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DNA FINGERPRINTING: POSSIBILITIES AND PITFALLS OF A NEW TECHNIQUE

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ABSTRACT

A technique popularly called DNA fingerprinting holds the potential to significantly impact legal evidence of identity. This article outlines the technical steps involved in DNA fingerprinting, distinguishing the test from similar techniques. The article further describes the technical limits of DNA fingerprinting, and suggests the legal questions the test may raise.

I. INTRODUCTION

The headlines proclaim it will revolutionize legal evidence: "DNA fingerprinting," a new method of identification that has caught the attention of the popular press.[1] The scientific community developed and uses this technique to investigate human genetics,[2] but now the technique is touted as the solution to legal questions from murder to paternity. Promotional literature from commercial firms offering the technique predict that it will be helpful in solving not

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[1] "DNA minisatellite analysis" would be a more appropriate title, as this article describes. The technique's popular nickname may prove to be particularly unfortunate because it creates in the mind of most persons as association with conventional fingerprinting. *See infra* note 65 and accompanying text.

[2] *See* Jeffreys, Wilson & Thein, *DNA Fingerprints and Segregation of Multiple Markers in Human Pedigrees*, 39 AM. J. HUM. GEN. 11 (1986) for a recent example.

only cases of paternity and homicide, but rape, assault, missing persons, unidentified bodies, unsolved crimes, and even hit-and-run.[3]

Are these predictions likely to come true? British immigration officials have relied on DNA fingerprinting at least once,[4] and other law enforcement applications are likely to follow. The technique has also been used to exclude suspects in one widely publicized murder case,[5] causing the press to call the test "foolproof," not unlike "supermarket bar code."[6] Jurors in a recent Florida case similarly believed the test "foolproof,"[7] and found the defendant guilty when no rebuttal was offered to the DNA evidence.[8] Courts on both sides of the Atlantic remain cautious about the DNA fingerprints, although reports in the popular press have begun to attract the notice of concerned American courts.[9]

This article reviews the process by which DNA fingerprints are generated, the advantages and disadvantages of the technique, and the technique's relationship to similar forms of genetic identification. Although scientific jargon and journalistic enthusiasm have previously obscured many details of the technique, a plain explanation should be comprehensible to judges, attorneys, and jurors from all backgrounds. Finally, the article raises several legal questions that stem from the technique's strengths as well as from its limitations; courts in the United States must carefully evaluate such questions before embracing this test. We must begin our description of DNA fingerprinting, however, by outlining some essential background information about DNA and its manipulation.

II. BACKGROUND

Our bodies are composed of tiny functional units called *cells,* each of which contains information packaged as deoxyribonucleic acid, or DNA. This enormously long molecule carries information for a cell much the same way

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[3]*Background Information: DNA-PRINT™ Identification Test*, Lifecodes Corporation (1986). Lifecodes is a firm offering a type of DNA test commercially in the United States; they have quite vigorously publicized and marketed their service.

[4]Jeffreys, Brookfield & Semeonoff, *Positive Identification of an Immigration Test-Case Using Human DNA Fingerprints*, 317 NATURE 318 (1985).

[5]*See* Begley, *Leaving Holmes in the Dust*, NEWSWEEK, Oct. 26, 1987, at 81; L.A. Times, March 11, 1987, at 113, col. 1.

[6]*DNA Prints: A Foolproof Crime Test*, TIME, Jan. 26, 1987, at 66; Washington Post, Sept. 20, 1987, at A23.

[7]Arizona Republic, Feb. 7, 1988, at A3, col. 1, reporting on Florida v. Andrews, No. CR 871400 (Orlando 1987).

[8]*Id.*

[9]Several trial courts have admitted DNA tests into evidence, but no cases have reached an appellate level, nor are any reported. A court in Rockland, New York admitted the test as evidence, and other New York trial courts are considering the matter. *See* New York Law Journal, Feb. 24, 1988, at 1, col. 3. Cases in Oklahoma and Pennsylvania have used DNA evidence, although the tests were insufficient to obtain convictions. *See* Moss, *DNA—The New Fingerprints*, A.B.A. J. May 1, 1988 at 68. A Maryland appellate court has also made passing mention of the test in its discussion of another type of genetic identification. *See* The Washington Post, Sept. 20, 1987, at A23; *see also* Cobey v. Maryland, No. 237, slip. op. at 2 (Md. Ct. Spec. App. filed Dec. 2, 1987) (LEXIS, States Library, Omni file).

magnetic tape carries information for a stereo system. DNA interacts with cellular machinery just as the tape interacts with a tape deck. Rather than recordings of music or words, though, our DNA molecules carry instructions on how to construct and operate a human body.[10]

Information is often carried most efficiently in a code. Morse code carries words as dots and dashes; computer memories carry software as binary digit code. DNA also carries its information in coded form. DNA is composed of two parallel chains of *bases*. The four different bases, designated A, T, C, and G, encode information for the cell. The *sequence* of the bases in a DNA chain carries instructions for the cell in the same way dots and dashes carry words in Morse code.[11]

The physical shape of the DNA molecule is a "double helix" structure. This may be thought of as a sort of twisted ladder, with the rungs corresponding to base pairs. Some have compared the DNA structure to that of a zipper: two parallel strands, with teeth or bases pairing in the middle.[12] DNA base pairing is very specific, however: A will pair only with T, and C will pair only with G. A DNA strand can only be "zipped up," or *hybridized* with another strand that has a matching, complementary base sequence.

DNA in the cell is contained in packages called *chromosomes*. An individual inherits half of his or her chromosomes from each parent. The combined information encoded in the base sequences of the inherited chromosomes is called the *genome*; this information determines the individual's physical characteristics. Each body cell contains a complete set of chromosomes, a complete DNA "blueprint" for the entire person. No cell uses the entire "blueprint," however. Cells in different parts of the body read only the sections of DNA that they need to perform their functions.

In a laboratory, DNA may be examined by cutting the long chromosomal chains into short pieces. The DNA is cut using protein molecules called *restriction enzymes*. These enzymes will cut DNA only at very specific points. The enzyme acts as a "magic pair of scissors"; it recognizes a specific base sequence in the DNA and cleaves the DNA only at that place.[13] Different restriction enzymes recognize different sequences. The sequences that the enzyme will recognize may be from 4–8 bases long. Such sequences are scattered at random throughout the genome. Because the restriction enzymes cut only at

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[10]For a more detailed discussion of DNA structure and function, *see generally* B. LEWIN, GENES II 17-22 (1985).

[11]Similarly, a sequence of ones and zeroes carries information for computers. Biological information storage and retrieval, in fact, closely parallels a computer model. The DNA molecule interacts with cellular machinery much the same way a floppy disk interacts with computer hardware. Sequences in the DNA define an "operating system" for reading and processing its coded information. The DNA code is acutally a "machine language"; cellular hardware must translate the code into a different language before it can be expressed.

[12]Kelly, Rankin, and Wink, *Method and Applications of DNA Fingerprinting: A Guide for the Non-Scientist*, CRIM. L. REV. (London) Feb. 1987, at 106.

[13]*See generally* B. LEWIN, *supra* note 10, at 68–70.

their specific recognition sequences, digesting a person's DNA with a certain restriction enzyme will produce the same pieces every time.

As an example, consider a section of DNA as illustrated in figure 1. The section is 10,000 bases or 10 *kilobases* long. This DNA section happens to have three cleavage sites which would be recognized by a certain restriction enzyme. Cutting this section with the enzyme, as illustrated by the arrows, produces two fragments: one 4kb long and another 6kb long. We will call these fragments A and B respectively. Each time this person's DNA is cut with this restriction enzyme, these same fragments will be produced. The production of these fragments is a recognizable characteristic, like height or eye color. This characteristic is inheritable. Because every body cell contains a complete copy of a person's DNA, the same fragments should be produced by cutting DNA from any body cell.

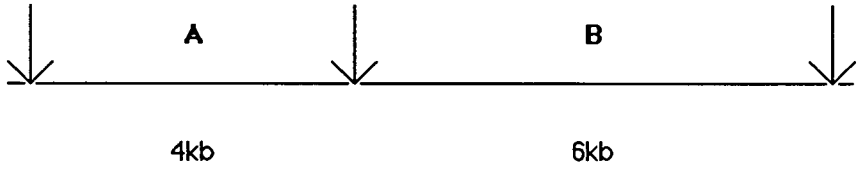

fig. 1

III. THE METHOD OF DNA FINGERPRINTING

Just as the characteristics of height or eye color may be useful for identification, the characteristic of producing certain restriction fragments may be useful for identification. Other biochemical identification tests, such as blood typing, compare some cellular expression of information in the DNA. Identification by comparing restriction fragments would examine the DNA itself. Since the same restriction fragments are produced from each body cell, this characteristic may be particularly useful for identification based upon forensic samples—they can be identified from cells in blood, semen, or hair roots.[14] Be-

[14]Although such samples seem tiny by everyday standards, in the worlds of biochemistry or forensics, these are fairly substantial amounts. *See infra* note 28 and accompanying text. The test is not quantitative, and compared to antibody techniques such as ELISA or RIA, quite insensitive. Recently publicized reports concerning DNA typing from single hairs concern techniques far less accurate than DNA fingerprinting. *See* Higuchi, von Beroldingen, Sensabaugh & Erlich, *DNA Typing from Single Hairs* 332 NATURE 543 (1988).

cause they comprise an inheritable characteristic, the fragments may be useful in determining relatedness, such as paternity.[15]

First, though, laboratory techniques must be employed to visualize and compare the fragments from different samples. DNA molecules are far too small to be examined individually; instead, groups of identical molecules are examined. Determining the sequence of these DNA molecules would be a difficult and time-consuming task; the behavior and physical characteristics of the molecules are much easier to observe. DNA fingerprinting and similar techniques therefore test samples of DNA first for the presence of certain restriction enzyme sites, and second for the size and type of restriction enzyme fragments produced.

Comparison of restriction fragments begins in the laboratory by cutting the DNA from a sample with a restriction enzyme. Samples of the fragmented DNA are then loaded into small holes cut into one end of an *agarose gel*. The gel, which resembles a slab of Jell-O, is placed in a tray of an electrolyte solution. An electric current is applied through the solution. Because DNA fragments have a negative electrical charge, they will migrate toward the positive electrode at the far end of the gel as illustrated in figure 2. This technique, called *gel electrophoresis*, sorts the DNA fragments according to their length.[16]

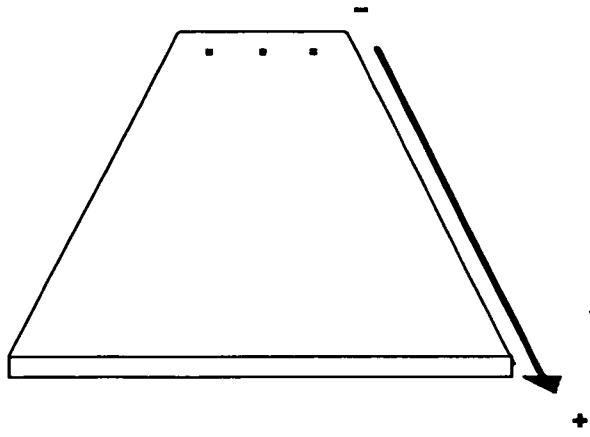

fig. 2

The movement of the fragments through a gel is similar to the movement of a person carrying a rod through a dense forest. If the rod is a short baton, she may move rapidly. If the rod is a long pole, however, her movement will be

[15]For discussion of a recent application, *see* Baird, Balazs, Giusti, Miyazake, Nicholas, Wexler, Kanter, Glassberg, Allen, Rubinstein, & Sussman, *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. GEN. 489 (1986) [hereinafter Baird].

[16]*See generally* B. LEWIN, *supra* note 10.

impeded and she will move quite slowly. By the same principle, short DNA fragments move a greater distance through the gel matrix; large fragments move more slowly. When the current is turned off, fragments of different sizes have moved different distances. Long pieces of DNA remain near the top of the gel, and short pieces are found near the bottom. Gel electrophoresis is sensitive enough to accurately measure a fragment's size by its final position in the gel.[17]

While agarose gels are excellent for separating fragments, the gel is messy and inconvenient for later phases of DNA manipulation. The separated DNA is therefore fixed to a thin sheet of *nitrocellulose* filter. This procedure, called *Southern blotting* for its inventor, transfers the fragments in exactly the same positions they occupied in the gel. The fragments of interest are now visualized using a DNA *probe*.[18]

Probes are created using sophisticated recombinant DNA technology. Using this technology, a fragment such as the 6kb length we designated B may be isolated and placed in a microorganism. There, the fragment is reproduced thousands of times. The fragment is then reisolated and purified; one strand of the fragment is labeled with a radioactive marker. The labeled strand, which we shall call B^{l}, is used to probe the nitrocellulose filter. Because DNA hybridization is very specific, B^{l} will pair only with strands on the filter which have a matching sequence—that is to say, with fragment B. Because of the probe's radioactive label, a piece of X-ray film left in contact with the filter will show a dark band at the position where the probe pairs with fragment B. The piece of exposed X-ray film, called an *autoradiograph*, allows us to see the positions of specific DNA fragments, as illustrated in figure 3.

Just as it is possible for individuals to have different eye or hair color, it is possible for individuals to display different band positions. Some individuals' autoradiographs may show a dark band closer to the top of the gel than the place we would expect for the 6kb B fragment. This change in band position is due to a difference in the person's DNA sequence. An inheritable change in DNA is called a *mutation*. A mutation in some ancestor may have changed a restriction enzyme recognition site, and no cut will occur at that point.

If such a sequence change occurs between sections A and B in figure 1, no 6kb fragment would be created. The 10 kilobase section would remain intact. The B^{l} probe would still recognize the matching B sequence, however, so a dark band would show the position of the 10kb fragment. Because the 10kb fragment is larger than a 6kb fragment, it will appear closer to the top of the gel.

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[17]*See generally* Elder & Southern, *Measurement of DNA Length by Gel Electrophoresis II: Comparison of Methods for Relating Mobility to Fragment Length*, 128 ANAL. BIOCHEM. 227 (1983).

[18]*See generally* B. LEWIN, *supra* note 10, at 287–89.

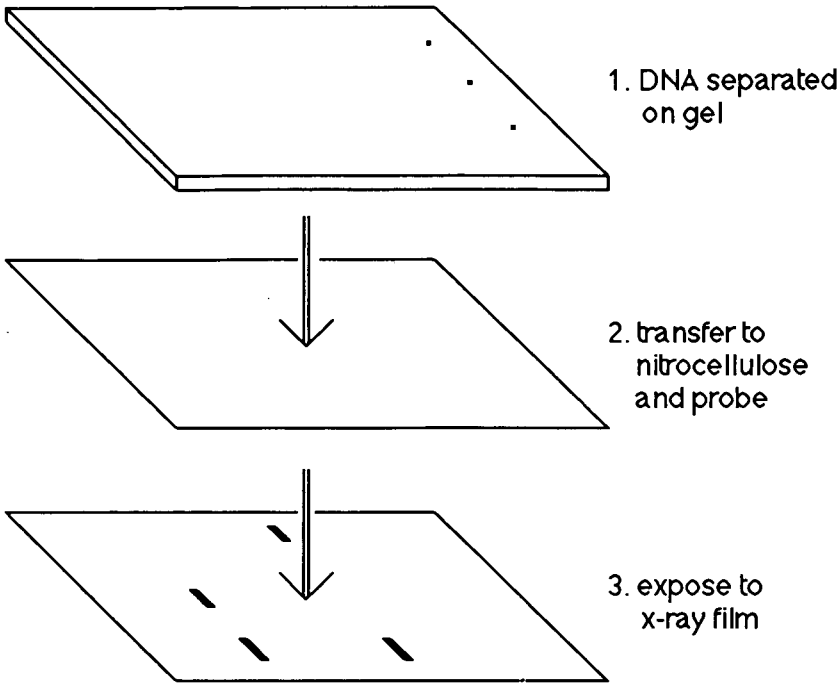

fig. 3

The presence of bands at different positions due to differences in a fragment's length is called *restriction fragment length polymorphism,* or RFLP.[19] The presence or absence of a certain enzyme cleavage site creates a possibility of two inheritable band positions. Such an inheritable characteristic is called an *allele.* If a person inherits the same allele from each parent, one band or the other will appear. Both bands may appear if a different allele is inherited from each parent. The three possibilities—one band, the other band, or both bands—are illustrated in lanes 1, 2, and 3 of figure 4.

RFLPs are generally discovered by accident; scientists find and characterize a few more each year.[20] Each is an identifiable, inherited characteristic which

[19]*See, e.g.*, Baird, *supra* note 15.

[20]A recent example with possible forensic applications is reported by Ali, *DNA Fingerprinting by Oligonucleotide Probes Specific for Simple Repeats,* 24 HUM. GEN. 239 (1986).

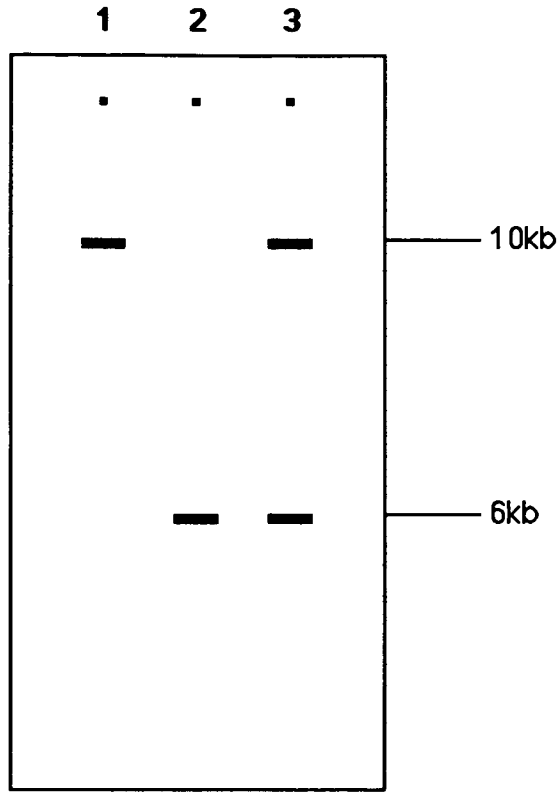

fig. 4

is somewhat useful for determining identity or relatedness. Testing for an RFLP is most useful in excluding the possibility of identity or relatedness; a person who doesn't display the allele found in a forensic sample must be the wrong person. A child who doesn't show one of a suspect's RFLP alleles cannot be that suspect's offspring. Many people in the population may by chance display the same allele, however, so that matching bands are not conclusive identification.

Some RFLPs have multiple alleles; people may display a band at more than two positions. RFLPs may show fifty or more different possible band positions. These "hypervariable" RFLPs occur when many different lengths are possible for a given restriction fragment.[21] A DNA fragment, such as section B in figure 5, may contain a short DNA sequence, or *minisatellite,* repeated over and over. Due to a type of chromosome rearrangement called *unequal crossing over,* these multiple adjacent repeats might occur twenty times in some people,

[21] *See, e.g.*, Baird, *supra* note 13.

thirty times in other people, and so on.[22] Variation in the number of minisatellite repeats creates variations in total fragment length. These fragments of different length move different distances in the gel, so the 6.0kb band might therefore appear at 5.7kb, 6.2kb, or some other position.

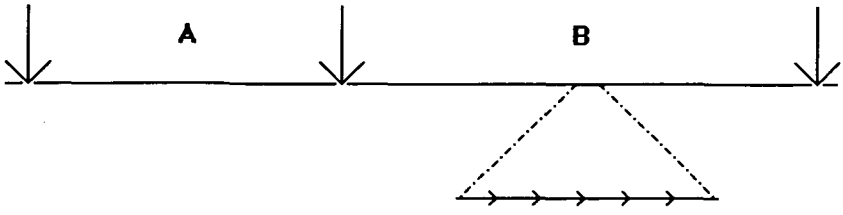

fig. 5

Naturally, an RFLP with multiple alleles is more useful in determining identification, since a smaller proportion of the population will show a given band. The chance of an accidental match is smaller. If several such RFLPs were examined, the possibility of all of them matching by chance would become quite small. The technique commonly called "DNA fingerprinting" does precisely that; it is equivalent to examining scores of hypervariable RFLPs at once.[23]

The minisatellite repeats which create multiple RFLP alleles occur in groups of related sequences; minisatellites with similar or identical sequences are scattered throughout a person's genome.[24] If the probe used to visualize fragments matches a minisatellite sequence, any fragment containing that minisatellite creates a band. Many bands appear, creating a characteristic pattern. This pattern may be very useful in determining a person's identity or relatedness by comparison with other such DNA fingerprint patterns.[25]

The end result of a DNA fingerprint, then, is a piece of X-ray film with dark bands showing the characteristic positions of certain fragments. The only information this test reveals about the DNA code sequence is the presence or absence of the restriction enzyme sites, and the presence or absence of the minisatellite sequences. This technique creates a pattern based on the DNA molecule's structure, and says practically nothing about the genetic information the molecule carries. In this regard, a DNA fingerprint really does resemble an ordinary fingerprint—they are simply highly individual patterns for comparison with other highly individual patterns. But how far will this analogy hold?

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[22] *See* Jeffreys, Wilson, & Thein, *Hypervariable Minisatellite Regions in Human DNA*, 314 NATURE 67–69 (1985).

[23] *Id.*

[24] *Id.*

[25] *Id.* at 72.

IV. TECHNICAL LIMITS OF DNA FINGERPRINTING

In determining how useful a DNA fingerprint pattern may be for determining identification or relatedness, we must consider the limitations of the techniques used in the test. One set of possible limitations depends upon the nature of the sample examined. The "fingerprinting" test requires a relatively large sample of well-preserved DNA for analysis.[26] Stories of scientists extracting DNA from 2,400-year-old Egyptian mummies, while based upon actual research, have become almost apocryphal.[27] In reality, the DNA obtained from such sources is too degraded for fingerprint analysis.[28] Success has been reported in fingerprinting DNA from dried blood and semen samples up to four years-old.[29] However, forensic samples that weather more adverse conditions may be inappropriate for this test.

Contamination of samples may also prevent DNA fingerprinting. Bands from foreign DNA cannot be distinguished from bands of interest. For example, vaginal cells invariably become mixed into the semen samples obtained from rape victims; this has caused problems in other biochemical identification tests.[30] In DNA fingerprinting, this particular problem has been overcome by destroying the fragile vaginal cells in a mild detergent solution, leaving the hardier sperm cells intact.[31] DNA for analysis can then be isolated from only the sperm cells. A contaminated sample such as mixed blood, though, would pose a serious obstacle to accurate DNA fingerprinting identification. The test is similarly unable to distinguish between samples which may have been accidentally or deliberately substituted.[32]

If an appropriate forensic sample is available for analysis, we must next determine what limits on identification are inherent in the nature of the test. The greatest asset of DNA fingerprinting is also its greatest liability: the technique generates a monstrous amount of information. DNA fingerprinting attempts to analyze, all at once, dozens of RFLPs from all over the human genome.[33] This amount of information allows highly specific identification, but may also become obscurative.

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[26]Gill, Jeffreys, & Warrett, *Forensic Application of DNA "Fingerprints,"* 318 NATURE 577 (1985). *See also* Siwolop, Hamilton, Clark, & Cooke, BUS. WEEK, Dec. 1, 1986, at 128E.

[27]Pääbo, *Molecular Cloning of Ancient Egyptian Mummy DNA*, 314 NATURE 644 (1985).

[28]Gill, Jeffreys, & Warrett, *supra* note 26.

[29]*Id.* at 578. For an editorial citing American researchers' success, see Dodd, *DNA Fingerprinting in Matters of Family and Crime*, 318 NATURE 506 (1985).

[30]Gill, Jeffreys, & Warrett, *supra* note 26.

[31]*Id.* at 578.

[32]Dr. Alec Jeffreys, the British scientist who developed the most sensitive version of the test, recently cautioned, "I would like, however, to point out that, contrary to statements in the popular press, this test is not foolproof. It cannot necessarily detect blood sample substitutions, whether accidental or deliberate." Dr. Jeffreys also cautioned against other difficulties discussed in this article, including mutations and closely related suspects. Jeffreys, *Highly Variable Minisatellites and DNA Fingerprints*, 15 BIOCHEM. SOC. TRANS. (London) 309, at 314 (1987).

[33]*See, e.g.*, Jeffreys, Wilson, & Thein, *supra* note 22, at 69.

Three obscurative limitations stem from digesting a large amount of DNA, then separating the fragments only by their length. First, two matching bands from different autoradiographs might consist of entirely different fragments which happen to be of the same length. Second, bands within the same autoradiographs may consist of different fragments having the same length; fragments from different sections of the DNA, as long as they are the same size, will migrate together. Third, fragments which are very close together in size may obscure each other's autoradiograph bands. This problem becomes particularly noticeable at the lower part of an autoradiograph, where the small fragments run. Restriction enzyme digests generate many small fragments, creating indistinguishable overlapping bands.[34]

Identification therefore depends upon bands near the top of an autoradiograph, where the larger and slower moving fragments run.[35] Here again, some bands may obscure others. Some bands may occur in all autoradiographs; these are useless for identification. Some bands may be very faint or correspond to a very heavy band when the patterns are compared; such bands must be disregarded. As a practical matter, approximately fifteen clearly distinguishable bands "of roughly similar autoradiographic intensity" are available for comparison with other DNA fingerprints.[36]

A high degree of technical expertise is therefore needed to perform the DNA fingerprinting technique in its present form.[37] Laboratory personnel are very familiar with the time and practice necessary to make gel electrophoresis yield consistent results. All conditions of the test must be uniform before results may be compared. In addition, a degree of human judgment enters the test when the autoradiographs are interpreted. The person who determines whether or not a certain band should be disregarded should have considerable experience in reading autoradiographs.

At present, then, if the DNA fingerprinting test is properly performed under optimal conditions, about fifteen clear autoradiographic bands will appear for identification. We must consider how accurate identification will be based upon comparisons of those bands. What is the likelihood that two individuals might demonstrate identical patterns of bands? Might two people by chance generate restriction fragments of the same size and electrophoretic mobility? The answers to these questions define limits upon our interpretation of the test.

The popular press, in addressing these questions, has often quoted a probability of one in thirty billion for two individuals to display by chance the same pattern of identifiable bands.[38] This figure is taken from the work of British

[34]Jeffreys, Wilson, & Thein, *Individual-Specific "Fingerprints" of Human DNA*, 316 NATURE 76 (1985).

[35]*Id.* at 76 (Table 1 caption).

[36]*Id.*

[37]*See* Dodd, *supra* note 29.

[38]Among others, *see* L.A. Times *supra* note 5; Dec. 20, 1985, at 134, col. 2; Miller, *DNA Fingerprints to Aid Sleuths*, 128 SCI. NEWS 390 (1985).

researchers who developed the DNA fingerprinting technique.[39] Based upon their initial studies of twenty British Caucasians, these researchers calculated the probability that a given band would be seen when comparing two patterns. From these calculations, they estimated the probability of two individual patterns showing fifteen identical bands.[40]

Forensic experts have expressed some concern that the figure of one in thirty billion, so often quoted, was based upon a small, very homogeneous population sample.[41] The total probability of two patterns matching by chance is dependent upon the frequency with which each individual band occurs in the population. The extensive data necessary to accurately assess the frequency of a given band in the general population—or in an ethnic subpopulation—is not yet available.[42] Research teams in Britain and the United States are continuing their studies and remain confident that their accumulated data will show the probability of chance matches to be very low.[43] Until such data is available, however, sweeping generalizations about the technique's accuracy seem premature.

The British scientists who initially gave the one in thirty billion estimate also observed that the possibility of a chance pattern match increases if the subjects are closely related. The chance of any band appearing in two siblings' autoradiographs is approximately fifty percent.[44] The chance of two siblings showing identical patterns therefore becomes about one in 33,000.[45] Identical twins—the most extreme case of relatedness—naturally display identical patterns.[46]

This trend becomes even more pronounced where the technique is used in paternity determination. Since half of an individual's DNA is inherited from each parent, six or seven of the fifteen bands from a pattern should be identifiable in each parental pattern.[47] In paternity testing, then, the possibility of a chance match increases again—only half as many bands are used to establish identity. If the suspected father were wholly unrelated to the actual father, the

[39]Jeffreys, Wilson, & Thein, *supra* note 32, at 77.

[40]*Id.*

[41]N.Y. Times, Feb. 4, 1986, at C10, col. 5; American Association of Blood Banks Committee on Parentage Testing, *Standards for Parentage Testing Laboratories*, Dec. 5, 1986; International Society for Forensic Haemogenetics, *Statement of the Society for Forensic Haemogenetics Concerning DNA-Polymorphisms* Vienna 1987.

[42]Surprisingly little data has actually been published in this regard. The British researchers who performed the initial studies on Northern Europeans have also accumulated data on individuals from India, but this remains unpublished. *See* Jeffreys, *supra* note 32, at 314. In the United States, researchers from Lifecodes have published copiously, but almost entirely on RFLP frequency, rather than on minisatellite probes. For an example, *see* Baird, *supra* note 15. Unfortunately, lawyers with little science background tend to confuse these RFLP papers with minisatellite research. The legal community must realize that the accuracy and reliability of these tests are very different. *See infra* note 67.

[43]N.Y. Times, *supra* note 41.

[44]Jeffreys, Wilson, & Thein, *supra* note 34, at 77.

[45]*Id.*

[46]*Id.*

[47]*E.g.*, Jeffreys, Wilson, & Thein, *supra* note 34, at 78.

probability of matching patterns is about one in 20,000.[48] If, however, the suspected and actual fathers are closely related, a chance match may be as likely as one in sixty-three.[49] The possibility of a chance match may be greatly reduced by running parallel tests. Different probes or different restriction enzymes would yield different patterns for comparison.[50] This, of course, is only possible if enough undergraded DNA can be extracted from a forensic sample to run multiple tests.

Finally, there is some possibility that mutation or unequal crossing over may occur within the space of a generation, altering one or two bands of a pattern. At least one such occurrence has already been observed by British scientists.[51] They estimate the chances of such an event happening as high as one in 240.[52] Such a genetic change might create one or two bands that would not match either parental pattern. A difference of one or two bands may therefore be insufficient to exclude relatedness.[53]

V. LEGAL LIMITS OF DNA FINGERPRINTING

We have examined how DNA fingerprinting produces an inheritable pattern of autoradiographic bands, approximately fifteen of which may be useful in determining identity or relatedness. While more extensive studies of this technique have been called for, studies performed so far indicate that, within its proper limits, the test has an estimated chance of false positives comparable to established biochemical tests for excluding suspects. More importantly, the DNA fingerprinting technique holds the potential for individual identification of suspects. These attributes of the test raise a host of technical and legal questions which will make its use as evidence far more complex than its proponents have yet suggested.[54]

To begin with, what criteria will American courts consider in admitting this test as evidence? Acceptance or rejection of scientific tests by our courts tends to be a quirky and complicated process, particularly in criminal cases. One or two standards will clearly be addressed. In evaluating controversial techniques, many jurisdictions have adopted the test articulated in *Frye v. United States*.[55] The *Frye* court, evaluating polygraph tests, stated that an

[48] *Id.*
[49] *Id.*
[50] Jeffreys, Wilson, & Thein, *supra* note 22 at 71.
[51] *Id.*
[52] *Id.*
[53] *Id.*
[54] Dr. David Housman, a biologist at M.I.T., has suggested that lawyers who question the accuracy of the test "don't know basic biology." Arizona Republic, March 13, 1988, at AA2, col. 1. However correct this assesment may be, the accuracy of the test rests primarily upon principles of physics, chemistry, and even psychology. Its admission into court rests wholly upon principles of law.
[55] Frye v. United States, 293 F. 1013 (D.C. Cir. 1923).

emerging scientific test should be generally accepted in its own field before it can be admitted by the court.[56] DNA fingerprinting may not yet be ready for such scrutiny: clearly, many experts and professional associations are hesitant to accept the test without further study of its reliability and accuracy.[57] While the methods employed in this technique are commonly used and well accepted in the scientific community, the interpretation of results obtained by those methods may not be so well accepted.

Imbedded within the *Frye* standard is a particularly sticky question concerning what portion of the scientific community a court should look to for acceptance of a new test. In the case of DNA fingerprinting, should the court look for acceptance by biochemists in general, by specialists in molecular biology, or by forensic experts?[58] This question becomes more troublesome when one realizes that many of the experts willing to testify concerning DNA fingerprinting are employed by firms offering the test commercially.[59] Because of the high degree of technical skill necessary to analyze DNA, most prosecutors wishing to employ the test will be forced to rely on these commercial firms. Experts from the firms naturally paint a rosy picture of the test and its accuracy.[60]

Because of such problems, several jurisdictions have never adopted the *Frye* court standard, and others are moving away from it.[61] These courts evaluate the admissibility of new scientific tests on the same basis as they evaluate other evidence.[62] The Second Circuit Court of Appeals, considering the admissibility of sound voice spectrometry, or "voiceprints," stated that the trial judge must weigh the evidence's probativeness, materiality, and reliability against its tendency to mislead, prejudice, or confuse the jury.[63] DNA fingerprinting may face serious challenges under this standard. As previously noted, the test's reliability is still open to question. More importantly, media portrayal of the technique as magically foolproof may make the admission of the test seriously misleading or prejudicial.[64] Even the name "fingerprinting"

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[56] *Id.*

[57] *See* examples *supra* note 41.

[58] Biochemistry is a broad field concerning the chemistry of living creatures, and so includes investigation of the DNA molecule. Molecular biology primarily concerns the study of nucleic acid structure and function; it is sometimes considered a subspecialty of biochemistry. Biochemists in general, and molecular biologists in particular, often use the techniques employed in DNA fingerprinting.

[59] Experts from Lifecodes have testified concerning the test's reliability in the Florida *Andrews* case and in the New York cases. *See* Arizona Republic, *supra* note 51; N.Y.L.J., *supra* note 9.

[60] Testimony from scientists performing a particular analysis is obviously important to establish that the test was done properly, the results are the best obtainable, and so on. Testimony on the overall reliability of the technique, when offered by executives from firms with a commercial interest in seeing the test widely accepted, is an altogether different matter which courts may wish to weigh accordingly.

[61] *See* Lacey, *Scientific Evidence,* 24 JURIMETRICS J. 254 (Spring 1984).

[62] *See id.*

[63] United States v. Williams, 583 F.2d 1194 (2d Cir. 1978).

[64] *Id.*

may create unsubstantiated beliefs and expectations in the minds of judges and jurors.[65]

If DNA fingerprinting is admitted into evidence, courts must then decide how much weight as evidence the test should be allowed. The test's ability to exclude a suspect will doubtless be treated in much the same way as that of established biochemical tests. DNA fingerprinting, however, has a unique potential to individually identify suspects. What degree of reliance should be placed on this attribute of the test? Courts may regard the test differently in criminal cases, requiring proof beyond a reasonable doubt, than in civil suits where a preponderance of evidence is sufficient.

Several factors should be considered in deciding how the test should be regarded in a particular case. As previously discussed, data concerning the rate of mutations or occurrence of given bands in the population is at best tentative.[66] Because the test's performance record is so sparse, juries should perhaps be cautioned against relying primarily upon the results of a DNA fingerprint analysis—especially if the accused's life or liberty may be at stake. This issue is further complicated by different versions of the test which have different estimated accuracies. One commercial version of the test has been estimated to yield false positives once in 200,000 times; a different firm's test has an estimated accuracy of thirty billion to one.[67] Courts may therefore wish to inquire into which laboratory performed the test, the laboratory personnel's level of expertise, the difficulty of their version of the test, and similar matters. Certainly prosecutors and defense attorneys should consider the weight of such factors in presenting their cases.

Similar questions revolve around the application of the technique. For example, the comparison of DNA fingerprints from different types of samples may not yet satisfy applicable legal standards. In theory, DNA analyzed from any body tissue should yield a pattern identical to the pattern from any other body tissue. Some question, though, may arise in criminal cases where semen samples are analyzed to identify rapists. Because each person receives half of his or her genetic material from each parent, sperm and ova cells contain only half as much DNA as other body cells. Each sperm cell in a semen sample will contain only half of a man's chromosomal complement, drawn at random from his entire genome. Presumably, enough sperm cells containing different portions of a rapist's total DNA complement will be present in a forensic sample to

[65]A similar problem occurred with the nickname "voiceprint" for sound spectrometry. *See* Williams, 583 F.2d 1194.

[66]Jeffreys, *supra* note 32; *see also* Jeffreys, Wilson & Thein, *supra* note 22.

[67]The Lifecodes version of the test examines a single RFLP; this is faster but less accurate than analysis offered by Lifecodes' competitor Cellmark. *See* Siwolop, Hamilton, Clark, & Cooke, *supra* note 26; *see also* Moss, *supra* note 9 at 69. Cellmark, founded by Dr. Alec Jeffreys, presumably uses more than one probe to achieve a far greater degree of accuracy. Cetus Corporation has also announced success with a different version of the test using recombinant DNA technology to amplify the number of DNA fragments; the Cetus test also examines a single RFLP. *See* Moss, *supra* note 9, at 69.

represent his entire genome. As yet, though, no published research appears to have examined whether some bands may become fainter or disappear when semen samples are analyzed against samples from other tissues. All data so far indicates that the theory holds true, but the question illustrates one area where little is known about the test's performance. Such questions are salient to determining whether the test's meager record is yet convincing beyond a reasonable doubt.[68]

In criminal cases, some questions about DNA fingerprinting may arise in conjunction with rights protected under the Federal Constitution. The United States Supreme Court has, for example, ruled that fundamental fairness often requires the State to provide indigent defendants with the necessary tools for an effective defense and appeal.[69] The cost of DNA fingerprinting by commercial firms is high; if the test becomes widely accepted, situations may arise where doctrines of equality compel states to pay for DNA fingerprinting or expert testimony.[70]

Previously established doctrines concerning consent and warrants for obtaining blood samples will presumably apply in obtaining samples for DNA fingerprinting. The United States Supreme Court has held that police may determine intoxication through blood samples obtained without a warrant from an unconscious person.[71] The Court stated that such tests are common and minimally intrusive.[72] Samples for DNA fingerprinting may also be obtained from sources such as hair roots or skin scrapings; these might be viewed as even less intrusive than blood sampling.[73]

The Supreme Court has also decided that blood samples to determine intoxication may be taken over an injured person's objection without violating the Fifth Amendment right against self-incrimination.[74] Even without a warrant, such sampling does not constitute an unreasonable search and seizure if the situation involves exigency and probable cause.[75] Unlike blood alcohol levels, though, DNA restriction fragment patterns do not diminish over time. Without such "destruction of the evidence," the exigency needed for warrantless blood sampling may not be present in obtaining "DNA fingerprint" samples.

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[68]Unforeseen exceptions to the test's reliability are already beginning to surface. For example, recent evidence indicates that chemotherapy alters DNA characteristics in a manner that would lead to false exclusions in RFLP or DNA fingerprint analysis. *See* Vink, DeHoog, Reekers, DeWitte, *Changes in RFLP-Patterns after Bone Marrow Transplantation* (Abstract on file with this author).

[69]*See* Britt. v. North Carolina, 404 U.S. 226 (1972); Griffin v. Illinois, 351 U.S. 12 (1956).

[70]The Court, for example, has ruled that states may have to pay for psychiatric evaluation and testimony where essential to an accused indigent's defense. Ake v. Oklahoma, 470 U.S. 68 (1985).

[71]Breithaupt v. Abram, 352 U.S. 128 (1954).

[72]*Id.*

[73]*See* Cupp v. Murphy, 412 U.S. 291 (1973) (warrantless taking of scrapings from fingernails permitted).

[74]Schmerber v. California, 384 U.S. 757 (1966).

[75]*Id.*

Some concern may arise that DNA fingerprinting constitutes a greater degree of privacy invasion than other sorts of biochemical tests. In a society concerned with blood tests exposing the stigma of AIDS, some might fear the ultimate invasion of privacy: examination and exposure of a person's genetic makeup. This type of concern would seem to be unwarranted, and probably deserves minimal court attention. As previously discussed, this technique says virtually nothing about the genetic information the DNA molecule carries. Autoradiographic patterns created by DNA fingerprinting show nothing concerning a person's intelligence, sex, or outward physical appearance.[76] A highly trained scientist might glean from the patterns some information concerning genetic disease, but this is true of many commonly considered biochemical tests.[77]

These are only a handful of preliminary concerns which courts may be required to address in evaluating DNA fingerprinting; other questions will arise. This test, with advancing technical expertise and public understanding, shows every indication of playing a significant role in our justice system. In defining that role, courts should be aware of the technical limits of this test, as well as its unique advantages. A test currently suitable for scientific research may not yet be suitable to alter people's lives and legal positions. The legal community should therefore continue to evaluate with caution the place of DNA fingerprinting in court.[78]

[76]Dr. Alec Jeffreys has observed that a DNA fingerprint autoradiograph does not even indicate the subject's species. *See* L.A. Times, *supra* note 5.

[77]*See* Jeffreys, Wilson & Thein, *supra* note 2. Some sort of argument might be made that exposing information on inheritable diseases is a substantial intrusion on privacy, but this is surely outweighed by compelling state interests.

[78]As this article went to press, both Cellmark and Lifecodes announced improved versions of their DNA analysis techniques; the Cellmark technique was admitted to evidence in a Florida murder trial. *See* Marx, *DNA Fingerprinting Takes the Witness Stand,* 240 SCIENCE 1616 (1988).