliability of DNA tests); C. Jenny, Grant, *supra* note 53, at 16–18 (Applied Genetics, a private lab, is now studying the effects of aging, nonhuman DNA, and DNA's reactions with various materials).

82. Ultraviolet light is known to cause mutation in DNA sequences. Sensabaugh, *supra* note 46, at 395–96.

83. Moisture accelerates the degrading of the sample by breaking down the cellular structure and exposing the DNA to the elements. For example, blood stains placed in a box and subjected to 100% humidity degraded after three days. *Evaluation*, *supra* note 36, at 42.

84. Sensabaugh, *supra* note 46, at 395.

85. One of the earliest studies on DNA and mutation used x-ray radiation to alter the DNA molecules of Drosophilia flies. R. GAENSSLEN, *supra* note 25, at 38 (Muller's 1927 experiments with the x-ray mutation of the DNA in flies earned him the Nobel prize); J. WATSON, *supra* note 52, at 340 (discusses rates of spontaneous mutation).

86. Natural enzymes or other chemicals in the environment can alter or destroy DNA's molecular structure. Applied Genetics is researching these types of contaminations. C. Jenny, Grant, *supra* note 53, at 13.

87. DNA probes have been performed reliably on aged, dried semen and bloodstains. Gill, *supra* note 37, at 577 (probed DNA from dried blood and semen over four years old using Jeffreys's probe). Kanter, *supra* note 36, at 403 (probed DNA from dried blood over three years old using White's probes); *see also* Paabo, *Molecular Cloning of Ancient Egyptian Mummy DNA*, 314 NATURE 644, 644–45 (1985) (DNA has even been recovered from ancient Egyptian mummies although the DNA was of low molecular weight). Of course, environmental conditions may alter the degrading process regardless of the sample's age.

88. Improvements in gathering, storing, and analyzing biological samples by police and criminal investigators should increase the rate of successful analysis. Improvements in storage may include: Use of subzero freezers, air drying, refrigeration of the sample, or sealing the sample in a container filled with an inert gas to prevent degradation. Research will help determine the optimal techniques to extend the range of samples which can be successfully tested. Interview with Carole Jenny, M.D., *supra* note 4.

sample size, produces unreadable, but not unreliable, results, and thus produces no identification at all.[89]

3. *Environmental Contamination: Potential for False Positives*

For DNA analysis to be reliable and accepted by the courts, it must not produce false positive results, which indicate a band where none should have appeared. If environmental contamination produced a false positive, then the reliability of DNA tests would be suspect because the sample could conceivably incriminate an innocent suspect or exculpate a guilty one.

Researchers believe the most likely sources of potential false positive results are bacterial[90] and other nonhuman[91] DNA cross-hybridization[92] with the DNA probe.[93] These researchers posit that false and misleading bands could be produced if the probe binds to any foreign DNA contained in the sample.[94] The presence of foreign DNA, how-

89. The bands will be blurred together at the small fragment end of the autoradiograph, and the results cannot be interpreted. *See* Moss, *supra* note 6, at 67 (describing the limits on DNA analysis due to sample size and condition).

90. Applied Genetics is working under a Justice Department grant to explore the effects of bacterial contamination on DNA test results. C. Jenny, Grant, *supra* note 53, at 13.

91. Other foreign DNA in the sample can include animal, bacterial, or viral DNA. *Id.* at 13, 16–17.

92. Cross-hybridization is the erroneous hybridizing of the DNA probe. Cross-hybridization can occur in two ways. First, the DNA probe may hybridize with foreign DNA in the sample. Second, the viral phage in which the probe was cloned might cross-hybridize with parts of the sample DNA in areas not associated with the probe itself. Interview with Carole Jenny, M.D., *supra* note 4.

93. Other sources include genetic mutation (changes in the location of the DNA bands). Spontaneous mutation can occur in human DNA, but such mutations are rare. J. WATSON, *supra* note 52, at 340; *see also* R. GAENSSLEN, *supra* note 25, at 38. Because DNA is relatively constant through an individual's lifetime, mutations are not likely to alter the banding pattern significantly. Interview with D. Stadler, Ph.D., University of Washington, Department of Genetics, Seattle, Wash. (Feb. 25, 1988). Although mutation rates within an individual are extremely low, mutations from parents to their offspring may be as high as 5% in the most unstable portions of DNA. This possibility of new or mutant bands occurring in the DNA of the child should be considered when DNA tests are used to establish parentage. Jeffreys, Royle, Wilson & Wong, *Spontaneous Mutation Rates to New Length Alleles as Tandem-Repetitive Hypervariable Loci in Human DNA*, 332 NATURE 278, 278 (1988). *But cf.* Interview with Michael Baird, Ph.D., *supra* note 64 (in 2000 paternity tests, no bands found in the offspring's DNA were attributable to mutation).

A second source of potentially inaccurate or misleading bands is incomplete digestion of the sample DNA by the enzyme. Partial digestion can be detected by using control DNA fragments of known lengths and thus should not be a major problem. *Evaluation, supra* note 36, at 44.

94. Lifecodes reports that erroneous bands have been produced by bacterial DNA present in the sample DNA. Interview with Michael Baird, Ph.D., *supra* note 64. Jeffreys's test appears to be unaffected by microbial contamination and does not hybridize with DNA from bacteria or yeast. *Evaluation, supra* note 36, at 38 (findings by the Central Research Establishment, a government forensic laboratory in the United Kingdom).

ever, can be detected by the use of "screening" probes, which alert scientists to the presence of bacteria and ensure that the sample DNA is of human origin.[95] Because foreign DNA can be detected, it does not affect the reliability of DNA tests.

In general, DNA is a stable substance, particularly when compared to protein or antigen genetic markers.[96] Accurate identifications have been achieved under numerous "real world" environmental conditions, which suggests that the tests are reliable.[97] The exact limits of DNA's stability in adverse environments, however, is still being assayed and catalogued.

F. Who Performs Forensic DNA Tests

The judicial acceptance of DNA tests as forensic evidence depends not only on a demonstration that DNA tests are theoretically sound and reliable, but also on the establishment of competent forensic testing laboratories and procedures.

1. Testing Facilities

In the United States,[98] forensic DNA tests are available from two commercial laboratories, Lifecodes and Cellmark Diagnostics,[99] but the number of laboratories performing the test is rapidly expanding.[100]

95. Lifecodes uses screening probes to alert the microbiologist to the presence of bacteria or human DNA. Baird, *Forensic Applications, supra* note 2, at 397. Another Lifecodes probe hybridizes with DNA found only on the Y chromosome, ensuring that the sample contains male DNA. *Id.*

96. *See* Sensabaugh, *supra* note 46, at 396. Analyzable DNA has been recovered from four-year-old dried bloodstains. In contrast, non-DNA tests of blood using ABO typing cannot be analyzed after six months. The more accurate Human Leukocyte Antigen ("HLA") test is even less stable and often deteriorates in days. *See* P. GIANNELLI & E. IMWINKELRIED, SCIENTIFIC EVIDENCE § 17-8 (1986 & Supp. 1987). In terms of accuracy, HLA, the most discriminating of the non-DNA blood tests, can only identify suspects in the range of one in a thousand or ten thousand. DNA's accuracy of identification is often in the range of one in a million or billion. *Id.*

97. *See generally Evaluation, supra* note 36, at 44.

98. The United Kingdom also is using forensic DNA tests. The Home Office Forensic Science Service of the Central Research Establishment ("CRE") (the equivalent of our FBI) and Imperial Chemical Industries, PLC ("ICI") (the parent corporation of Cellmark Diagnostics) are both actively engaged in the development and use of forensic DNA tests. *See. e.g., Evaluation, supra* note 36, at 38 (CRE conducted an independent evaluation of the probes and techniques used by Jeffreys and Cellmark). Additionally, the Canadian Ministry of the Attorney General, Toronto, Ontario, is in the process of preparing its first case using DNA tests. Telephone interview with Ricardo Federico, Student-at-Law, Ministry of the Attorney General (May 2, 1988).

99. *See supra* note 4.

100. *Id.*

Both Lifecodes and Cellmark analyze DNA samples with similar tests that use different probes.[101]

Lifecodes, which was the first lab to have had its tests admitted in any state criminal court, employs probes developed by Ray White of the University of Utah.[102] Each probe produces only one or two bands in the 1.5 to 20 kilobase range.[103] Multiple probes[104] are needed to obtain the high probabilities attributed to DNA analysis.[105]

Cellmark Diagnostics, whose test has been used in numerous court cases in the United Kingdom and more recently in a number of civil and criminal cases in the United States,[106] employs a single probe developed by Alec Jeffreys of the University of Leicester in England.[107] This probe yields about 11 to 15 bands in the 4 to 20 KB range[108] and can produce extremely high probabilities that a sample came from a particular individual.[109]

2. *Comparison of the Competing Techniques*

Proponents of each test claim advantages over the other. Lifecodes and advocates of White's probes claim that the presence of just one or

101. The specific RFLP probes used are different, but the techniques—DNA isolation, enzyme cleavage, electrophoresis, blotting, denaturing, hybridization, and autoradiographic imaging—are very similar. *See, e.g.*, Giusti, *supra* note 36, at 410–11 (describing Lifecodes procedures); Jeffreys, *DNA Fingerprints, supra* note 51, at 76–77 (describing the same procedures as used by Cellmark).

102. Haller, *supra* note 4, at 20. White's probes are also being used by Applied Genetics in Seattle. C. Jenny, Grant, *supra* note 53, at 10–11. Lifecodes also uses other probes from other sources or that it has developed on its own. These probes are similar to White's probes in that they only produce one or two bands. Interview with Michael Baird, Ph.D., *supra* note 64.

103. Von Beroldingen & Sensabaugh, *supra* note 24, at 36.

104. The use of combined multiprobes, which hybridize on different portions of the sample membrane, is being investigated to simplify the procedure. Wainscoat, Pilkington, Peto, Bell & Higgs, *Allele-Specific DNA Identity Patterns*, 75 HUM. GENETICS 384, 384 (1987) (discussing a method using one restriction enzyme and a mixture of five probes). This may help lower the cost of the tests. Interview with Carole Jenny, M.D., *supra* note 4.

105. Baird, *Forensic Applications, supra* note 2, at 396. Lifecodes calculates that with four matching DNA probes, the probability of matching by chance is less than one in one hundred million. *Id.* Lifecodes, using five probes, now claims the probability of matching by chance is less than one in one billion. Telephone interview with Michael Baird, Ph.D., *supra* note 64.

106. *See supra* note 64.

107. Jeffreys has actually developed several of these probes but because of their high number of bands, only one is usually necessary to produce a unique autoradiograph. Jeffreys, *DNA Fingerprints, supra* note 51, at 76. Cellmark also is developing probes similar to those employed by Lifecodes. These probes produce only one or two bands, and have the benefits attributable to Lifecodes' probes. *See infra* notes 110–11 and accompanying text.

108. Jeffreys, *DNA Fingerprints, supra* note 51, at 77 (reported a mean of 15 bands per sample). *But cf. Evaluation, supra* note 36, at 40 (reported a mean of only 11 bands per sample).

109. Jeffreys, *DNA Fingerprints, supra* note 51, at 76 (Jeffreys calculates the probability that bands matching in two individuals chosen at random are less than one in thirty billion).

two bands makes for a clear and unambiguous interpretation. In contrast, the numerous bands produced by the Jeffreys probe makes the interpretation and matching of the bands difficult.[110] Additionally, White's probes, unlike Jeffreys's, produce readable bands from shorter fragments of DNA in the 1.5 to 4 KB range. This feature allows for the testing of slightly degraded fragments of DNA.[111]

Cellmark and Jeffreys's supporters claim that their technique offers four advantages. First, each probe produces numerous bands, and thus the technique is highly discriminating.[112] Second, because the technique employs only one probe, it is simpler and reduces the possibility of testing errors.[113] Third, because the Jeffreys probe has been used widely in the United Kingdom, it has a larger population database[114] than do Lifecodes' probes. Finally, the technique has been extensively tested by an independent government lab.[115]

Although both methods of DNA analysis appear scientifically sound, the type of probes used by Lifecodes may be easier to computerize and hence may be more useful if databanks containing DNA analysis from convicted offenders are to be established.[116] Neverthe-

110. Von Beroldingen & Sensabaugh, *supra* note 24, at 36; Interview with Carole Jenny, M.D., *supra* note 4; *see also* Dodd, *supra* note 61, at 7 (describes Jeffreys's technique as requiring "meticulous expertise and much experience in reading and interpretation of the bands . . ."). Interpretation is more difficult when both the victim's and the assailant's DNA are mixed in a sample, but techniques are available to separate the sperm from vaginal fluid. *Id.* at 5; *Evaluation, supra* note 36, at 38. Supporters of White's method assert that separation is not necessary under their technique and that the presence of the victim's band or bands is helpful because it can be used as a control to ensure that the sample is actually from the victim. C. Jenny, Grant, *supra* note 53, at 12.

111. The longer fragments of DNA degrade sooner than do the smaller fragments. Because White's probes produce interpretable bands with smaller fragments at the 1.5 to 4 kilobase range, slightly degraded DNA samples can still be successfully analyzed. Jeffreys's probes are often unreadable at that range because of background interference. *Evaluation, supra* note 36, at 40.

112. Eleven to fifteen bands are produced from a single probe. *See supra* note 108. Proponents of White's probes counter with the claim that probabilities are still compelling whether it is one in one hundred million or one in thirty billion. Telephone interview with Michael Baird, Ph.D., *supra* note 64.

113. One probe is quicker, easier, and less costly to administer than multiple probes. Additionally, Jeffreys's probe has shown no cross reaction (hybridization) with bacterial DNA. *Evaluation, supra* note 36, at 38. *But cf.* C. Jenny, Grant, *supra* note 53, at 13 (reports occasional bacterial cross reaction with Jeffreys's probe).

114. *See supra* note 64 (discussing population data).

115. *Evaluation, supra* note 36.

116. Unlike the pattern of a fingerprint, the bands of an autoradiograph are easily digitalized and computerized. White's probes are particularly easy to read because they produce a limited number of bands and are easier for a computer to "read." A databank could be extremely helpful in identifying repeat offenders. Because of the high rate of recidivism among sexual offenders, many state, county, and national law enforcement organizations have proposed the establishment of routine testing and recording of DNA samples from convicted sex offenders. On March 28, 1988, King County, Washington passed an ordinance requiring DNA testing of all

less, both techniques seem to offer reliable matching of DNA samples under a variety of conditions.

G. Proposed Safeguards and Standards for DNA Testing

Regardless of which technique is used, certain procedural safeguards should be followed to ensure the reliability of the DNA test results. Recently, several sets of standards have been promulgated.[117] These standards are designed to address the concerns about the reliability of DNA tests in forensic situations. Because the laboratories currently performing the tests have adopted their own safeguards and standards, these proposed standards are not prerequisites for judicial acceptance. Nevertheless, implementation of these safeguards and standards means that all currrent and future laboratories will operate under proven standards, which will help assuage judicial concerns about the reliability of the tests. The concerns expressed in these proposals can be summarized as follows.

1. Stability of the Probe Used in DNA Test

A stable probe ensures that the results of DNA tests are constant and can be independently verified. Therefore, any probe used must be validated as a stable genetic marker.[118] A stable genetic marker will produce bands at the same location throughout an individual's lifetime, and a portion of those bands will be passed on to any offspring. Both Jeffreys's and White's probes appear to meet these criteria.[119]

convicted sex offenders. King County, Wash. Ordinance 8453 (Mar. 28, 1988). The California Attorney General's Office plans to have a state-wide database on-line in three to five years, and currently requires blood and saliva samples of all convicted sex offenders. Barinaga, *supra* note 70, at 203.

117. American Association of Blood Banks ("AABB") Parentage Committee, Proposed Standards For Tests Involving DNA Polymorphisms (Nov. 1987); Society For Forensic Haemogenetics, Statement Concerning DNA-Polymorphisms (1987); *see also* Sensabaugh, *supra* note 46, at 394; Von Beroldingen & Sensabaugh, *supra* note 24, at 36; Guest Lecture by E. Blake, *Scientific and Legal Issues Raised by DNA Analysis,* 7–8, DNA Seminar, Cal. Ass'n of Crime Lab. Directors (Nov. 18–19, 1987).

118. AABB Parentage Committee, *supra* note 117; Society of Forensic Haemogenetics, *supra* note 117.

119. Baird, *Forensic Applications, supra* note 2, at 396; Gill, *supra* note 37, at 577. Extensive pedigree studies by White and others have confirmed the stability of the probes as well as their inheritance from generation to generation. *But cf. supra* note 93 (mutation rates should be considered in paternity determinations).

2. *Sufficient Population Data*

The bands produced by DNA tests can be reliably interpreted only if their frequency of occurrence in the population is known.[120] The only way to determine the frequency of each band's occurrence is by extensive testing of the general population, including various ethnic groups which might have different frequencies of occurrence for the bands.[121]

Presently, Lifecodes has tested over 2400 people while Cellmark has generated a population base of over 5000. Scientists believe that these numbers are sufficient to ensure reliability, and the population base grows every day, increasing the reliability and accuracy of the DNA tests.[122]

3. *Continued Testing of Environmental Factors*

Although environmental contamination does not appear to affect the reliability of DNA tests, as tests run on a contaminated sample produce no identification, the exact limits of the effects of environmental contamination have not been catelogued. To avoid concerns that environmental contamination could potentially produce false or misleading results, continued empirical testing must be conducted to clearly delineate the limits of DNA tests and to devise controls for the environmental factors which could affect analysis.[123] Experts from the commercial labs and the academic community believe that this further empirical testing will only confirm the reliability of DNA tests.[124]

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120. AABB Parentage Committee, *supra* note 117; Society of Forensic Haemogenetics, *supra* note 117.

121. AABB Parentage Committee, *supra* note 117; Society of Forensic Haemogenetics, *supra* note 117. The number of samples needed to establish a population frequency varies depending on the number of alleles present. Alleles are alternate genes capable of occupying a single location on a chromosome (e.g., a plant which carries a gene for red or white flower has two alleles). As few as several hundred samples may be sufficient when only a few alleles are present. The larger the number of possible alleles, the larger the necessary sample population. When numerous bands are matched, however, the precision of the bands' frequencies becomes less important. Interview with Ellen Wisjam, statistical geneticist at the University of Washington, Seattle, Wash. (Feb. 29, 1988).

122. *See infra* notes 243–51 and accompanying text.

123. AABB Parentage Committee, *supra* note 117; Society of Forensic Haemogenetics, *supra* note 117. Controls include screening for bacterial and other nonhuman contaminants, ensuring complete digestion by the restriction enzyme, and using a control DNA of known length to assure the uniform measurement of samples run on different gels.

124. *See, e.g.*, Moss, *supra* note 6, at 69 (Dr. George Sensabaugh of the University of California at Berkeley's School of Public Health believes that further empirical testing will not produce "any surprises" affecting the reliability of DNA tests). This view is shared by Carole Jenny, M.D., Medical Director of Harborview Hospital's Sexual Assault Center, Seattle,

4. *Written Laboratory Protocols and Independent Review*

Every lab offering DNA tests should follow written guidelines, or protocols, which lay out the procedures for training, equipping, and reviewing the labs and their personnel.[125] All labs now performing forensic analysis of DNA have established some sort of lab protocols to ensure the reliability of their DNA tests.[126]

These protocols should cover the entire process, from the "chain of custody" once the sample is received,[127] to step-by-step testing procedures,[128] and review of the results, including administrative or record-keeping procedures.[129] Results should be interpreted by a technician who was not involved in the test and is unaware of the sources of the samples. All results should be reviewed by the senior scientist or labo-

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Washington, and consultant with Applied Genetics. Interview with Carole Jenny, M.D., *supra* note 4.

125. AABB Paentage Committee, *supra* note 117; Society of Forensic Haemogenetics, *supra* note 117.

126. For example, the Central Research Establishment, a government forensic lab in the United Kingdom, has produced a 51-page lab protocol outlining the procedure for receiving a sample for DNA analysis and describing in detail the isolation, sorting, and probing of the DNA. Werrett & Lygo, The Analysis of Samples For DNA "Fingerprints" (unpublished document on file with the *Washington Law Review*). Lab protocols should be written and available for peer review. Lifecodes is in the process of compiling a written protocol and has had its protocol reviewed "in some detail" by an independent scientist, Professor David Housman of the Massachusetts Institute of Technology. Trial Excerpt at 13, State v. Andrews, No. 87-1400, (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20, 1987). Cellmark Diagnostics also employs strict lab protocols in its DNA testing. Letter from Bruce Lehr, *supra* note 63.

127. For example, at Cellmark Diagnostics, the three parties in paternity cases (mother, child, and putative father) must present identification, sign a form acknowledging who they are, and be photographed. In some jurisdictions, thumb prints also are taken. Once the blood sample has been drawn, it is placed in a container along with the photograph and a statement by the technician who drew the blood. The container is then sealed with evidence tape. Upon arrival at Cellmark, it is inspected for tampering and catalogued. The sample is stored in a locked freezer and must be signed out by a technician in the presence of a second technician. Letter from Bruce Lehr, *supra* note 63.

128. Procedures include isolating, cutting, and sorting the DNA, as well as methods to ensure complete cutting of the DNA by the enzyme, the use of controls to alert the lab technician to inconsistencies in the test, and the uniformity of enzymes, gels, and probes used during the test. *See, e.g.*, Werrett & Lygo, *supra* note 126, at 4–23. These procedures will vary somewhat from lab to lab but should be available for review by any interested party.

129. The record should include documentation of the chain of custody, the type of enzyme, probe, and technique used, and any problems or anomalies encountered during the test or in the interpretation of the results. Further, the nylon membrane containing the sample should be preserved and made available for independent analysis by the defense. *See infra* note 202 (discussing the defense's right to retest DNA samples). Access to the DNA can be a problem when the biological sample is limited. In Seattle, Washington, a rape suspect objected to the testing of the biological evidence (a semen stain) because it would alter the evidence. A compromise was eventually reached and only half the sample was sent for DNA analysis. Telephone interview with Carole Jenny, M.D., July 26, 1988.

ratory supervisor.[130] The protocols also should establish minimum qualifications and training requirements[131] for technicians who perform the tests and for the supervisors who review them.[132]

Protocols currently used by the forensic laboratories seem to adequately cover these concerns. Nevertheless, not all labs have clearly codified their protocols or made them available for peer review. Access to written protocols would demonstrate that labs have adopted proper procedures and facilitate independent evaluation of lab procedures and standards.

Periodic evaluations of laboratories, including "blind tests,"[133] should be performed by independent, disinterested experts to ensure that the results of the DNA tests are accurate and that the lab protocols are properly implemented.[134] Independent testing currently is being done by the FBI's laboratory in Quantico, Virginia and at several universities.[135]

The need for protocols and independent review is particularly important if DNA tests eventually are to be performed by forensic

130. For example, at Cellmark each test is separately scored by two technicians and then reviewed by the laboratory manager. All three persons must independently agree on the presence of a band and all interpretations of results are kept on file. Letter from Bruce Lehr, *supra* note 63.

131. Cellmark requires at least a Bachelor of Science degree of its technicians, but many have Master's degrees as well. In addition to their educational requirements, Cellmark's technicians complete a training program and must demonstrate proficiency before they are allowed to conduct any tests. *Id.*

132. Laboratory supervisors at both Lifecodes and Cellmark have Ph.D.'s and extensive prior experience with DNA technology. Letter from Bruce Lehr, *supra* note 63; telephone interview with Michael Baird, Ph.D., *supra* note 64.

133. Blind tests are controlled tests in which the technician does not know which samples are from which individual. Successful matching of the samples in a blind test assures the accuracy and reliability of a testing procedure. In the U.K., blind trials were conducted on Jeffreys's technique. *Evaluation, supra* note 36, at 39–40 (correctly matched all blood and semen samples containing sufficient DNA to be analyzed). Lifecodes has allowed independent scientists to impartially review and verify Lifecodes's procedures and results. A. MOENSSENS, F. INBAU & J. STARRS, SCIENTIFIC EVIDENCE IN CRIMINAL CASES 358–59 (3d ed. 1986) [hereinafter A. MOENSSENS]. This type of independent review is essential to assure the reliability of a technique and the laboratory that uses the technique.

134. In addition to general peer review, some type of accreditation may be necessary by the FBI, Justice Department, the American Association of Blood Banks, the Society of Forensic Haemogenetics, or some other peer review organization. For example, the American Board of Forensic Toxicology ("ABFT") certifies forensic toxicologists. ABFT certification requires an advanced degree from an accredited institution as well as professional experience. A. MOENSSENS, *supra* note 133, at 388. Certification and licensing requirements are a growing "trend . . . in all forensic sciences." *Id.* at 470.

135. The FBI is studying the techniques and probes used by both Lifecodes and Cellmark Diagnostics, as well as the PCR analysis developed by Cetus and used by Forensic Science Associates. Researchers at the Universities of California at Davis and at Berkeley also are testing various DNA analysis techniques. Moss, *supra* note 6, at 69–70.

laboratories. In the past, many forensic labs have exhibited a poor track record when performing sophisticated blood analysis.[136] Because most forensic labs are government agencies, they may be viewed as extensions of the prosecution in criminal cases.[137] Thus, indepenent testing ensures that the DNA tests are performed accurately.

As an additional requirement, when the results of DNA tests are used in a civil or criminal proceeding, the defendant should have access to independent review and retesting of the DNA analysis.[138]

5. *Ultimate Goal: Standardized System of Forensic DNA Analysis*

Eventually, one standardized system of DNA analysis should be adopted.[139] A standardized system has many virtues. First, uniform use of one or several probes will help generate large population statis-

136. The potential problems of improper training and procedures in forensic labs were identified in a three-year study funded by the Justice Department to test the analytical proficiency of forensic laboratories nationwide. Labs were sent identical dried blood stains for analysis. 71.2% of the 128 labs which submitted results either mistyped the blood or reported "inconclusive" results not supported by the testing results. Peterson, *Final Report Laboratory Proficiency Testing Research Program,* Grants 74NI-99-0048 and 76NI-99-0091 (National Institute of Law Enforcement & Criminal Justice, Law Enforcement Assistance Administration, U.S. Department of Justice, 1978). Thus, all forensic labs may not be adequately equipped and their personnel may not be adequately trained to perform DNA tests.

137. *See infra* notes 192–95 and accompanying text. Proponents of commercial labs claim they not only have greater expertise, but also are free from this prosecutorial taint because they will perform the DNA test for either side.

138. AABB Parentage Committee, *supra* note 117; Society of Forensic Haemogenetics, *supra* note 117. Independent retesting of samples (not a problem in paternity) may be a problem in criminal cases where the size of the sample allows only one analysis. At least two separate analyses of the autoradiograph and detailed records of the test and procedures also should be available to the defendant. *Id.; see also* Letter from Bruce Lehr, *supra* note 63, (discussing multiple confirmations of test results); Werret & Lygo, *supra* note 126, at 2 (the CRE protocol requires duplicate testing of samples whenever possible until the accuracy and error rate are clearly established).

139. AABB Parentage Committee, *supra* note 117; Society of Forensic Haemogenetics, *supra* note 117. "System" describes the entire process used by different labs in analyzing forensic DNA samples. Any standards promulgated should adequately protect the legitimate commercial interest and investment by the developers of these forensic tools but also should ensure access to the necessary tools, including the probes, by the forensic community. *Id.* The availability of enzymes, gels, and probes at a reasonable fee is an important factor in selecting any standard system. *Id.* The United Kingdom has adopted a standardized system using the Jeffreys technique and has benefited from these virtues. Establishment of a single system was guided by the United Kingdom's Home Office of Forensic Science's Central Research Establishment ("CRE"). The CRE has been active in the testing and introduction of DNA analysis into the courtroom. *See Evaluation, supra* note 36 and accompanying text. No comparable governmental action has been taken in the United States, although the FBI lab in Quantico, Virginia is conducting an in-depth analysis of the various tests. Telephone interview with Randy Murch, *supra* note 81; Schmitz, *supra* note 2, at 17 (FBI is conducting a 18-month study on DNA test reliability).

tics quickly because the samples from different labs can be aggregated into a common population data bank for determining population frequencies. Second, uniform procedures are easier to regulate, and to criticize if they deviate from accepted procedures. Independent testing by different labs would be facilitated, since they would all use the same probes and procedures. Finally, DNA samples collected from convicted sex offenders could be compiled in a national databank.

While the benefits of a standardized system are strong, there are concerns and rationales for proceeding slowly.[140] A sensible approach might be to standardize those parts of the process common to all,[141] while encouraging the testing and evaluation of the competing probes and methods until the optimal system,[142] based on empirical data, becomes evident.

The lack of a standardized national system should not affect the admissibility of any particular system as long as the test is reliable and the laboratory offering the test uses sound testing procedures. Although the lack of a national system does create some problems of uniformity, it does not affect the reliability of competing systems and should not be a bar to their use.

DNA testing is a potent tool for determining the identity of an individual from biological evidence left at a crime scene, and appears scientifically reliable. The admission of the results of DNA tests as evidence, however, depends on whether the tests meet the standards of reliability established by courts in admitting the results of similar techniques.

II. JUDICIAL ACCEPTANCE OF DNA TESTS

DNA tests are the latest example of scientific techniques that attempt to identify individuals.[143] Because not all scientific techniques

140. One concern is that the system chosen might not be the best system—that is, not state of the art. By ordaining that system as "the standard system," it is given a momentum that might crush the development of rival and possibly superior techniques. Even if alternative systems did emerge, their adoption still might be slowed by the weight of the "standard system."

141. Common standardizable aspects may include isolation and denaturing techniques, control DNA, and gels. Additionally, a uniform nomenclature should be promulgated for consistent and unambiguous analysis and recording of DNA samples. Sensabaugh, *supra* note 46, at 394.

142. The superiority of a system is determined by the following factors: Reliability, sensitivity, powers of discrimination, technical expertise required to perform and interpret the DNA analysis, costs per analysis, and availability to different labs. It is possible that no one system will emerge as the clear choice, but rather that a combination of tests—depending on the size, type and condition of the sample—will be employed.

143. Detecting drugs in blood, analyzing fibers, matching blood samples, fingerprinting, matching voice patterns, determining the reliability of eyewitness testimony, and detecting

are reliable,[144] courts screen novel techniques[145] to ensure that they are reliable before admitting their results as evidence.

This section reviews the admissibility standards used by courts to evaluate novel scientific techniques such as DNA tests and discusses whether courts should admit the results of DNA tests.[146]

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psychological trauma are tests that link people to crimes with varying degrees of reliability. Over the past sixty years, courts have grappled with the admissibility of evidence derived from these tests. *See* United States v. Christophe, 833 F.2d 1296, 1299–1300 (9th Cir. 1987) (expert testimony on the unreliability of eyewitness testimony is inadmissible); United States v. Williams, 583 F.2d 1194 (2d Cir. 1978) (voiceprints), *cert. denied*, 439 U.S. 1117 (1979); United States v. Stifel, 433 F.2d 431 (6th Cir. 1970) (neutron activation analysis), *cert. denied*, 401 U.S. 994 (1971); Frye v. United States, 293 F. 1013 (D.C. Cir. 1923) (polygraphs); People v. Adamson, 27 Cal. 2d 478, 165 P.2d 3 (1946) (fingerprinting), *aff'd*, 332 U.S. 46 (1947); People v. Young, 425 Mich. 470, 391 N.W.2d 270 (1986) (blood typing); State v. Black, 109 Wash. 2d 336, 745 P.2d 12 (1987) (rape trauma syndrome); State v. Coe, 101 Wash. 2d 772, 684 P.2d 668 (1984) (hypnotically enhanced testimony); State v. Allery, 101 Wash. 2d 591, 682 P.2d 312 (1984) (battered woman syndrome).

144. "Reliability" contains two components: accuracy and consistency. *See, e.g.*, Giannelli, *The Admissibility of Novel Scientific Evidence:* Frye v. United States, *a Half-Century Later*, 80 COLUM. L. REV. 1197, 1201 n.20 (1980). An accurate test identifies certain symptoms or characteristics, but does not detect what is not there. For example, an accurate DNA test would detect the presence of a genetic marker, but would not report finding a marker if none were present. Consistency requires that a test's results be repeatable. *Id.* Reliability generally is established through empirical testing. *See infra* notes 243–64 and accompanying text.

145. "Novel scientific techniques" are scientific tests that have not yet been judicially sanctioned. 3 J. WEINSTEIN & M. BERGER, WEINSTEIN'S EVIDENCE ¶702[03], at 702-15 (1987 & Supp. 1988) [hereinafter WEINSTEIN]. Once a scientific technique is sufficiently established and has been accepted by the courts, proponents no longer need to meet the threshold inquiry of reliability, and courts may take judicial notice of the technique's reliability. *See* United States v. Downing, 753 F.2d 1224, 1234 (3d Cir. 1985); Giannelli, *supra* note 144, at 1202–03 (citing radar, intoxication tests, and fingerprints as examples of tests that courts have recognized as reliable).

Courts apply the same admissibility tests to "hard" (technical) sciences and "soft" (social) sciences, to techniques offered by the prosecution and the defense, and to criminal and civil cases. *See, e.g.*, Frye v. United States, 293 F. 1013 (D.C. Cir. 1923) (polygraph offered by defense); United States v. Zeiger, 350 F. Supp. 685 (D.D.C. 1970) (polygraph offered by prosecution), *rev'd*, 475 F.2d 1280 (D.C. Cir. 1972); People v. Young, 425 Mich. 470, 391 N.W.2d 270 (1986) (blood tests in criminal case); Kofford v. Flora, 744 P.2d 1343 (Utah 1987) (blood tests to prove paternity in civil suit); State v. Black, 109 Wash. 2d 336, 745 P.2d 12 (1987) (rape trauma syndrome).

Even though they judge "hard" and "soft" sciences by the same tests, courts tend to evaluate "hard" sciences more rigorously to ensure that they are reliable because juries may tend to accept the highly technical tests without critical scrutiny. *See infra* notes 172–75 and accompanying text.

146. In addition to challenging reliability, criminal defendants may raise constitutional challenges to the obtaining of evidence such as blood samples, which are needed for DNA tests. Extraction of blood does not violate the fifth amendment's privilege against self-incrimination because it is physical and not testimonial evidence; drawing blood samples after the issuance of a warrant upon probable cause does not violate the fourth amendment. *See* Schmerber v. California, 384 U.S. 757, 763–64 (1966). Blood extractions must be performed in a "hospital environment according to acceptable medical practices." *Id.* at 771. An in-depth examination of

A. *Admissibility Standards Used to Evaluate Novel Scientific Evidence*

Both federal and state courts generally evaluate the reliability of novel scientific techniques under one of two standards:[147] the general acceptance test first stated in *Frye v. United States*[148] (the "*Frye* test") or the more permissive standard set forth in the Federal Rules of Evidence (the "Federal Rules test").[149]

1. *The Frye Test of General Acceptance*

The *Frye* test is the primary test used by federal and state courts to determine the admissibility of scientific evidence,[150] and thus is the standard that courts probably will use to evaluate DNA tests. Under the *Frye* test, courts admit evidence derived from novel scientific techniques only when the techniques have gained general acceptance in the relevant scientific community.[151]

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constitutional limits on DNA tests is beyond the scope of this Comment. For a general discussion, see P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, Chapter 2.

147. *See* WEINSTEIN, *supra* note 145, ¶ 702[03], at 702–15.

148. 293 F. 1013 (D.C. Cir. 1923).

149. FED. R. EVID. 401, 403, 701, 702, and 703. For convenience, the term "Federal Rules test" will be used to describe the identical tests applied by both state and federal courts. The state test actually is based upon state rules that parallel the Federal Rules of Evidence.

All federal courts are bound to follow the Federal Rules test, although some federal courts also apply the *Frye* test. *See infra* note 176. Similarly, some state courts apply both state evidence rules and the *Frye* test.

Alternatives have been proposed to the *Frye* and Federal Rules tests. For example, some commentators have proposed that independent panels of experts assess novel scientific evidence before it is admitted in court, but no such plan has been implemented. *See, e.g.*, Jasanoff & Nelkin, *Science, Technology, and the Limits of Judicial Competence*, JURIMETRICS J. 266, 274 (Spring 1982).

150. *See* WEINSTEIN, *supra* note 145, ¶702[03], at 702-18 n.8 (citing cases in the Sixth, Ninth, and D.C. Circuits). Many states also apply the *Frye* test. *See, e.g.*, State v. Black, 109 Wash. 2d 336, 745 P.2d 12 (1987); *see also* MCCORMICK ON EVIDENCE (E. Cleary 3d ed. 1984 and Supp. 1987) (Hornbook Series) [hereinafter MCCORMICK], § 203, at 69 (Supp.).

151. Frye v. United States, 293 F. 1013, 1014 (D.C. Cir. 1923). In a nine-paragraph opinion, the *Frye* court rejected the defendant's attempt to introduce the results of a lie-detector test and stated:

> Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidentiary force of 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.

Id. Evaluating the qualifications of testifying experts and determining the relevant scientific community are problems under both the *Frye* and Federal Rules tests, and are discussed *infra* at notes 187–209 and accompanying text.

By requiring acceptance of scientific techniques by scientists, the *Frye* test attempts to ensure that the techniques are reliable.[152] In effect, a technical jury passes judgment on the probative value of the evidence before it is presented to a lay jury, which might be unduly swayed by the perceived infallibility of "science."[153] Thus, under the *Frye* test, when scientists generally accept that novel scientific techniques are reliable, courts conclude that the techniques produce admissible evidence.[154]

When evaluating highly technical procedures such as DNA tests, courts often require a high degree of acceptance by scientists.[155] Both courts and juries lack technical expertise and thus cannot independently evaluate reliability. Instead, they must depend on expert testimony and thus are concerned that the basis for the expert testimony is well-accepted by scientists as reliable. Thus, proponents of DNA tests should expect that under the *Frye* test, courts will require a broad level of scientific acceptance of DNA tests.

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152. *See* United States v. Addison, 498 F.2d 741, 743–44 (D.C. Cir. 1974) (scientists are those most qualified to assess reliability).

153. People v. Barbara, 400 Mich. 352, 255 N.W.2d 171, 194 (1977); *see also infra* notes 172–75 and accompanying text. Other justifications for the *Frye* test are as follows. First, the *Frye* test ensures that a minimum pool of experts will be available to assess the novel scientific technique's reliability. *See infra* notes 201–202 and accompanying text. Second, a preliminary *Frye* hearing prevents the trial from becoming a time-consuming trial of the technique itself. Reed v. State, 283 Md. 374, 391 A.2d 364, 371–72 (1978).

154. Though courts usually examine only the degree of scientific acceptance, sometimes they also examine whether the techniques are reliable, that is, empirically valid. *See, e.g.,* United States v. Franks, 511 F.2d 25, 33 n.12 (6th Cir. 1975) (general acceptance is nearly synonymous with reliability; if a scientific process is reliable or sufficiently accurate, courts may deem it generally accepted), *cert. denied,* 422 U.S. 1042 (1975); State v. Hall, 297 N.W.2d 80, 85 (Iowa 1980) (general acceptance is not required for admission if the reliability of evidence is otherwise established). These cases demonstrate that courts sometimes do not apply the *Frye* test when they feel it deprives the jury of reliable evidence but instead directly assess the reliability of the technique themselves. *See also* Giannelli, *supra* note 144, at 1219–21 (confirms this conclusion by citing cases in the Sixth Circuit, Massachusetts, and Missouri).

155. A strict standard of general acceptance is appropriate with complex scientific procedures because the jury is likely to accept them without critical scrutiny. *See infra* notes 172–75 and accompanying text. The *Frye* test does not quantify the amount of scientific acceptance needed to establish reliability. Different jurisdictions require varying degrees of general acceptance, although most courts apparently recognize that some divergence of views among scientists is inevitable. *See, e.g.,* United States v. Zeiger, 350 F. Supp. 685, 688 (D.D.C. 1970) (acceptance must be "common to many, or the greatest number; widespread; prevalent; extensive though not universal"), *rev'd,* 475 F.2d 1280 (D.C. Cir. 1972); United States v. Gould, 741 F.2d 45, 49 (4th Cir. 1984) (substantial acceptance); People v. Guerra, 37 Cal. 3d 385, 690 P.2d 635, 656, 208 Cal. Rptr. 162, 183 (1984) (acceptance by a "clear majority"); Commonwealth v. Lykus, 367 Mass. 191, 327 N.E.2d 671, 678 n.6 (1975) ("a degree of scientific divergence of view is inevitable"); *cf.* State v. Coe, 101 Wash. 2d 772, 785, 684 P.2d 668, 676 (1984) (rejected use of hypnosis for aiding a witness's testimony because it was not generally accepted; based decision on conclusions of only one leading authority).

2. *The Federal Rules Test*

The principal alternative to the *Frye* test is the test embodied in the Federal Rules of Evidence,[156] which favor the admission of all relevant evidence.[157] Under the Federal Rules test, courts treat scientific evidence like any other expert testimony.[158] Expert testimony is admissible if it is probative, but courts may refuse to admit expert testimony if the dangers of admitting it substantially outweigh its probative value.[159]

a. *Probative Value*

To be probative, expert testimony must be helpful to the trier of fact,[160] and the evidence must be relevant.[161] In addition, testifying experts must be qualified,[162] and the basis for their testimony must be

156. Some commentators refer to the Federal Rules test as the "relevancy test." *See, e.g.*, MCCORMICK, *supra* note 150, § 203, at 605; Giannelli, *supra* note 144, at 1203.

All federal courts must follow the Federal Rules of Evidence, although some courts also apply the *Frye* test. *See infra* note 176. Some commentators disagree with this "hybrid" approach and maintain that the Federal Rules of Evidence (and the parallel state evidence rules) abolish the *Frye* test. Nevertheless, federal and state courts continue to apply the *Frye* test. A discussion of whether the *Frye* and Federal Rules tests are compatible is beyond the scope of this Comment. For an overview, see WEINSTEIN, *supra* note 145, ¶702[03], at 702-15 to 702-21.

157. *See infra* note 167–71 and accompanying text.

158. MCCORMICK, *supra* note 150, § 203, at 605.

159. FED. R. EVID. 403, FED. R. EVID. 702.

160. "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise." FED. R. EVID. 702.

Helpfulness to the trier of fact thus requires that the expert's testimony help the jury and that the expert be sufficiently qualified. In determining helpfulness, courts also may look to the degree that the expert's testimony invades the province of the jury. *See, e.g.*, State v. Black, 109 Wash. 2d 336, 348–49, 745 P.2d 12, 19 (1987) (expert testimony on rape trauma syndrome is merely an opinion as to the guilt of the defendant, thereby invading the exclusive province of the finder of fact); *see also* FED. R. EVID. 704 and advisory committee's note (opinions on the ultimate issue are permissible so long as the opinions meet the requirements of Rules 701, 702, and 403). In addition, some courts apply the common law rule that expert testimony is allowed only for technical matters that are beyond the jury's understanding. *See, e.g.*, United States v. Eckmann, 656 F.2d 308, 313 (1981). DNA evidence clearly meets this common law test. For a more in-depth discussion of expert testimony, see WEINSTEIN, *supra* note 145, ¶¶702–704, at 702-1 to 702-29.

161. FED. R. EVID. 401. Rule 401 defines relevant evidence as "evidence having any tendency to make the existence of any fact that is of consequence to the determination of the action more probable or less probable than it would be without the evidence."

162. FED. R. EVID. 702. Whether experts are qualified seems to require a separate inquiry from whether courts should admit the results of novel scientific techniques. However, courts cannot determine the admissibility of novel scientific evidence without examining expert qualifications and the basis for expert opinion. *See* WEINSTEIN, *supra* note 145, ¶702[04], at 702-23.

reasonably relied upon by experts[163] in the particular scientific field to which the scientific technique belongs.[164]

Because the Federal Rules of Evidence require that the basis for expert testimony be reasonably relied upon by qualified experts, the Federal Rules test, like the *Frye* test, requires some degree of scientific acceptance of novel scientific techniques.[165] As under the *Frye* test, acceptance by scientists is a means of ensuring that the scientific techniques are reliable. The Federal Rules test, however, is not the same as the *Frye* test of general acceptance, but is a more lenient standard that favors the admissibility of scientific evidence.[166]

b. Dangers of Admitting Evidence

Although the Federal Rules of Evidence allow courts to exclude relevant scientific evidence if its probative value is substantially out-

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163. FED. R. EVID. 703. Rule 703 states:

> The facts or data in the particular case upon which an expert bases an opinion or inference may be those perceived by or made known to him at or before the hearing. If of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence.

Rules 401 and 702 allow experts to testify about almost anything that is helpful and relevant. Rule 703 covers the permissible basis for an expert's opinion: expert opinion may be based on sources of information that are otherwise inadmissible (because of hearsay or other evidentiary rules) as long as the expert's reliance is reasonable. FED. R. EVID. 703.

164. Evaluating expert qualifications and defining the relevant scientific community are concerns under both the *Frye* and Federal Rules tests and are discussed *infra* at notes 187–209 and accompanying text.

165. *See, e.g.*, State v. Maule, 35 Wash. App. 287, 667 P.2d 96 (1983):

> Both before and after the adoption of Washington's Rules of Evidence [modeled on the Federal Rules], courts have required that the factual, informational, or scientific basis of an expert opinion, including the principle or procedures through which the expert's conclusions are reached, must be sufficiently trustworthy and reliable to remove the danger of speculation and conjecture and give at least minimal assurance that the opinion can assist the trier of fact.

35 Wash. App. at 294, 667 P.2d at 99 (citations omitted).

It is not clear what constitutes "reasonable reliance" by experts or what level of acceptance is required by courts. Apparently, a known technique that has attracted only minimal support within the community will be found unreliable. United States v. Downing, 753 F.2d 1224, 1238 (3d Cir. 1985) (citing United States v. Williams, 583 F.2d 1194, 1195 (2d Cir. 1978), *cert. denied*, 439 U.S. 1117 (1979)). Rule 702 requires "reasonable," but not "customary," reliance by experts. For example, experts could customarily rely on polygraphs in their psychological research, but this reliance nevertheless would not be deemed reasonable by most courts, which have held that polygraph results are unreliable and inadmissible. The determination of "reasonable" ultimately is within the discretion of the trial court, and such determinations may generally be reversed only for clear abuse of discretion. *See generally* WEINSTEIN, *supra* note 145, ¶702[04], at 702-21 to 702-29. Thus it is difficult to predict how critically a court that applies the Federal Rules test will define "reasonable reliance" and evaluate novel scientific evidence.

166. *See infra* notes 167–71 and accompanying text.

weighed by the dangers of unfair prejudice or confusion,[167] courts that apply the Federal Rules test often apply a liberal admissibility standard and admit scientific evidence.[168] These courts rely on trial safeguards to offset any dangers and presume that the jury thus can evaluate the evidence's reliability.[169] Trial safeguards include notice that the test was administered, discovery of test results, cross-examination of experts, use of opposing experts, and cautionary instructions to the jury.

Thus, novel scientific techniques can be reliable under the Federal Rules test even if they do not have an established track record in the scientific community.[170] Conceivably, applying the Federal Rules test could result in the admission of any relevant evidence supported by qualified expert testimony unless the dangers of prejudice or confusion are overwhelming.[171] Accordingly, courts that apply the Federal Rules test may admit the results of DNA tests more readily than courts that apply the *Frye* test.

Nevertheless, under the Federal Rules test, courts might not apply a lenient admissibility test but instead might rigorously evaluate whether DNA tests are reliable. Courts might conclude that a heightened inquiry is appropriate because jurors, lacking technical expertise, tend to accept highly technical procedures without critical scrutiny and cannot assess reliability.[172] DNA tests involve complex scientific

167. FED. R. EVID. 403. Rule 403 describes the dangers of admitting evidence: "Although relevant, evidence may be excluded if its probative value is substantially outweighed by the danger of unfair prejudice, confusion of the issues, or misleading the jury, or by considerations of undue delay, waste of time, or needless presentation of cumulative evidence."

168. *See* United States v. Baller, 519 F.2d 463, 466 (4th Cir. 1975) ("Unless an exaggerated popular opinion of the accuracy of a particular technique makes its use prejudicial or likely to mislead the jury, it is better to admit relevant scientific evidence in the same manner as other expert testimony and allow its weight to be attacked by cross-examination and refutation."), *cert. denied,* 423 U.S. 1019 (1975); WEINSTEIN, *supra* note 145, ¶702[04], at 702-21.

169. *See generally* Giannelli, *supra* note 144, at 1239–45.

170. MCCORMICK, *supra* note 150, § 203, at 608–09; *cf.* State v. Hall, 297 N.W.2d 80 (Iowa 1980) (general acceptance is not required to admit novel scientific evidence if reliability is otherwise established).

171. *Id.*

172. United States v. Addison, 498 F.2d 741, 744 (D.C. Cir. 1974) (scientific evidence seems mystically infallible to a lay jury); People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 1245, 130 Cal. Rptr. 144, 149 (1976) (misleading aura of certainty often envelops a new scientific process). Jurors similarly may accept without critical scrutiny the testimony of highly qualified experts, such as DNA experts, who often have impressive credentials. *See Kelly,* 549 P.2d at 1245, 130 Cal. Rptr. at 149 (jurors "give considerable weight to 'scientific' evidence when presented by 'experts' with impressive credentials"); Smith v. United States, 389 A.2d 1356, 1359 (D.C.) (air of authority surrounds expert opinion), cert. denied, 439 U.S. 1048 (1978); see also Rosenthal, Nature of Jury Response to the Expert Witness, 28 J. Forensic Sci. 528, 529–30 (1983) (Professor Rosenthal interviewed jurors who convicted a defendant in a voiceprint case; he concluded that

procedures[173] which are explained in terms of probabilities.[174] Even the names of the tests—"DNA fingerprinting[tm]" and "DNA prints[tm]"—possess an air of certainty and reliability.[175] Under the Federal Rules test, then, courts may well apply a *Frye*-type standard and rigorously review whether DNA tests are reliable.

Thus, courts that apply the Federal Rules test might apply a strict *Frye*-type admissibility standard to DNA tests or they might apply a lenient standard to admit the test results as long as they are supported by qualified expert testimony.[176] The following section contains an

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the jurors did not understand the testimony but based their verdict on their impressions of the expert's authority; the jurors described an expert who impressed them as a "real scientist" and stated that "some of the others looked like hippies").

Courts may be less concerned about the perceived infallibility of scientific evidence when the novel scientific test is not technical because the jury can independently evaluate the evidence. For example, jurors may be able to evaluate the reliability of eyewitness testimony but may be ill-equipped to evaluate a technical ballistics test. *See, e.g.*, WEINSTEIN, *supra* note 145, ¶702[03], at 702-20 (some scientific evidence aids the jury in its own assessment of the evidence; other evidence is too complex, so the jury must rely on the expert); MCCORMICK, *supra* note 150, at 609 (when the science is comprehensible to the jury, the concern that the evidence may exert undue influence has little force). Thus, although a strict admissibility standard is appropriate for highly technical sciences such as DNA tests, a more lenient standard may be appropriate for expert testimony that either contradicts lay impressions or aids the jury's commonsense evaluation of the evidence.

173. Data generated by scientific procedures may possess an unwarranted air of certainty even though humans interpret the data. An example is the polygraph, where a juror may assume that because a polygraph reliably measures physiological responses, the interpretation linking those responses to the subject's truthfulness also is accurate. *See, e.g.*, United States v. Alexander, 526 F.2d 161, 168 (8th Cir. 1975) (polygraph evidence is shrouded with an aura of infallibility "akin to the ancient oracle of Delphi"); Strong, *Questions Affecting the Admissibility of Scientific Evidence*, 1970 U. ILL. L.F. 1, 13 n.48 (1970) (citing Highleyman, *The Deceptive Certainty of the "Lie Detector"*, 10 HASTINGS L.J. 47, 63 (1958)).

174. *See supra* notes 60–69 and accompanying text. Jurors tend to be impressed by probabilities, so it is important that these probabilities be reliable. Tribe, *Trial by Mathematics: Precision and Ritual in the Legal Process*, 84 HARV. L. Rev. 1329, 1331 (1971). *See infra* notes 234–64 and accompanying text (discussing the admissibility of statistical evidence and the empirical validation of statistics).

175. Courts may criticize the name of the DNA tests. Summing Up at 3–4, Regina v. Davies (Crown Court at Mold, November 26, 1987) ("evidence . . . is quite wrongly called DNA fingerprinting; proper phrase is DNA profile . . . ."); *see also* United States v. Baller, 519 F.2d 463, 465 n.1 (4th Cir.) (the term "voiceprint" suggests an air of accuracy that is unjustified and unwarranted), *cert. denied*, 423 U.S. 1019 (1975); State v. Coolidge, 109 N.H. 403, 260 A.2d 547, 560–61 (1969) (hair analysis rejected in part because it was presented as being as infallible as fingerprints), *rev'd on other grounds*, 403 U.S. 443 (1971); State v. Black, 109 Wash. 2d 336, 348–49, 745 P.2d 12, 19 (1987) (the term "rape trauma syndrome" creates an aura of reliability and suggests that the alleged victim was in fact raped and that the defendant is guilty of the crime).

176. Although all federal courts must follow the Federal Rules of Evidence, some federal courts (or state courts that apply state evidence rules) also apply the *Frye* test so that novel scientific techniques must meet the standards of the Federal Rules of Evidence and be based on a

analysis of whether DNA test results are admissible under either a lenient test or a strict *Frye* analysis.[177]

B. Admissibility of DNA Test Results

Under both the *Frye* and Federal Rules tests, courts probably will evaluate whether DNA test results are admissible by examining the soundness of the underlying scientific principle that explains DNA tests and the reliability of the test that applies the scientific principle.[178] In addition, each DNA test introduced as evidence must be administered properly,[179] but challenges to proper administration go to the weight given to the evidence, not to the evidence's admissibility.[180]

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generally accepted scientific theory. *See, e.g.*, United States v. Kilgus, 571 F.2d 508, 510 (9th Cir. 1978).

The ambiguity of Rule 703's reasonable reliance standard may be one reason that federal courts continue to apply the *Frye* test or apply a stricter admissibility standard when the evidence is highly technical. *See supra* note 165 (discussing the ambiguity in Rule 703). Because the determination of "reasonable reliance" under Rule 702 is ambiguous and is within the trial court's discretion, it is difficult to predict how critically courts that apply the Federal Rules test will evaluate DNA tests. *See supra* note 165.

177. In this section, the discussion of whether DNA test results are admissible under the Federal Rules test is limited to the lenient Federal Rules test. The determination of admissibility under a stricter, *Frye*-type Federal Rules test will be covered in the discussion of admissibility under the *Frye* test.

178. United States v. Kilgus, 571 F.2d 508, 510 (9th Cir. 1978) (admission of evidence from infrared tracking device predicated on the reliability of the underlying theory and the technique applying the theory); City of Seattle v. Peterson, 39 Wash. App. 524, 527, 693 P.2d 757, 758 (1985) (admission of radar evidence requires a valid scientific principle and evidence that the machine reliably employs that scientific principle); Giannelli, *supra* note 144, at 1200–04, 1210. Once numerous courts have sanctioned a scientific technique, a court may take judicial notice of the soundness of the principle and the reliability of the technique, and proponents no longer need to meet the threshold test of reliability. *See supra* note 145.

A general scientific principle is the proposition that interprets the significance of scientific evidence. Strong, *supra* note 173, at 9. Components of a test's reliability include whether the test was validated empirically, whether it is standardized, and whether it has defined limits and abilities. *Id.* at 17; *see also* Giannelli, *supra* note 144, at 1201.

179. Giannelli, *supra* note 144, at 1201. Proper application of a particular test requires equipment that is in good condition, adherence to proper procedures, and qualified persons performing the test and interpreting the results. *Id.* at 1201–02. The difference between a reliable test and proper application of the test is that a reliable test requires standardized procedures which produce replicable results while proper testing on the particular occasion requires adherence to those standardized procedures.

180. Once a court accepts a novel scientific test as reliable, evidence derived from it must still meet the standards applied to determining the admissibility of other evidence. Thus, challenges may go to weight or admissibility. *Cf.* P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 1.8(B), at 43–45 (some jurisdictions hold that failure to properly administer a test in the particular case results in exclusion of the evidence; others hold that failure goes to weight, not admissibility).

1. Soundness of the Underlying Scientific Principle

Part I of this Comment establishes that the underlying scientific principle of DNA tests, that individuals have unique DNA patterns, is uniformly accepted by geneticists, medical researchers, and other scientists.[181] Their research and routine analysis of DNA confirm the principle that each individual's DNA is unique and is transmitted from generation to generation.[182] Their research also confirms that DNA can be isolated from a variety of biological sources,[183] sorted by electrophoresis,[184] and analyzed with radioactive probes to identify specific molecular patterns in the DNA.[185]

Thus, scientists agree that it is theoretically possible to identify individuals from their unique DNA patterns. Because the underlying scientific principle is generally accepted, thereby meeting both the *Frye* and Federal Rules tests, the pertinent inquiry becomes whether DNA tests employ this theory reliably in forensic situations.

2. Reliability of DNA Tests in Forensic Situations

In evaluating the reliability of novel scientific techniques, courts generally look to three sources: Expert testimony from the relevant scientific community, scientific and legal writings, and judicial opinions from other jurisdictions.[186] This section contains an analysis of whether these sources establish that forensic DNA tests are reliable. Because courts often require that scientific techniques be thoroughly

181. Because it would be difficult to dispute commonly-recognized genetics principles, courts probably will not dispute the underlying scientific principles of DNA tests but instead may decide to review only the use of DNA tests in crime-solving or paternity determinations.

182. *Supra* notes 29–34 and accompanying text.

183. *See supra* notes 27–28 & 71–76 and accompanying text.

184. *See supra* notes 43–48 and accompanying text. Courts have sanctioned the use of electrophoresis in other forensic tests. *See infra* notes 223–33 and accompanying text.

185. *See supra* notes 52–59 and accompanying text.

186. *See* Giannelli, *supra* note 144, at 1215–19 (courts that employ the *Frye* test use these sources in determining whether novel scientific techniques have been generally accepted by scientists); United States v. Downing, 753 F.2d 1224 (3d Cir. 1985) (applied the Federal Rules test; enumerated factors that courts may consider when determining the reliability of novel scientific techniques including the level of acceptance in the scientific community, the testifying expert's qualifications, existence of specialized literature dealing with the technique, the use that has been made of the technique, expert testimony in previous cases, the novelty of the technique, frequency and type of error, and the existence of testing standards); WEINSTEIN, *supra* note 145, ¶702[03], at 702-18 to 702-19 (discussing the *Downing* factors).

Under the *Frye* test, judicial reliance on a previous court's finding of general acceptance may undercut the rationale that those who are most qualified to assess reliability (scientists) should do so, although presumably the other jurisdictions have heard expert testimony from those scientists. *See* United States v. Addison, 498 F.2d 741, 743–44 (D.C. Cir. 1974).

tested, this section also reviews the extent to which DNA tests have been empirically validated.

a. Expert Testimony

DNA tests are so technical that courts cannot independently assess their reliability. Instead they must depend on testifying experts.[187] Thus, courts, regardless of whether they apply the *Frye* or Federal Rules test, probably will not evaluate the content of the expert testimony on DNA but instead will require that the testifying experts be highly qualified.[188] To date, the experts that have testified in DNA cases have been well-qualified molecular biologists who are experienced in the use and analysis of DNA.[189] This section identifies the concerns that courts may have with the qualifications of experts in future DNA cases.

In general, two types of experts are likely to testify as to the reliability of DNA tests: molecular biologists from the laboratories that perform the DNA test and molecular biologists from the academic community.[190] Both have advantages and disadvantages.

Molecular biologists from the laboratories who testify, typically senior scientists,[191] are familiar with the lab facilities, the testing stan-

187. *See* United States v. Wilson, 361 F. Supp. 510, 513 (D. Md. 1973) ("It is the rare attorney that knows as much as the expert."); A. MOENSSENS, *supra* note 133, § 1.03 at 7 (attorneys and judges often lack the expertise to evaluate technical evidence); Strong, *supra* note 173, at 22 (courts generally are forced to accept the expert's testimony of the probative value of evidence).

188. Experts must be qualified to testify about a particular technique by knowledge, skill, training, or education. FED. R. EVID. 702.

189. *See, e.g.*, Excerpt of Trial Proceedings at 5–7, 22–23, State v. Andrews, No. 87-1400 (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20, 1987) (DNA tests admitted; the qualifications of the testifying experts were as follows: David Housman, Ph.D. (Biology), professor of biology at M.I.T. since 1975, head of the molecular genetics laboratory at M.I.T., published 120 papers on DNA, member of genetic disease foundations; Michael Baird, Ph.D. (Genetics), published 50 papers (35 on DNA), manager of forensic testing at Lifecodes); Evidence and Summing Up at 26, 34, 36, Regina v. Davies (Crown Court at Mold, Nov. 24–27, 1987) (DNA test results admitted; testifying experts were Alec Jeffreys, Ph.D., professor of genetics at the University of Leicester, developer of DNA fingerprint™; Peter Gill, Ph.D. (Genetics), forensic scientist from the Home Office Central Research Establishment; David Werrett, Ph.D. (Biology), forensic scientist from the Home Office Central Research Establishment).

190. The FBI currently is testing the reliability of DNA tests. *See supra* note 135 and accompanying text. Molecular biologists from the FBI lab would be qualified to testify, although courts may not allow testimony as to reliability from other forensic scientists. *See infra* notes 206–07 and accompanying text.

191. For example, Michael Baird, Ph.D. (Genetics), a senior scientist and the manager of forensic testing at Lifecodes, has testified in several DNA admissibility hearings. *See, e.g.*, Excerpt of Trial Proceedings at 25, State v. Andrews, Case No. 87-1400 (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20, 1987).

dards, and the type of DNA test used on the sample. These experts perform or supervise numerous tests and have valuable experience with forensic samples gathered under field conditions. Nevertheless, courts may conclude that the testimony of lab experts is tainted. The experts have intimate connections with the laboratories and financial interests in the DNA tests, and often their reputations and careers are built on the success of the tests and the admissibility of test results. Consequently, their testimony is susceptible to charges of bias.[192] Thus, courts may discount their testimony[193] as to the reliability of DNA tests[194] and look to the academic community to assess the tests impartially.[195]

Molecular biologists from the academic community may be preferable as reliability experts because they do not have financial interests in DNA testing.[196] They are knowledgeable about lab procedures and

192. For example, molecular biologists from Lifecodes, Cellmark Diagnostics, and Forensic Science Associates all have personal interests in the judicial acceptance of DNA tests. *See supra* notes 98–116 and accompanying text (discussing these laboratories).

193. Courts might avoid the effects of biased testimony by appointing their own experts under Federal Rule of Evidence 706, but they rarely do. *See generally* WEINSTEIN, *supra* note 145, ¶706[01], at 706-6 to 706-12. Courts do not necessarily require that an expert be unbiased. *In re* Agent Orange Product Liability Litigation, 611 F. Supp 1267, 1279–80 (E.D.N.Y. 1985) (expert testimony may have been influenced by personal interest; the court found this interest bore on weight, not admissibility), *aff'd*, 818 F.2d 187 (2d Cir. 1987). However, some courts have admitted new scientific evidence only upon testimony given by impartial, disinterested experts. Courts are particularly concerned when the expert developed the technique and profits by it. People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 130 Cal. Rptr. 144 (1976) (reliability of voiceprints cannot be established by individuals whose careers depend on it); People v. Young, 425 Mich. 470, 391 N.W.2d 270, 274–75 (1986) (general acceptance of electrophoresis method of blood typing must be established by disinterested and impartial experts; court excluded reliability testimony by two prosecution experts who were full-time employees of law enforcement agencies). Courts may be concerned that the personal bias of the examiners can presuppose the outcome of the test. People v. Monigan, 72 Ill. App. 3d 87, 390 N.E.2d 562, 568–69 (1979) (subjectiveness surrounds the interpretation of polygraph results; claims of accuracy for the technique seem to come only from the polygraph examiners themselves). *But cf.* Giannelli, *supra* note 144, at 1245–46 (developer of voiceprints was allowed to testify that voiceprints are virtually infallible) (citing United States v. Wright, 17 C.M.A. 183, 37 C.M.R. 447 (1967)).

194. If courts determine that DNA test results are admissible, the testimony of lab experts will still be necessary to demonstrate that the actual test, whose results are being offered as evidence, was administered properly. This testimony goes to the weight given to the evidence, not to its reliability or admissibility. *See supra* notes 179–80 and accompanying text.

195. For example, David Housman, Ph.D. (Biology) from M.I.T. has testified in DNA admissibility hearings. Excerpt of Trial Proceedings at 25, State v. Andrews, No. 87-1400 (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20. 1987); *see also* People v. Young, 425 Mich. 470, 391 N.W.2d 270, 276–77 (1986) (admitted nonforensic scientists as experts on DNA testing because they had the understanding and experience to evaluate the evidence).

196. Although all experts are paid for their testimony, molecular biologists generally are not professional experts and are unlikely to undermine their reputations for an expert fee. The defense counsel in *State v. Andrews* unsuccessfully argued that David Housman from M.I.T. was

use similar tests in their research.[197] Thus, they have the necessary background to evaluate whether DNA tests identify individuals reliably and whether the forensic labs' procedures are accepted as proper by the greater scientific community. One drawback of academic molecular biologists is that they may lack first-hand experience as to the reliability of the particular type of forensic DNA test being offered as evidence[198] and may be unfamiliar with the forensic lab's capabilities and procedures.[199] These deficiencies may be remedied if they familiarize themselves with the lab facilities, the testing standards, and the type of DNA test used.[200]

Both types of experts should testify as to the reliability of current DNA tests. Their combined testimony maximizes the trier of fact's knowledge of the reliability of forensic DNA testing and minimizes

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an interested party because "he draws his paycheck by virtue of doing five to ten of these [nonforensic tests] a week." The court nevertheless admitted his testimony regarding the DNA test. Excerpt of Trial Proceedings at 66, 68–70, State v. Andrews, No. 87-1400 (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20, 1987); *see also* People v. Young, 391 N.W.2d at 275–76 (a certain degree of interest must be tolerated if scientists familiar with a technique are to testify at all; allowed testimony from defense expert who opposed an electrophoresis technique, was an original developer of the technique but withdrew from the project, and was possibly seeking vindication; did not allow testimony from those whose livelihood depended on the success of the technique).

197. *See supra* notes 8–23, 35 and accompanying text; Excerpt of Trial Proceeding at 12–14, State v. Andrews, No. 87-1400, (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20, 1987).

198. Different forensic labs, such as Lifecodes and Cellmark, use different types of DNA tests. *See supra* notes 98–116.

199. Some courts have defined expertise as direct and empirical experience, and have excluded those with only theoretical knowledge. *See* Commonwealth v. Lykus, 367 Mass. 191, 327 N.E.2d 671 (1975) (voiceprints); *see also* United States v. Hendershot, 614 F.2d 648, 654 (9th Cir. 1980) (admitted shoeprint-lifting technique based on expert testimony by crime technicians); People v. Williams, 164 Cal. App. 2d 858, 331 P.2d 251 (1958) (medical profession unfamiliar with narcotics test; court selected the relevant community as those who would be expected to be familiar with its use and admitted the test).

Narrowly defining the field of experts as only those actually using a particular DNA test may result in a community of biased experts. An expert who develops a technique and profits by it may "accept" it without regard to its reliability. Thus, courts infrequently use this approach. *See* People v. Young, 391 N.W.2d at 277 (academic geneticists, though unfamiliar with evidentiary bloodstain analysis, need only to explain the gaps in their knowledge for their judgment to be respected).

200. For example, David Housman, a professor in molecular genetics at M.I.T., testified at the *Frye* hearing in *State v. Andrews* after reviewing "in some detail" and "rather carefully" (a) the protocols of Lifecodes, the lab that conducted the DNA test (a similar DNA test to the one that Housman uses), (b) the actual test results to see that the test had been run properly, and (c) Lifecodes's facilities and the performance of actual tests (although not the particular test offered as evidence). Excerpt of Trial Proceedings at 12–14, 20, State v. Andrews, No. 87-1400 (Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, Oct. 20, 1987).

the adverse effects of biased testimony.[201] The broader base of experts also ensures that the defense has access to experts to rebut the testimony of the prosecution's experts.[202]

Courts might not allow molecular biologists to testify about statistical frequencies,[203] which may be outside the scope of their expertise.[204]

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201. The combined testimony thus ensures that the testimony of "interested" experts can be corroborated. The bigger pool of experts also can demonstrate to courts that DNA tests have been generally accepted by a larger scientific discipline than the handful of molecular biologists who perform forensic DNA tests. *See* People v. Young, 391 N.W.2d at 276–77 (because the community of scientists having direct empirical experience with electrophoresis of evidentiary bloodstains did not seem sufficiently large to reach the *Frye* objective of general acceptance, the court looked to nonforensic scientists using the test because they had the understanding and experience to evaluate the evidence). Courts may be lenient in admitting expert testimony when the defense has profferred experts to show lack of scientific acceptance. *See* State v. Chatman, 156 N.J. Super. 35, 383 A.2d 440, 442 (1978) (allowed expert with no practical experience to testify about atomic absorption spectrometry because he had read scientific literature and was familiar with the problems of the technique).

202. Only a few commercial laboratories perform DNA tests, so there are not many laboratory molecular biologists who can testify. Not all courts, however, are concerned with the availability of defense experts. *See* United States v. Franks, 511 F.2d 25, 33 (6th Cir.) (admitted voiceprints in part because of the absence of defense experts), *cert. denied*, 422 U.S. 1042 (1975). Lack of defense experts may signal lack of funds, not lack of expert opposition. While the state has access to forensic laboratories and outside experts, the defense may not be able to afford experts. Arguably, if the state intends to use DNA tests, it should pay for the tests for indigent defendants. *See, e.g.*, Stifel v. United States, 433 F.2d 431, 441 (6th Cir. 1970) (if the government uses neutron activation analysis, an expensive fact-finding tool, it must pay for the tests for indigent defendants), *cert. denied*, 401 U.S. 994 (1971).

A related concern is that the defense must have notice that the prosecution has run a DNA test. *See, e.g.*, United States v. Kelly, 420 F.2d 26, 29 (2d Cir. 1969) (neutron activation analysis was conducted after discovery; new trial ordered so defense could run its own tests).

The defense also may assert a right to retest samples. In Brady v. Maryland, 373 U.S. 83 (1963), the Supreme Court recognized a limited right to discover exculpatory evidence in the prosecution's possession. Some courts have considered whether this right translates into a right to retest samples or have evidence preserved. *See* McNutt v. Superior Court, 133 Ariz. 7, 648 P.2d 122 (1982) (blood samples must be preserved and disclosed). *But cf.* California v. Trombetta, 467 U.S. 479, 489 (1984) (no duty to preserve breath samples; intoxilyzer is so accurate that preservation is not likely to be exculpatory).

The defense similarly may challenge the loss or destruction of biological evidence or the failure to conduct tests. Most courts have not imposed a duty to take samples or run tests, although when a reliable and potentially exculpatory test exists, arguably such a duty should be imposed. *See, e.g.*, United States v. Hensen, 486 F.2d 1292, 1298 n.3 (D.C. Cir. 1973) (no right to fingerprint analysis); *cf.* People *ex. rel.* Gallagher v. District Court, 656 P.2d 1287, 1292 (Colo. 1983) (defense requested that the murder victim's hands be subjected to trace metal detection analysis; police refused; court held that prosecution had a duty to make the hands available for testing); People v. Robinson, 27 N.Y.2d 864, 265 N.E.2d 543, 317 N.Y.S.2d 19 (1970) (prosecution tested semen for blood type but failed to make potentially exculpatory test; court held that the defendant was denied due process when his motion for the exculpatory test was denied); *see also* Rock v. Arkansas, 107 S. Ct. 2704 (1987) (per se state rule barring all hypnotically refreshed testimony by defendants is unconstitutional in light of present scientific knowledge).

203. *See infra* notes 234–42 and accompanying text (discussing the admissibility of statistical evidence).

One solution is to retain genetics statisticians to testify regarding genetic marker frequencies. Many molecular biologists have some formal training in statistics, however, which should be sufficient to allow them to explain the DNA tests in terms of statistics.[205]

Finally, once courts determine that a particular DNA test is reliable, technicians with a lower level of education, such as a bachelor of science degree, probably are qualified to testify that they conducted DNA tests for the presence of DNA bands, found bands in specific locations, and calculated the percent of the population that possesses those bands.[206] In short, these technicians are qualified to determine whether DNA tests have been properly administered according to established procedures, which goes to the weight given to the evidence. These technicians, however, are not qualified to determine whether DNA tests are reliable enough so that test results are admissible. The expertise of molecular biologists is needed to assess the reliability and admissibility of DNA tests, testing procedures, and population frequencies. Accordingly, under both the *Frye* and Federal Rules tests, proponents of DNA tests will make persuasive presentations as to reliability by using molecular biologists as experts.[207]

Although courts rely primarily on expert testimony in determining reliability,[208] DNA tests must be accepted as reliable by a larger group

204. *See, e.g.*, State v. Garrison, 120 Ariz. 255, 585 P.2d 563 (1978) (Gordon, J., dissenting). In *Garrison*, the expert testified that there was an eight in one million chance that teeth marks were not made by the suspect. The dissent noted, "[W]hile Dr. Campbell may have a great deal of expertise in the actual comparison techniques of bite-mark identification, he is totally out of his field when the discussion turns to probability theory." 585 P.2d at 568; *see also* Comment, *The Evidentiary Uses of Neutron Activation Analysis*, 59 CALIF. L. REV. 997, 1031 (1971) (the qualifications of experts as chemists do not necessarily establish their competence to explain the statistical relevance of their tests).

205. P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 17-2, at 567. In practice, experts often testify beyond the scope of their expertise. A. MOENSSENS, *supra* note 133, at 9. Further, defining the limits of expert testimony is within a court's discretion and is reversible only for abuse of discretion. *See generally* WEINSTEIN, *supra* note 145, ¶ 702[04], at 702-21 to 702-29.

206. *See* P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 17-2, at 567–68. Also, courts often are liberal in holding that experts are qualified to testify, and their determinations are reversible only for abuse of discretion. *See generally* WEINSTEIN, *supra* note 145, ¶ 702[04], at 702-21 to 702-29.

207. Some courts may require a high level of expertise. *See* People v. Young, 425 Mich. 470, 391 N.W.2d 270, 290 (1986) (Boyle, J., dissenting)l (for blood-typing case, majority allowed as experts only scientists, not technicians; dismissed as technicians (a) head of the FBI's serological unit with a B.S. (Bacteriology), a M.S. (Microbiology), and extensive experience with electrophoresis, and (b) co-developer of the challenged system with a B.S. and a M.S. (Forensic Chemistry) who had taught for 10 years). *But cf.* State v. Crowder, 285 N.C. 42, 203 S.E. 2d 38, 44 (1974) (allowed forensic chemist with bachelor's of science and master's of science degrees and only 50 semester hours of chemistry to testify about atomic absorption spectrometry).

208. *See supra* notes 187–205 and accompanying text.

in the scientific community than just the experts who testify for admissibility.[209] Scientific and legal writings may augment expert testimony to show the level of acceptance.

b. Scientific and Legal Writings

A review of scientific literature[210] confirms that individuals have unique DNA patterns[211] and that forensic DNA tests can identify individuals reliably.[212] Most literature on the forensic use of DNA tests, however, is generated by commercial labs[213] and other proponents[214] of forensic DNA testing. The literature thus is susceptible to

209. Under either the *Frye* or Federal Rules test, courts should not admit DNA tests based on a single expert's testimony, although a single expert probably could testify that a test is accepted by the scientific community. *Cf., e.g.*, People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 1248, 130 Cal. Rptr. 144, 152 (1976) (questioned whether the testimony of a single witness is ever sufficient to represent general scientific acceptance); Burkett v. Northern, 43 Wash. App. 143, 715 P.2d 1159 (1986) (one physician's testimony does not establish general acceptance of thermography because he failed to give numbers of supporters or publications supporting his statements); United States v. Downing, 753 F.2d 1224, 1238 (3d Cir. 1985) (under the Federal Rules test, a technique that has attracted only minimal support is likely to be found unreliable); State v. Catanese, 368 So. 2d 975, 981 (La. 1979) (under the Federal Rules test, the testimony of a single expert is not enough to admit polygraph evidence). *But cf.* P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 1-6, at 32 (testimony of one expert could be enough under the Federal Rules test).

210. A review of scientific literature to determine whether a novel scientific technique is accepted within the scientific community can be dangerous, because courts may not understand highly technical information or may not discover all relevant articles. *See* Giannelli, *supra* note 144, at 1217. Courts should instead rely on experts. A review to establish lack of acceptance may be more appropriate; for example, a court may want to determine whether reliability studies have been conducted. *See, e.g.*, People v. Young, 425 Mich. 470, 391 N.W.2d 270, 272 (1986) (court was concerned that no independent reliability studies existed for a new blood test and that the record did not show that any studies had examined the effects of crime scene contaminants on test results even though the experts testified that there would be no adverse effects).

211. *See supra* notes 27–34 and accompanying text.

212. *See supra* notes 70–142 and accompanying text.

213. For example, Michael Baird from Lifecodes has co-authored at least three articles with other scientists (most of whom are also from Lifecodes). Baird, *Forensic Applications, supra* note 2; Guisti, *supra* note 36; Kanter, *supra* note 36.

214. Alec Jeffreys has coauthored at least seven articles. (Jeffreys is not primarily a forensic scientist, but an academic molecular biologist who has developed a forensic DNA test). Gill, *supra* note 37; Address by Alec Jeffreys, *Highly Variable Minisatellites and DNA Fingerprints,* Twenty-third Colworth Medal Lecture by Alec Jeffreys, 15 BIOCHEM. SOC. TRANS. 309 (1987); Jeffreys, *Segregation Analysis, supra* note 61; Jeffreys, *Positive Identification, supra* 2; Jeffreys, *DNA Fingerprints, supra* note 51; Jeffreys, *Minisatellite Regions, supra* note *22;* Wong, *Characterization of a Panel of Highly Variable Minisatellites Cloned From Human DNA,* 1987 ANN. HUM. GENETICS 1.

Peter Gill, a scientist with the Home Office's Central Research Establishment in the United Kingdom (an agency similar to the FBI's Crime Lab) has coauthored at least two forensic articles. *Evaluation, supra* note 36; Gill, *Forensic Application of DNA 'Fingerprints',* 318 NATURE 577 (1985).

the same charges of bias as is the testimony of experts from the commercial labs.[215]

Nevertheless, these articles are relevant for several reasons. First, they discuss problems, techniques, and testing methods that are unique to the forensic use of DNA tests.[216] Second, forensic journals offer the best opportunity for peer review and criticism[217] of the various DNA tests. Finally, because the authors of forensic articles concur that DNA tests are reliable, these articles suggest that the tests have achieved a certain level of scientific acceptance.[218] This acceptance, if supported by adequate empirical testing,[219] may meet the general acceptance test of *Frye v. United States*[220] and the more lenient Federal Rules test.

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215. As a result, courts may attach more importance to the published articles of academics, whose livelihoods do not depend on the success of DNA tests. *See supra* note 192–95 and accompanying text.

216. For example, scientists from Lifecodes have published articles dealing with the forensic analysis of dried bloodstains and semen, sample material that is of particular importance to forensic testing. For citations of the articles, see note 213.

In the context of blood typing, one commentator has suggested that courts should be careful in assessing the adequacy of studies regarding the effects of forensic conditions (such as the effects of age and contamination on blood) because the studies often are conducted by interested parties such as law enforcement agencies (or, in the case of DNA tests, commercial laboratories). Jonakait, *Will Blood Tell? Genetic Markers in Criminal Cases,* 31 EMORY L.J. 833 (1982). Nevertheless, only forensic scientists are likely to study the reliability of DNA tests under the field conditions unique to forensic analysis. Thus, courts must rely on forensic scientists for empirical testing to ensure the reliability of forensic DNA tests. *See infra* notes 243–64 and accompanying text discussing empirical validation and independent testing.

217. Publication and peer review are not limited to forensic journals. Jeffreys has published extensively in *Nature*, a prestigious journal in the United Kingdom. Jeffreys's 1985 article about DNA testing in immigration cases received some suggestions from a reply article from a nonforensic scientist. Hill, *DNA Fingerprint Analysis in Immigration Test-cases,* 322 NATURE 290 (1986) (did not dispute Jeffreys's conclusions; suggested some refinements in the statistical methodology).

Peer review journals are useful to impeach the credibility of expert witnesses or establish general acceptance because "a high standard of accuracy is engendered by various factors: the treatise is written primarily . . . for professionals, subject to scrutiny and exposure for inaccuracy, with the reputation of the writer at stake." FED. R. EVID. 803 advisory committee note 18 (learned treatises exception to the hearsay rule).

218. Courts also may be concerned that the number of articles on the forensic use of DNA tests is too low to demonstrate general acceptance. Studies reported in scientific literature, however, involve new findings. Other scientists duplicate the results, and report any inconsistencies. For an example, see the articles cited above in note 217. Because subsequent research often is reported only if there are inconsistencies or new findings, scientific literature does not document all research regarding the reliability of forensic DNA tests. Therefore, lack of refutation can be significant. Comment, *The Admissibility of Electrophoretic Methods of Genetic Marker Bloodstain Typing Under the* Frye *Standard,* 11 OKLA. CITY U.L. REV. 773, 787 (1986) [hereinafter *Admissibility of Genetic Markers*]. In addition, the numerous nonforensic scientific articles on DNA testing may allay this concern.

219. *See infra* notes 243–64 and accompanying text.

220. 293 F. 1013 (D.C. Cir. 1923).

Although courts also may review legal writings to establish whether a technique has been accepted by scientists,[221] commentators have not addressed the forensic use of DNA tests in any comprehensive detail. The legal literature that is available does support the admissibility of DNA test results.[222]

c. *Judicial Opinions*

Although evidence from DNA tests has been admitted in numerous criminal and civil cases,[223] no cases have yet reached the appellate level, and most of the trial cases provide little guidance on how courts should analyze the admissibility of DNA test results. Therefore, this section considers analogous appellate cases involving non-DNA genetic markers. Because DNA tests are explained by reference to probabilities, this section also will examine the admissibility of statistical evidence to explain the results of scientific tests.

i. *Admissibility of Non-DNA Genetic Markers*

Tests that identify blood and tissue types also are used to establish paternity or to identify suspects in violent crimes. Courts have admitted evidence resulting from many types of tests that detect certain genetic markers[224] in the blood or tissues. Geneticists can compare the markers that a suspect possesses with the markers in a sample found at a crime scene. If the markers match, geneticists cannot positively identify the suspect as the perpetrator or putative father, but

221. *See supra* note 186.

222. No comprehensive legal articles have been written because no appellate courts have ruled on the admissibility of the results of DNA tests. Several summaries have been published, but they contain little analysis of whether courts should admit the results of DNA tests. *See* P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, at 602–04; MCCORMICK, *supra* note 150, at 73–75 (Supp. 1987); A. MOENSSENS, *supra* note 133, at 355–59 (test results could meet a standard of verifiable certainty); Haller, *Can DNA Save Dotson?*, 11 CHICAGO LAW. 1 (Feb. 1988); Moss, *DNA—The New Fingerprints*, 74 A.B.A. J. 66 (May 1988) (cites M.I.T.'s David Housman as stating that disputing DNA technology is like disputing the law of gravity). One forensic scientist has addressed whether the results of DNA tests are admissible and has identified some concerns that courts may have with DNA tests. Guest Lecture by Edward T. Blake, D.Crim., DNA Seminar, California Association of Crime Laboratory Directors (Nov. 18 & 19, 1987).

223. *See supra* notes 2-7.

224. These genetic markers are not the same as DNA bands; they are the proteins whose structures are genetically determined and thus manifest an individual's DNA. Genetic proteins are typically found in blood and other bodily fluids. They range from the familiar blood groups (A, B, AB, and 0) to antigens, such as human leukocyte antigens, that enable scientists to distinguish among individuals with a high degree of certainty. These proteins cannot identify individuals with the precision of DNA bands, however, because they are shared with at least some other members of the general population, although in some cases the proportion may be small. For a general discussion, see P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, Ch. 17.

they can narrow the class of possible culprits.[225] Some tests, such as the Human Leukocyte Antigen ("HLA") test, can identify individuals with a high degree of certainty.[226]

The tests most analogous to DNA tests are those that identify genetic markers by electrophoresis, and thus use some of the same procedures used in DNA tests.[227] Electrophoresis is used widely in scientific research and is accepted as a reliable separator of molecules according to length by both scientists[228] and the courts.[229]

Some courts have criticized the use of electrophoresis to separate certain protein markers in aged or dried bloodstains because research has not adequately documented the effects of age and contamination on the markers.[230] These criticisms, however, cannot be extrapolated to DNA tests, which type DNA itself, not protein markers.[231] Nevertheless, the criticisms are useful because they demonstrate that DNA tests must be extensively validated to ensure that they reliably type forensic samples recovered in field conditions.[232] The decisions suggest that under either the *Frye* or Federal Rules test, DNA tests

225. Although courts frequently admit these tests to exculpate, courts differ as to admissibility when the evidence serves to include the suspect or putative father within a class of potential culprits because of possible jury confusion over the meaning of such a statistical inclusion. *See infra* notes 234–42 and accompanying text.

226. Human Leukocyte Antigen ("HLA") tests analyze antigens found in an individual's white blood cells. P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 17-8(B), at 586–87. Some proponents claim that HLA testing can positively exclude a falsely accused father in over 90% of the cases. *Id.*, § 17-8(C), at 597. DNA tests provide a much higher degree of certainty. Proponents of one test claim that the probability of a match occuring by chance between a suspect's DNA and DNA recovered from a crime scene is one in thirty billion. *See supra* note 109.

227. *See supra* notes 43–48 and accompanying text (discussing electrophoresis).

228. *Id.*

229. *See Admissibility of Genetic Markers, supra* note 218; *see, e.g.*, State v. Washington, 229 Kan. 47, 622 P.2d 986 (1981), *modified on other grounds sub nom.*, State v. Hayes, 239 Kan. 443, 720 P.2d 1049 (1986); People v. Borcsok, 114 Misc. 2d 810, 452 N.Y.S.2d 814 (Sup. Ct. 1982).

230. *See, e.g.*, People v. Brown, 40 Cal. 3d 512, 709 P.2d 440, 220 Cal. Rptr. 637 (1985); People v. Young, 425 Mich. 470, 391 N.W.2d 270 (1986). Other courts, however, have admitted electrophoresis of dried bloodstains, and commentators have suggested that electrophoresis of dried bloodstains is reliable. *See, e.g.*, People v. Crosby, 116 A.D.2d 731, 498 N.Y.S.2d 31 (1986); *Admissibility of Genetic Markers, supra* note 218, at 787–90 (cites reliability study conducted by the Ad Hoc Committee of the American Academy of Forensic Sciences).

231. *See supra* note 36 and accompanying text. DNA samples, however, may have their own degradation and contamination problems. *See supra* notes 78–97 and accompanying text.

232. Although forensics tests may work well under laboratory conditions, where sufficient DNA is easily obtainable without the problems of environmental contamination, tests must be validated to ensure that they work with dried samples exposed to the environment. For example, courts routinely admitted test results in early genetic marker electrophoresis cases, but in 1982 a commentator suggested that further empirical validation of the accuracy of tests performed on dried bloodstains was needed. As a result, courts took a more cautious approach to admitting tests of dried bloodstains. P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 17-8(C), at 600

should be admitted if they are supported by adequate empirical testing.[233]

ii. Admissibility of Statistical Evidence

Courts generally admit probability calculations[234] based upon empirical sampling of population frequencies of a particular biological characteristic.[235] Nevertheless, some jurisdictions may limit the use of statistical evidence.

Some courts exclude the evidence if the jury might overestimate the probabilities' probative value.[236] These courts are especially concerned when the statistical evidence merely includes the defendant

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(citing Jonakait, *Will Blood Tell? Genetic Markers in Criminal Cases*, 31 EMORY L.J. 833 (1982)).

233. *See infra* notes 243–64 and accompanying text.

234. Experts introduce this statistical evidence to show that only a limited part of the population possesses the suspect's characteristics. *See supra* notes 63–69 and accompanying text. For example, statistical analysis of a traditional blood test might show that five percent of the population possesses the suspect's blood markers.

DNA tests are usually explained in terms of the probability of two different individuals possessing the same band pattern, i.e., the probability that the suspect's bands have matched the sample's bands only by chance. This probability is derived by multiplying together the population frequencies derived from the product rule. *See supra* notes 63–69 and accompanying text (explaining probability calculations). Other probability calculations, such as the probability of exclusion or a probability of paternity, could be calculated with DNA bands, but DNA tests are so discriminating that other statistics often will be unnecessary. If they are introduced for a less-discriminating DNA test like PCR analysis (discussed *supra* at note 70), they can pose some risks because a jury may have difficulty evaluating them. An analysis of the various probabilities is beyond the scope of this Comment. *See generally* P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 17-9; Jonakait, *When Blood is Their Argument: Probabilities in Criminal Cases, Genetic Markers, and, Once Again, Bayes' Theorem*, 1983 U. ILL. L. REV. 369.

235. *See, e.g.*, United States v. Green, 680 F.2d 520, 523 (7th Cir. 1982) (trial court properly admitted testimony demonstrating the frequency of genetic markers in the population), *cert. denied*, 459 U.S. 1072 (1982); State v. Washington, 229 Kan. 47, 622 P.2d 986, 994–95 (1981) (citing cases showing that population statistics on the percentage of certain combinations of blood characteristics, based on established facts, are admissible as relevant to identification), *modified on other grounds sub nom.*, State v. Hayes, 239 Kan. 443, 720 P.2d 1049 (1946); People v. Camon, 110 Mich. App. 474, 313 N.W.2d 322 (Mich. 1981) (defendant had type 0 blood which he secreted into bodily fluids such as semen; court admitted evidence showing 36% of population are type 0 secretors); People v. Crosby, 116 A.D.2d 731, 498 N.Y.S.2d 31, 32 (1986) (victim's blood type occurs in .4% of population and matched a sample taken from the defendant's clothes); State v. Nicholas, 34 Wash. App. 775, 663 P.2d 1356 (1983) (admitted testimony showing that 60% of male population would have semen matching that found in vaginal smear); *see also* People v. Brown, 40 Cal.3d 512, 726 P.2d 516, 528 n.6, 230 Cal. Rptr. 834, 846 n.6 (1986) (court suggested that population frequency data would be acceptable despite *People v. Collins*, discussed *infra* at note 245), *rev'd on other grounds*, 479 U.S. 538 (1987).

236. *See* State v. Carlson, 267 N.W.2d 170, 176 (Minn. 1978) (cannot admit probabilities even if they are based on empirical, scientific data of unquestioned validity); State v. Kim, 374 N.W.2d 814, 816 (Minn. Ct. App. 1985) (not clearly erroneous to exclude testimony that only 3.6% of the population could have been the source of the semen), *aff'd*, 398 N.W.2d 544 (1987).

within a relatively large class of potential suspects.[237] For example, a suspect's blood type may match the assailant's, but the blood type also may be common to a sizeable segment of the population.[238] DNA tests identify individuals so much more precisely than blood tests, approaching virtual certainty,[239] that arguments of wrongful inclusion are not persuasive. In addition, DNA tests are so accurate and conclusive that jurors are less likely to overvalue their weight. If only one in thirty billion persons possesses the suspect's DNA, jurors rightfully conclude that the DNA tests are conclusive.[240]

Furthermore, courts appear to be abandoning barriers to the admissibility of statistical evidence.[241] Most courts now admit probability estimates to explain the results of blood- and tissue-typing tests.[242] Thus, regardless of whether they apply the *Frye* or Federal Rules test, courts are likely to admit statistical evidence to explain the results of DNA tests.

d. Empirical Validation of Tests

Courts, especially those that apply the *Frye* test, may require extensive empirical validation (repeated testing) to ensure that DNA tests identify individuals reliably.[243] Four factors are relevant to the sufficiency of validation: The amount of testing, error rates, the existence of testing standards, and validation by an independent source.

First, the limited amount of testing performed may be too small to adequately validate any of the DNA testing techniques. DNA tests derive their probative value from the population frequencies of the different matching bands. These bands link a suspect to a crime by showing that the odds of anyone else in the population possessing the suspect's characteristics are infinitesimal.[244] To be reliable and to

237. *See* People v. McMillen, 126 Mich. App. 211, 336 N.W.2d 895 (1983) (evidence placing the defendant within a group of 35% of all males was not admitted; potential for adverse influence on the jury is too great).

238. In these situations, courts may also be concerned that a jury might equate a 5% general population characteristic with a 95% probability of guilt. *See* MCCORMICK, *supra* note 150, § 210, at 654–55.

239. *See supra* notes 68 & 105 and accompanying text.

240. In contrast, a less accurate test might determine that five percent of the population possesses a suspect's characteristics, and jurors might wrongly conclude that the test results are damning.

241. *See* People v. Camon, 110 Mich. App. 474, 313 N.W.2d 322 (1981) (objections of remoteness go to weight of evidence); P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, Supp. § 17-9, at 52.

242. MCCORMICK, *supra* note 150, § 205, at 620–22.

243. *See* Strong, *supra* note 173, at 13–14 (citing as examples fingerprinting and ballistics).

244. *See supra* notes 63–69 and accompanying text.

accurately reflect the true frequencies in the general population, the frequencies must be calculated from the DNA test results of a large sample population.[245]

Courts have not stated how much empirical validation is enough. When courts initially admitted fingerprint evidence, there were 25,000 impressions on file in the United States.[246] In contrast, some courts have accepted voiceprint analysis based on the testing of 250 voices.[247] To date, forensic DNA tests have been performed on several thousand people,[248] and scientists maintain that this population base provides accurate predictions of frequencies.[249] Because scientists agree that the population base is sufficient, the amount of testing should satisfy the "reasonable reliance" standard of the Federal Rules test. Nevertheless, courts, especially those that apply the *Frye* test, might require a larger population base before accepting DNA tests.

A related concern is that the frequencies of DNA bands may differ among blacks, whites, hispanics, and other ethnic groups.[250] Labs report that differences among populations do not affect the tests' abil-

245. *See supra* notes 63–69 and accompanying text. The sample population must be large enough to provide an accurate calculation of the frequency in the general population. *See* United States v. Massey, 594 F.2d 676, 679–81 (8th Cir. 1979) (expert referred to study indicating that the probability of matching hair samples was 1/4500 but could not explain basis for the probability calculation); Graham v. State, 168 Ga. App. 23, 308 S.E.2d 413 (1983) (cannot admit mathematical odds to identify a defendant when the odds are based on estimates, which have not been demonstrated to be valid).

People v. Collins, 68 Cal. 2d 319, 438 P.2d 33, 66 Cal. Rptr. 497 (1968), demonstrates a related concern: when determining the overall probability of multiple, independent events, experts must show that the individual variables are in fact independent or unrelated. In *Collins*, the prosecutor's expert tried to link a couple with a crime by assuming that their characteristics—interracial, interracial in car, man with mustache, woman with ponytail, woman with blond hair, and partly yellow car—were independent, unrelated events. The expert then hypothesized their frequencies of occurrence in the population and "calculated" that one in twelve million couples would possess these characteristics. Because, among other reasons, the expert hypothesized but did not prove by population sampling that the variables were independent, the appellate court excluded the calculations.

The locations of different DNA bands are independent events and are not subject to the problems seen in *Collins*. *See supra* notes 65–66.

246. Note, *Evolving Methods of Scientific Proof*, 13 N.Y.L.F. 677, 743 n.8 (1968). 100,000 fingerprints were on file in Scotland Yard at that time. *Id.* at 743 n.7.

247. P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 10-2, at 314 (34,992 experimental trials of 250 male voices were performed over a two-year period); *see also* United States v. Brown, 557 F.2d 541, 557 (6th Cir. 1977) (rejected ion microprobic analysis of hair samples because testing involved only 130 samples).

248. *See supra* note 64.

249. Interview with Michael Baird, Ph.D., *supra* note 64.

250. With other scientific techniques, courts have expressed concern that tests not be extrapolated to untested situations. State v. Huynh, 49 Wash. App. 192, 742 P.2d 160, 164 (1987) (experts agree that gas chromatography is generally acceptable to compare unaltered, but not weathered or burned, gas samples). *But cf.* State *ex rel.* Trible v. Hedman, 291 Minn. 442,

ity to identify individuals reliably.[251] Again, courts that apply the *Frye* test might require testing of a larger population base to confirm this conclusion.

Second, courts may be concerned with the potential for errors in DNA testing.[252] Scientists currently researching DNA tests report that errors produce only inconclusive results, but do not wrongly incriminate the innocent or exonerate the guilty.[253] Accordingly, proponents maintain that for forensic samples recovered in field conditions, DNA tests will either result in an accurate identification or no identification. Nevertheless, because the exact limits of the stability of DNA have not been fully delineated, courts that apply the *Frye* test might require further testing to ensure the accuracy of this conclusion.

Third, courts may be concerned with the existence of testing standards,[254] procedures establishing the chain of custody of test samples,[255] and certification of the competence of those who analyze and interpret the tests.[256] DNA forensic labs have adopted their own lab

192 N.W.2d 432 (1971) (court admitted voiceprint of female voice despite empirical testing only of male voices).

251. *See supra* note 63.

252. United States v. Williams, 583 F.2d 1194, 1198 (2d Cir. 1978) (citing evidence that the error rate for voiceprints was as low as 2.4%), *cert. denied*, 439 U.S. 117 (1979). Courts may be more concerned when a test has the potential to erroneously implicate innocent persons than when it has the potential to erroneously exculpate the guilty.

253. *See supra* notes 70–97 and accompanying text.

254. United States v. Williams, 583 F.2d at 1198 (citing guidelines issued by the International Association of Voice Identification); United States v. Bruno, 333 F. Supp. 570, 574 (E.D. Pa. 1971) (party offering ink analysis test must demonstrate adherence to proper procedures); People v. Kelly, 17 Cal. 3d 24, 549 P.2d 1240, 1244, 130 Cal. Rptr. 144, 148 (1976) (proponents of voiceprints must show that correct scientific procedures were used in the particular case); People v. Young, 418 Mich. 470, 340 N.W.2d 805 (1983) (juries give tremendous weight to electrophoresis tests so courts must be cautious in admitting tests until the test's accuracy and standardization are clearly shown). Adherence to the proper procedures on the particular occasion may go to the weight of the evidence, though some courts exclude the evidence when the proper procedure is not followed. *See supra* notes 179–80 and accompanying text.

255. Proper procedures ensure that evidence presented at trial is the same evidence that was involved in the crime. State v. Foster, 198 Kan. 52, 422 P.2d 964 (1967). Standardized procedures are particularly necessary when evidence is susceptible to deterioration or contamination. *See* Ritter v. State, 3 Tenn. Crim. App. 372, 462 S.W.2d 247, 249 (1970) (blood samples should be handled with care; all who handle samples should be ready to testify as to their custody and unchanged condition).

256. *See* People v. Anderson, 637 P.2d 354, 360 (Colo. 1981) (absence of qualification standards for polygraph examiners heightens the possibility for grave abuse); State v. Newton, 421 A.2d 920, 922 (Del. Super. 1980) (proper foundation for admission of radar device should include evidence of operator qualifications and training). If a qualified analyst can conduct a

protocols,[257] which should ensure the reliability of test procedures. Further, some of the laboratories have invited independent experts to assess the reliability of the test results and review lab protocols,[258] which also enhances reliability. Because these lab procedures are generally accepted as proper by the greater scientific community,[259] they should meet the standards of both the *Frye* and the Federal Rules tests.

Fourth, courts may require that independent studies be conducted to confirm the reliability of different DNA techniques.[260] Some independent testing already has been performed. Forensic laboratories have asked independent experts to review their tests and lab protocols.[261] Further testing is being conducted at government and university laboratories.[262] This independent review supports the conclusion that DNA tests can identify individuals reliably.[263] Courts should con-

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reliable test, then lack of competence among analysts may go to the weight of the evidence because a particular analyst's qualifications can be examined in court.

DNA labs probably will rely on field investigators to collect samples. These field investigators also should be properly trained in the collection and preservation of evidence to prevent contamination, thus allowing more DNA tests to be run. A. MOENSSENS, *supra* note 133, at 475.

257. *See supra* note 126 and accompanying text.

258. A. MOENSSENS, *supra* note 133, § 6.14, at 358 (scientists from Lifecodes have subjected the DNA test to extensive experimentation and have invited independent experts to assess their lab and test results).

259. *See also* text accompanying notes 184–88.

260. Independent empirical testing can resolve uncertainties regarding a technique's reliability. In 1972, Michigan State University published a study on the reliability of voiceprints and reported favorable results, which played a major role in judicial acceptance of voiceprint evidence. P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 10-2, at 314–16, 319. The FBI later requested that the National Academy of Sciences ("NAS") evaluate the reliability of voiceprints. The NAS concluded that forensic applications should be approached with caution. *Id.* at 317 (citing NATIONAL ACADEMY OF SCIENCES, ON THE THEORY AND PRACTICE OF VOICE IDENTIFICATION 6 (1979)). The FBI now conducts voiceprints only for investigative purposes, not for court evidence. *Id.* at 318.

Courts, especially those that apply the Federal Rules test, do not necessarily require or rely upon independent studies to validate a scientific technique. Some courts have accepted the voiceprint technique based on the testimony of experts and without consulting the impartial NAS study. A. MOENSSENS, *supra* note 133, at 669–70; *see also* Barefoot v. Estelle, 463 U.S. 880 (1983) (lower court properly admitted testimony of future dangerousness despite amicus brief submitted by the American Psychiatric Association stating that two out of three such predictions were wrong). In addition, courts may not be as concerned with "interested" testimony if the test has been extensively performed and if there generally is no disagreement among experts who administer the test. For example, fingerprint analysis has been extensively tested, and examiners rarely disagree over identifications. P. GIANNELLI & E. IMWINKELRIED, *supra* note 96, § 16-9(E), at 553.

261. *See supra* notes 126 & 133 and accompanying text.

262. *See supra* note 135 and accompanying text.

263. Prosecutors in DNA trial cases apparently recognize that courts may require independent confirmation, and have called as experts both molecular biologists from the private labs and academic molecular biologists to confirm reliability. *See* State v. Andrews, No. 87-1400

tinue to require independent testing to monitor private labs and to ensure that DNA tests are properly administered.[264]

III. CONCLUSION

DNA tests are a powerful tool for establishing paternity or identifying suspects in criminal investigations. Although the forensic application is relatively new, several factors support judicial acceptance of the tests under both the strict *Frye* test of general scientific acceptance and the more lenient Federal Rules test. First, the soundness of the scientific principle, that individuals have unique DNA patterns, is well established in the academic scientific community. Further, non-forensic DNA tests are used extensively in other scientific disciplines, demonstrating their reliability and acceptance by the general scientific community. Second, the laboratories currently performing forensic DNA tests are staffed by highly-trained and qualified personnel, which ensures that the tests can be performed reliably and with consistent results. Third, the tests are performed under strict protocols, which also ensure reliability. Fourth, a review of scientific literature shows that forensic scientists agree that DNA tests can identify individuals reliably. Fifth, empirical testing indicates that DNA tests do not wrongly incriminate suspects. Degraded or insufficient samples are merely inconclusive. Finally, independent testing to date supports the conclusion that forensic DNA tests are reliable.

These factors demonstrate that both forensic and non-forensic scientists accept that DNA tests can identify individuals reliably. This acceptance provides a reasonable basis for expert testimony so that DNA test results, if offered by qualified experts, should be admissible under the lenient admissibility test of the Federal Rules of Evidence.

Nevertheless, courts that apply the *Frye* test may have some valid concerns about DNA tests. Population data is still limited, and empirical testing has not yet fully delineated the limits of DNA tests in forensic conditions. These courts also may be concerned about the potential for biased expert testimony. Many experts have professional

(Ninth Judicial Circuit Ct., Orange County, Florida, Division 15, October 20, 1987) (the prosecution called as experts David Housman, Ph.D., professor of biology at M.I.T., and Michael Baird, Ph.D., manager of forensic DNA testing at Lifecodes). In *State v. Andrews*, the defense was unable to find an expert willing to dispute the reliability of DNA tests. Telephone conversation with Ken Cotter, defense attorney for Tommie Lee Andrews, Feb. 8, 1988. This level of acceptance by both academic and lab scientists at the very least establishes that courts should admit the results of DNA tests in civil paternity cases and in cases where the results are offerred by the defense.

264. *See supra* notes 139–42 and accompanying text (discussing how monitoring of the private laboratories enhances the reliability of DNA tests).

and financial interests in the tests' success, and courts may fear that these experts are not objective. Further, only a few forensic labs administer the tests, and courts may conclude that there are insufficient experts to demonstrate general acceptance under the *Frye* test.

Despite these legitimate concerns, courts should conclude that DNA tests identify individuals reliably and admit the test results into evidence under the *Frye* test. Experts, both from the commercial labs and the academic community, believe that further empirical testing will only confirm that DNA tests are reliable and statistically sound. Adoption of the safeguards proposed in Section I will further enhance the reliability of DNA tests. Objective experts from the academic community can corroborate the testimony of experts from the commercial labs. In addition, these experts comprise a larger scientific community that accepts DNA tests as reliable, thereby meeting the *Frye* test of general acceptance. Judicial acceptance of DNA tests will enhance society's interests in solving violent crimes while ensuring that innocent suspects are freed.

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