03A004I

03A004I

IQP-52-DSA-5787
IQP-52-DSA-1032
IQP-52-DSA-4262

DNA FINGERPRINTING

An Interactive Qualifying Project Report

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By:

Vince Bullinger

Tzipporah Kertesz

Jonathan Meredith

August 27, 2003

APPROVED:

David S. Adams

Prof. David S. Adams, Ph.D.
Project Advisor

Page missing or incorrectly numbered in original

IQP/MQP SCANNING PROJECT

Table of Contents

Executive Summary

Chapter-1: DNA Fingerprinting Description and Types

The DNA sequence of a human and the DNA sequence of a chimpanzee are approximately 98% identical. The only exception to this rule is identical twins, which usually have 100% similar DNA (some minor random changes occur in their DNA over time). Humans differ by only 1% between themselves, however this 1% of different genetic code between people is enough to ensure that no two people are the same. And it is these unique areas of the DNA that we analyze in forensics.

For DNA fingerprinting, we must deal with the portion of the genetic code which differs from person to person. The term for these unique portions is variable number tandem repeats (VNTR), because these portions are randomly replicated over and over again in our DNA. These VNTRs are, in part, what allow our traits to differ and distinguish us from other humans. During the process of DNA fingerprinting, VNTRs are isolated and closely examined through a method called "Southern Hybridization". The most common technique for currently analyzing DNA is STR (short tandem repeats). These regions of DNA vary in length between individuals, and are short enough to be amplified by PCR. Thus no radioactivity is required for probe hybridization. The STR technique can even be performed on partially degraded samples.

Chapter-2: DNA Forensics

Many different tests can be used to analyze samples assumed to contain DNA: presumptive tests. First a strong light can be shined on all surfaces to try to distinguish

any traces of biological fluid left behind. This is the best way to find these samples because the light does not destroy the DNA needed for testing. However, if nothing is detected by the light, but DNA evidence is suspected to be present, a chemical by the name of "luminol" can be used to find the presence of blood at the crime scene (Ramsland, 2003). When luminol is mixed with hydrogen peroxide, with hydroxide acting as a catalyst, the luminescence reaction is accelerated by the iron in the hemoglobin in blood emitting a chemiluminescence which looks like a blue glow in a dark room (Harris, 2003). The chemical "fluorescein" can also be used to yield the same results (Harris, 2003). However, this chemical reacts with the blood and destroys its usefulness in blood typing tests, leaving pictures of where the blood was shed as the only remaining data obtainable from these tests. In addition, fluoresceins can give false positives because they react with materials other than blood, such as bleach. Although different materials yield different types of glow, multiple tests should be done to prevent a false positive (Ramsland, 2003). New evidence has shown, however, that although luminol destroys the classical serological markers used in blood typing, it does not actually destroy DNA. Therefore, PCR can be completed on the DNA followed by analysis of the short tandem repeat regions to drastically increase the effectiveness of the results obtained on luminol treated blood (Della Manna and Montpetit, 2000).

The overall most important practices that must be followed are those that properly document the source of the specimen, its position, the investigator who collected it and the time and method of collection. Each specimen must be kept isolated, properly dried as required, and properly frozen as needed for preservation. Only when such stringent

records are kept of the handling of all samples can the court accept the samples without fear of contamination or manipulation of the data (Handbook, 1999).

Chapter-3: Landmark DNA Cases

The landmark US court case of Frye v US, held in 1923, established the precedent that any scientific technique used to obtain evidence in a court of law must have *general acceptance* in the scientific community before any evidence found with it can be deemed admissible (The Polygraph, 2003). The Frye standard held for almost 52 years.

Unfortunately this "*general acceptance*" standard was difficult to actually achieve in real life, so the standard was overwritten in 1975 with the establishment of Federal Rules of Evidence, and especially Rule 702. This ruling allowed the use of qualified witnesses to testify on technical procedures, and required the procedures to be *reliable* (not necessarily generally accepted).

The ruling in the US v Downing trial of 1985 did not directly involve DNA fingerprinting evidence, however it expanded on Rule 702 requiring a pre-trial *relevancy* test to determine whether the technical evidence to be presented was actually relevant to the trial, or whether it would merely confuse the jury.

In Andrews v Florida, 1988, DNA evidence was first used to obtain a conviction in the U.S. in a trial that used both the relevancy and reliability standards.

Chapter-4: Sensational DNA Cases

The public is usually not aware of any of the landmark cases mentioned above. Instead, they have likely heard of DNA fingerprinting via sensational cases widely

covered in the press. Overall, what the world learned from this trial of the century was that although the technique of DNA fingerprinting had by now become commonly accepted in the courtroom (unlike some of the trials of chapter-3), the way the DNA evidence is collected is extremely important. The process through which the evidence was collected didn't follow the books and standards of forensic science. The designated procedure was created in order to be followed explicitly, and because it was disregarded a clearly guilty O.J. Simpson was allowed to roam without being brought to justice in the criminal trial where the standard is "without a shadow of a doubt". OJ was subsequently held liable for the two deaths in a civil trial in which the standard shifted to "a preponderance of the evidence".

Chapter-5: DNA Databases

It is unreasonable using current technology and Molecular Biology methods to expect the whole span of a suspect's DNA to be sequenced for forensics purposes. After all, scientists only recently succeeded in sequencing one human genome (About The, 2003). Such a process would take too much time and money to be practical for the hundreds of thousands of samples ready for forensic analysis. Instead scientists have found short segments of DNA that are highly variable between people. Therefore, by inspecting a few of these variable sights or loci the probability of false positives decrease since the probability of multiple people having the same group of identical segments becomes more and more unlikely when the number of sites inspected increase. The segments used for such analysis are called short tandem repeats. However, with the increased study of population genomics, it has been discovered that the previously

conceived methods of calculating the probability of another individual having the same group of short tandem repeats were not accurate (Lewontin and Hartl, 1991) and this is where DNA databases can help.

In order for scientists to discover which sequences predominate in which communities, and thereby make DNA fingerprinting probability determinations more accurate, they must have access to the genetic information of numerous people within different social circles. If people would agree to contribute only 1 ml of blood to a DNA database this could be easily accomplished. However, many people are concerned about losing their privacy if they contribute their DNA.

The DNA Identification Act of 1994 (United States, 1994) gave the FBI the authority to establish a national DNA index for crime scene evidence and convicted felons for the sole purpose of law enforcement. The FBI then formed a three level indexing called CODIS (Combined DNA Index System): local on the bottom (LDIS), state in the middle (SDIS), and national at the top (NDIS). By having the database set up in such a layered manner, the local agencies can still operate according to their own legislative and legal requirements. The local information flows up into the state level, and then both the local and the state flow into the national database. In this manner the FBI has accumulated more than 210,000 profiles of crimescene evidence and convicted felons from 24 states (The FBI's, 2000). Within CODIS there are two indexes: the Forensic Index and the Offender Index. The Forensic index contains the DNA profiles compiled from crime scene evidence. The Offender Index contains the DNA profiles collected from individuals convicted of crimes as decided by the legislation in each state. By dividing the profiles in this manner, profiles in the Forensic Index can be compared to

serial offenders. The Offender Index is helpful to see if any of the profiles recently found at a crime scene matches a profile of a past offender which could then become a suspect in the case. All in all, this FBI database has become a very powerful tool in linking criminals to their crimes. However, the database is not given free reign. There are many controls and legislations overseeing the databases to protect the public (The FBI's, 2000).

Project Objective

Although scientists and detectives have discovered DNA fingerprinting to be the greatest advance in the forensic sciences since the discovery of the fingerprint, DNA fingerprinting is still not universally accepted in the courtroom due to the fact that detectives sometimes do not understand how the DNA evidence should be collected and stored, the proper way of using controls while performing the DNA fingerprints, and how DNA fingerprinting works. Without this understanding for the jurors, and standardization of DNA fingerprinting methods, jurors would not be well informed enough to determine whether to believe the results from the DNA fingerprinting analysis. The purpose of this IQP is to examine the method of DNA fingerprinting and then explain it in layman's terms. Past court cases that have used DNA fingerprinting are then examined in order to understand the evolution of how DNA evidence has slowly been allowed into courts, and to discuss those sensational cases where the public has likely already heard of DNA fingerprinting. Lastly, the ethics of DNA databases is examined.

Chapter-1: Introduction to DNA Fingerprinting

If you've ever watched the news, you know that every day there are major advances in utilizing DNA with new applications. DNA fingerprinting has been called the greatest invention in the history of forensic science, yet this controversial new technology has societal effects far beyond the technology itself. To understand DNA fingerprinting, we first need an introduction to DNA.

Introduction to DNA

What is going to be explained now is precisely what DNA is, what function it serves, and a few examples of how it is used in fingerprint analysis. DNA, technically known as *deoxyribonucleic acid*, is a complex chemical structure that is a major component of chromosomes. The DNA in chromosomes can be divided into genes. Genes are what determine our characteristics or traits. Such traits include height, facial features, hair color, etc. DNA is useful in one particular way because, much like a standard fingerprint, no two people have identical DNA.

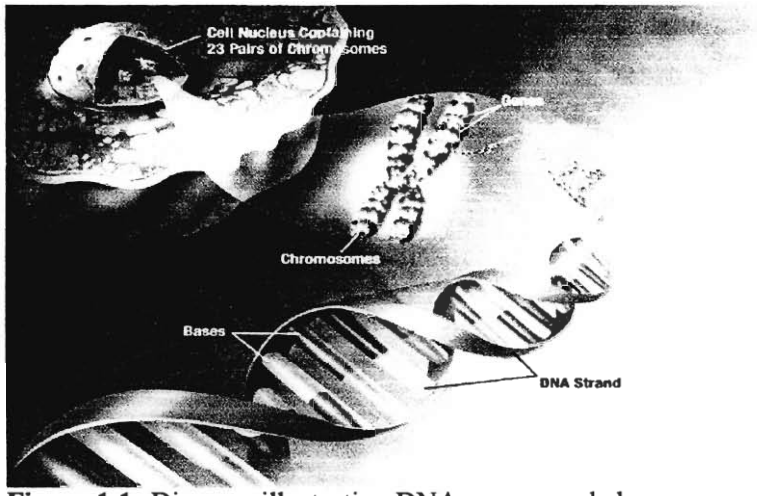


Figure 1.1: Diagram illustrating DNA, genes, and chromosomes. (ADEAR, 2003)

Figure 1.1 illustrates where chromosomes are found within the nucleus of a cell. It is further illustrated how DNA composes the chromosome, and even goes on to point out some degree of complexity in the construction of the DNA itself. The shape that a strand of DNA will take is termed a "double-helix", which is shaped like a staircase curved up the inside of a cylinder. A clearer and more straightforward image of a double-helix may be seen in *Figure 1.2.*

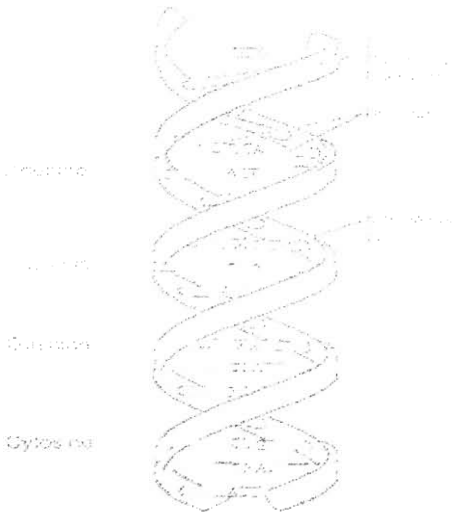


Figure 1.2: Detailed depiction of the double-helix structure of a DNA strand. (Genomic Gibberish?, 2002)

The substances which connect the two sides of the double-helix are called base pairs. The base pairs come from the two nucleotides which pair up to create the bonds which hold the structure together. There are four types of nucleotides, Adenine, Cytosine, Guanine, Thymine (Symbolically known as A, C, G, and T).

The base pairing occurs in a typical pattern each time a free nucleotide requires a bond. Nucleotide A always bonds with nucleotide T. Conversely, nucleotide C always bonds with nucleotide G. The bonds that the nucleotides form are called hydrogen bonds. Nucleotide pairs form the skeleton of our genetic code. Our genetic code is basically a blueprint for our body. Cell growth, reproduction and function are all regulated by this

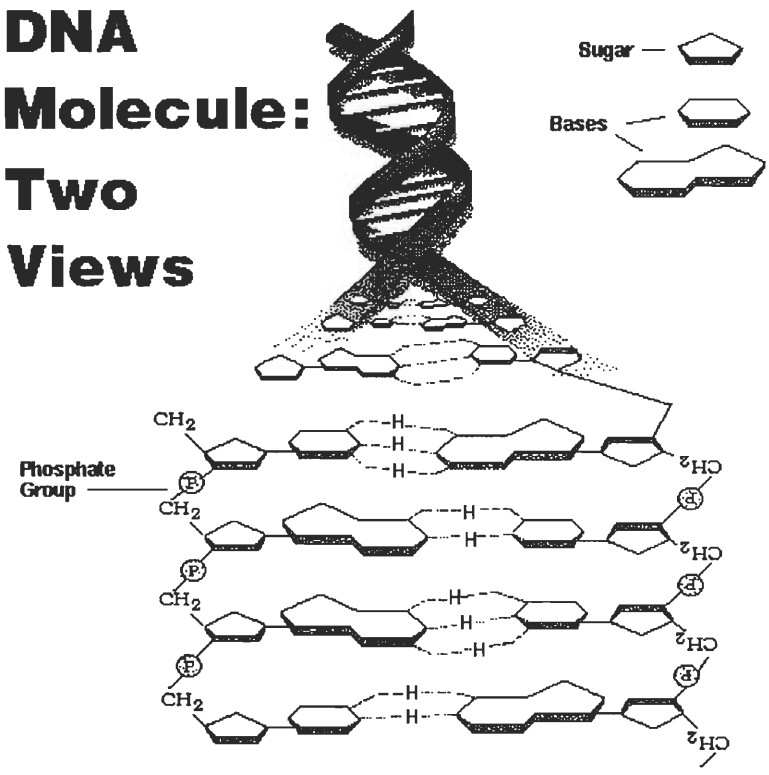


Figure 1.3: The DNA structure in detail. (MIT Biology Hypertextbook, 2001)

tiny instruction manual.

The fact that no two people have identical DNA was stated in an earlier passage, however, in actuality the structure of the DNA in general only changes minutely between each person. As a general comparison, the DNA sequence of a human and the DNA sequence of a chimpanzee are approximately 98% identical. The only exception to this rule is identical twins, which usually have 100% similar DNA (some minor random changes occur in their DNA over time). Humans differ by only 1% between themselves, however this 1% of different genetic code between people is enough to ensure that no two people are the same. And it is these unique areas of the DNA that we analyze in forensics.

VNTRs

For DNA fingerprinting, we must deal with the portion of the genetic code which differs from person to person. The term for these unique portions is variable number tandem repeats (VNTR), because these portions are randomly replicated over and over again in our DNA. These VNTRs are, in part, what allow our traits to differ and distinguish us from other humans.

During the process of DNA fingerprinting, VNTRs are isolated and closely examined through a method called "Southern Hybridization". Southern Hybridization arranges the VNTRs so that they can be examined in a certain order and recorded. Further details on Southern Hybridization will be explained later.

VNTR patterns are hereditary, which means they are passed down from the parent to the child. This also means that the child's DNA is a composite of both of its parent's DNA.

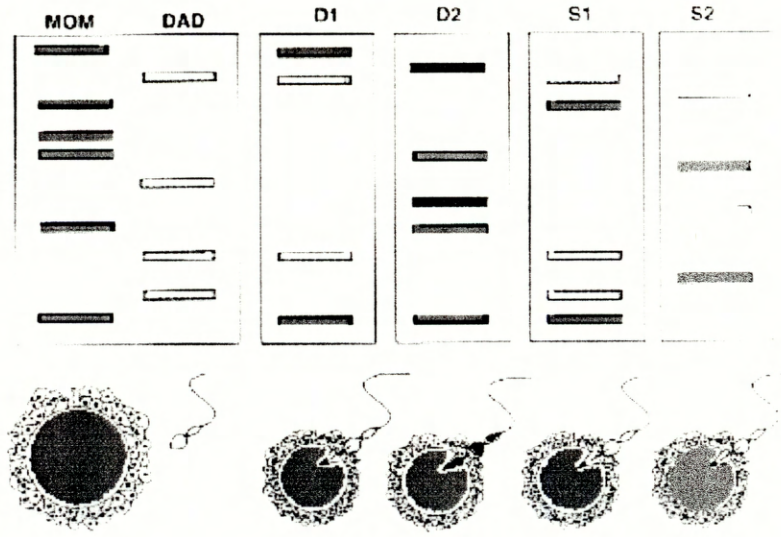


Figure 1.4: Diagram of how parents pass VNTRs down to children. (University of Washington, 2003)

In *Figure 1.4*, we have a visualization of how a child obtains various traits from its parents. The column labeled D1 represents the biological daughter of a set of parents. Observe closely that the VNTRs she has are traceable to her mother and father. The column labeled D2 represents a stepdaughter that the mother had with another father. The daughter has a mixture of traits from her mother and traits from her father whom is not exhibited in this figure. The column labeled S1 represents the biological son of the mother and father. Observe that his VNTRs are traceable back to both recorded parents. Lastly, the column labeled S2 represents an adopted child, whose VNTRs are not traceable to either parent which is recorded. This type of cross referencing is how paternity and maternity is determined when using DNA fingerprinting.

RFLPs

Now it's time to tackle some processing of samples, since we have discussed a few of the applications of DNA fingerprinting. There are two primary methods of

extracting the necessary VNTRs from a DNA sample. The first is Restriction Fragment Polymorphism Analysis (RFLP) and the second is Polymerase Chain Reaction Analysis (PCR).

RFLP analysis consists of taking the sample DNA strand, and dicing it up into smaller pieces at specific sites by using restriction enzymes. The restriction enzymes cleave the DNA at a base sequence pattern which is recognized by each enzyme. On average, about two or three restriction enzymes are used per sample to get a viable result. Once this cleaving process has completed a series of DNA fragments remains. The fragments are then separated by size in a process called electrophoresis which uses an electrical charge to force the molecules through a sieving medium. Due to the slight negative charge that DNA has, it is naturally attracted to the positive lower portion of the gel. The smaller DNA fragments will travel through the gel faster and further, and be closer to the bottom, whereas the larger fragments will travel more slowly and not very far by the time the gel has run its course.

The samples are then run through a process called Southern Hybridization which involves transferring the separated DNA fragments onto a nitrocellulose membrane, which is baked to attach the DNA. The membrane is then hybridized to a probe which is specific for one VNTR region. The position of the probe is visualized on film, giving a bar-code-like pattern. *Figure 1.5* is a diagram showing how a southern blot is prepared.

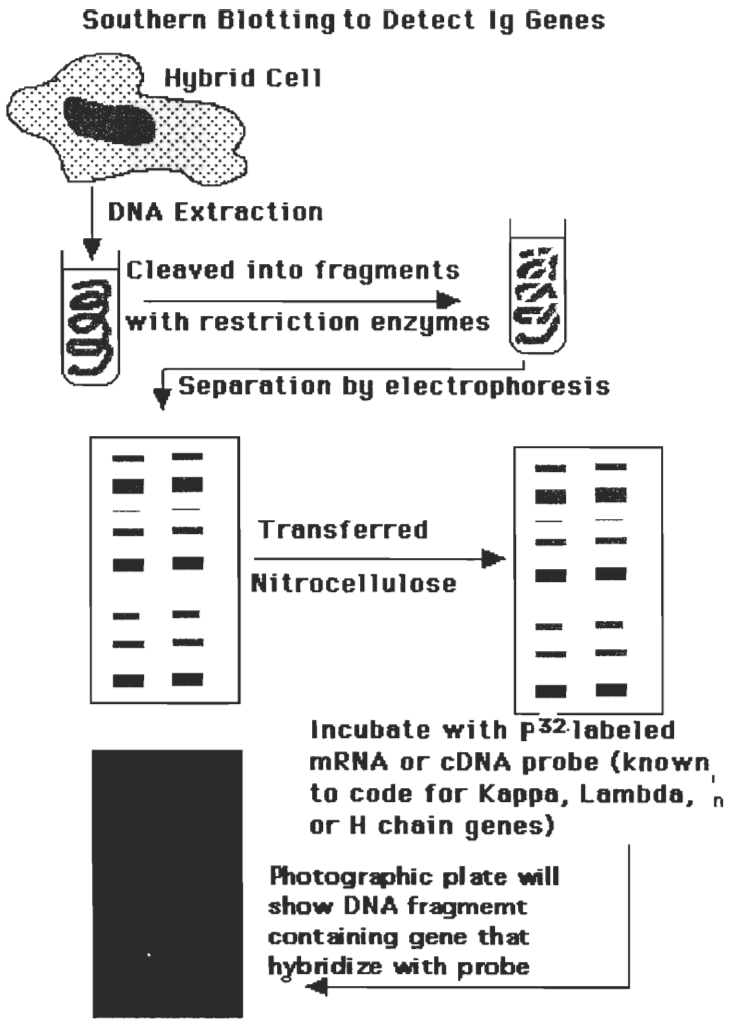


Figure 1.5: A diagram of how a Southern Blot is produced.
(Texas A&M University, 2003)

PCR

When investigating a crime scene, oftentimes there is a rarity in DNA samples to be tested and examined, which makes RFLP very difficult to be implemented, or impossible, as it requires a fairly large sample in order to run effectively. A much more effective analysis, which can produce results on very little sample DNA, is PCR. PCR is much more effective when working with limited samples of DNA because rather than cleaving

the DNA strands, PCR involves amplifying the repeated VNTR sequences by replicating them. *Figure 1.6* is an actual completed Southern Blot.

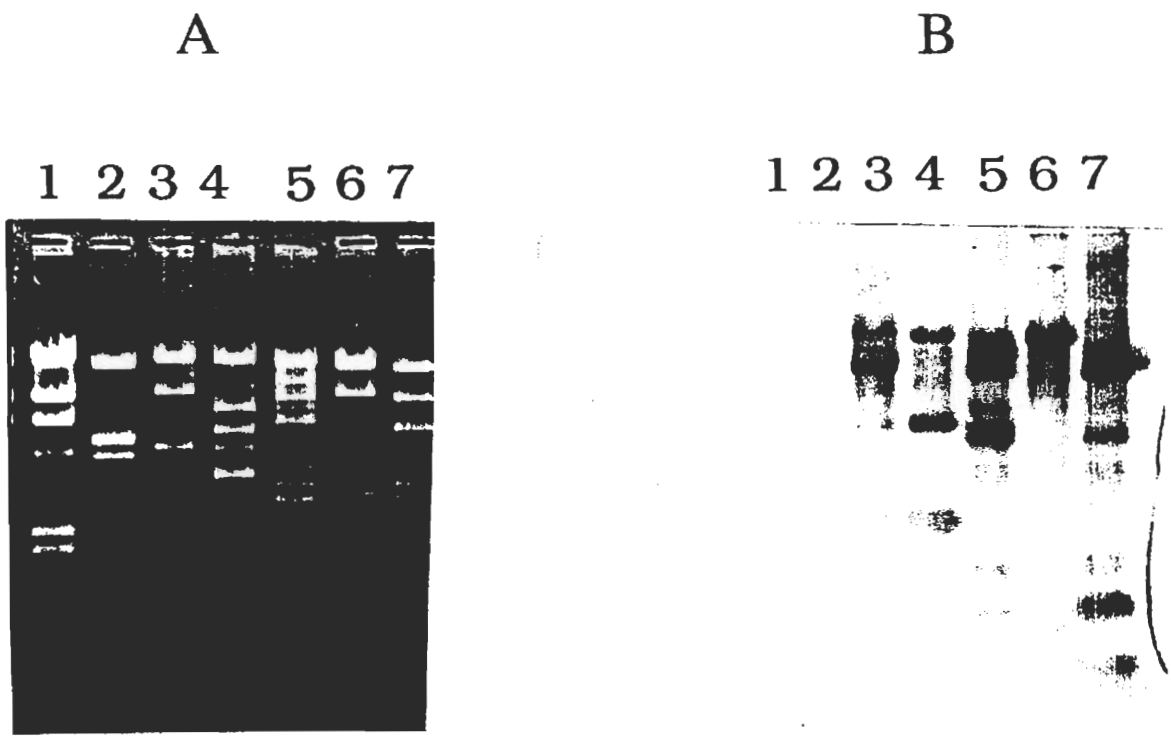


Figure 1.6: A photo of a completed Southern Blot and a photo of the reversed spectrum. (Association for Biology Laboratory Education, 1999)

The basic principles and techniques described so far will allow you to further understand the latter chapters in this paper. It is not expected for you to be a professional and understand all the fine points of DNA and how it functions, but this paper is designed to teach you some basic concepts involves with DNA fingerprinting as if you were just learning about DNA for the first time.

Chapter-2: DNA Forensics

In the history of the Judiciary System, the goal of each case has been to determine what really happened, by whom, and to whom. However, the tools were not always present to enable the judge and jury to fully identify evidence at the crime scene, and thereby make a fully informed decision. With the advance of the Forensic Sciences, and especially DNA Forensics, scientists are now capable of obtaining even more information from the crime scene than ever before. However, as painfully realized in a variety of court cases, this tool is only useful and accurate if it is used correctly under specified procedures which are acceptable in a court of law.

Non-DNA Forensics

Approximately 80% of the human population are "secretors," meaning that their bodily fluids, such as semen, tears, urine, and saliva, as well as their tissues contain the same identifiable antigens, proteins, antibodies, and the characteristic enzymes of their blood. Preliminary "blood type" analysis can sometimes help identify the secretor of these non-DNA molecules. Therefore, the presence of any of these secretions at a crime scene can sometimes be used to link a suspect to the crime scene, or more often exclude a suspect. However, these non-DNA tests only help to a limited extent when trying to link a suspect to a crime because many people have similarities in these proteins. For example, to say that blood at a crime scene is type AB would help eliminate a suspect that is type A, B, or O; but it can not prove that a suspect with type AB was positively at the crime scene. Although AB is the rarest of all blood types, so many people have this

blood type that this test is not very helpful in determining for certain whether an individual was the donor of the blood. It is therefore much more helpful to analyze DNA.

Sources of DNA

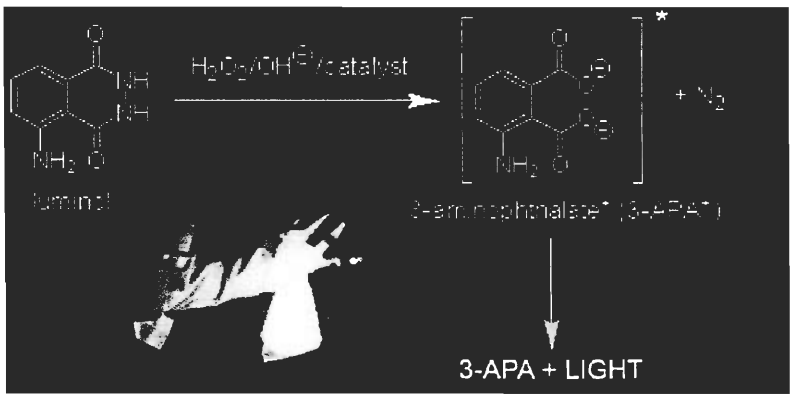
The process of DNA Forensics starts at the crime scene with identifying possible sources of DNA. With the advent of the Polymerase Chain Reaction, and its ability to amplify DNA, the useable sources of DNA from a crime scene have increased dramatically since now even a very small quantity of DNA can be analyzed. Recently it has been discovered that in addition to blood, semen, and hair roots, dandruff (Lorente et al, 1998), lip cosmetics (Webb et al, 2001), the crown body, root body, and root tip of a tooth (Gaytmenn and Sweet, 2003), toothbrushes (Tanaka et al, 2000), saliva and saliva stained material (Walsh et al, 1992), and latent fingerprints even after they have been lifted by adhesive tape (Zamir et al, 2000) can all be used as sources for DNA. DNA is left behind all the time; detectives just have to know where to look for it. The following chart demonstrates the extent of places to look for DNA.

Evidence	Possible Location of DNA on the Evidence	Source of DNA
baseball bat or similar weapon	handle, end	sweat, skin, blood, tissue
hat, bandanna, or mask	inside	sweat, hair, dandruff
eyeglasses	nose or ear pieces, lens	sweat, skin
facial tissue, cotton swab	surface area	mucus, blood, sweat, semen, ear wax
dirty laundry	surface area	blood, sweat, semen
toothpick	tips	saliva
used cigarette	cigarette butt	saliva
stamp or envelope	licked area	saliva

tape or ligature	inside/outside surface	skin, sweat
bottle, can, or glass	sides, mouthpiece	saliva, sweat
used condom	inside/outside surface	semen, vaginal or rectal cells
blanket, pillow, sheet	surface area	sweat, hair, semen, urine, saliva
"through and through" bullet	outside surface	blood, tissue
bite mark	person's skin or clothing	saliva
fingernail, partial fingernail	scrapings	blood, sweat, tissue

(Source: What Every, 1999)

Many different tests can be used to analyze samples assumed to contain DNA: presumptive tests. First a strong light can be shined on all surfaces to try to distinguish any traces of biological fluid left behind. This is the best way to find these samples because the light does not destroy the DNA needed for testing. However, if nothing is detected by the light, but DNA evidence is suspected to be present, a chemical by the name of "luminol" can be used to find the presence of blood at the crime scene (Ramsland, 2003). When luminol is mixed with hydrogen peroxide, with hydroxide acting as a catalyst, the luminescence reaction is accelerated by the iron in the hemoglobin in blood emitting a chemiluminescence which looks like a blue glow in a dark room (Harris, 2003).



(Lewis, 2003)

The chemical "fluorescein" can also be used to yield the same results (Harris, 2003). However, this chemical reacts with the blood and destroys its usefulness in blood typing tests, leaving pictures of where the blood was shed as the only remaining data obtainable from these tests. In addition, fluoresceins can give false positives because they react with materials other than blood, such as bleach. Although different materials yield different types of glow, multiple tests should be done to prevent a false positive (Ramsland, 2003). New evidence has shown, however, that although luminol destroys the classical serological markers used in blood typing, it does not actually destroy DNA. Therefore, PCR can be completed on the DNA followed by analysis of the short tandem repeat regions to drastically increase the effectiveness of the results obtained on luminol treated blood (Della Manna and Montpetit, 2000).

Semen is easier to find than blood due to its natural florescent properties when a UV light is shined on it. However, there is still the problem of false positives occurring due to optical brighteners present in cloth and detergents. Research has therefore been pursued to find a more accurate method of identifying semen. The results have shown that using a Xenon lamp known as a Polilight at a wavelength tested to be within the emission lengths of semen (350 nm through 500 nm), but not in the emission range of the fabric being tested, while using the interference filters that come with the light regularly shows the presence of semen without interference from false positive emissions (Kobus et al, 2002).

Left: Analysis of a semen sample using a Xenon lamp at the proper wavelength, but with no interference filter.

Right: Analysis of the same semen sample as above but with an interference filter (Kobus et al, 2002)

Collection and Handling of DNA Evidence

However, locating a DNA containing sample at a crime scene is only the first step in obtaining the DNA containing specimens. Once sources of DNA are identified, and their positions at the crime scene are properly noted, comes the even more difficult task of properly collecting and handling the evidence so that it can be acceptable in a court of law. Each different state has its own regulations regarding proper handling of evidence in that state. However, there is an overwhelming pattern of proper handling techniques in common everywhere that must be followed to prevent contamination of the evidence, to ensure proper preservation of the specimen so that it can still be accurately tested when it reaches the lab, and to keep track of the circumstances of the evidence at the crime scene. There are two acceptable methods of collecting evidence from a crime scene: collecting the actual stained item or removing a sample of the stain. The former option is preferred because there is a smaller risk of loss or contamination of sample because it is not manipulated as much before it reaches the laboratory for analysis. However, collecting the stained item is not always an option. If there is a pool of blood on a couch, for

example, it is not rational to try to bring the entire couch to the laboratory. Instead it is necessary to log the position of the stain, the type of fabric it was removed from, and then use a proper method of transporting some of the sample to the laboratory. A standard procedure for sample preservation is to dry the sample. A wet, or even damp, sample has an increased probability of bacterial growth, and thus contamination, so it is essential to properly dry all DNA containing samples (Inman and Rudin, 1997).

When a sample must be taken from a wet pool, a sterile swab should be used to pick up the sample, and then it is allowed to air dry. The sample must then be placed in a paper pouch for transport since paper is less likely to contain moisture and allow the growth of bacteria. Each sample should be placed in separate containers to prevent contamination between samples. The sample should also be frozen and transported to the laboratory as quickly as possible to preserve the biological material (Handbook, 1999).

When the sample is a dried stain there are the same two options. When the entire object can be transported, such as small items or garments of clothing, the whole item should be packaged and sealed in paper. Each sample should be transported in its own paper package. For larger items which cannot be transported to the laboratory, a portion of the stain should be scraped into a clean piece of paper which is then folded to secure the sample inside of it and secured inside its own paper pouch. The stain must be scraped with a freshly washed and dried knife that is cleaned between each collection of separate samples to prevent contamination. These samples should also be frozen for preservation (Handbook, 1999).

When blood samples are drawn they must be stored in labeled designated purple-topped tubes with EDTA to prevent coagulation for the DNA analysis. These tubes

should not be frozen but instead refrigerated and packaged in cold packs during transit. Drawn blood is the only sample that should not be air dried, but instead left wet and packaged in a plastic tube (Handbook, 1999).

The overall most important practices that must be followed are those that properly document the source of the specimen, its position, the investigator who collected it and the time and method of collection. Each specimen must be kept isolated, properly dried as required, and properly frozen as needed for preservation. Only when such stringent records are kept of the handling of all samples can the court accept the samples without fear of contamination or manipulation of the data (Handbook, 1999).

Investigators must take the time to properly document all records of evidence recovery and follow the specified guidelines for sample collection. Only when all investigators follow these guidelines can the field of the Forensic Sciences advance to be further accepted in the courtroom. People are currently suspicious of Forensics because they have only heard about the sensational DNA cases. When investigators scrupulously collect their evidence, people can finally learn to accept Forensics as trustworthy.

Chapter-3: Landmark DNA Cases

The road to the utter dominance that DNA fingerprinting evidence enjoys in today's courtroom has been a long, winding and still incomplete one. Although DNA fingerprinting evidence was first deemed admissible in a court of law in the mid 1980's, many landmark cases took place over the last century that paved the way for such highly technical evidence to be allowed and revered. These cases did everything from qualifying evidence of high complexity - which later was interpreted to include DNA - to clarifying exactly how DNA fingerprinting evidence was to be obtained and used in a court of law. In order to understand the process that has given DNA fingerprinting evidence its clout, it is important to examine some of the cases that helped lay the roots for its general acceptance.

Before DNA could ever even be considered in a court of law, it had to follow certain guidelines established for admitting technical evidence from many previous court cases. These guidelines outline how scientific evidence must be performed, if and how it can be submitted, and how it can be determined whether or not it is admissible, among other things.

Frye v US, 1923

The landmark US court case of Frye v US, held in 1923, established the precedent that any scientific technique used to obtain evidence in a court of law must have *general acceptance* in the scientific community before any evidence found with it can be deemed admissible (The Polygraph, 2003).

James Frye was arrested for murder in Washington, D.C. At first, he denied committing the murder or even knowing anything about it. Later, he admitted to committing the murder and gave police some seemingly well-informed information about the crime. A few days after that, he retracted his statement of guilt. He said that the only reason he lied about committing the murder was that he was told that if he did, he would get a cut of the reward offered for information leading to the arrest and conviction of the murderer. William Moulton Marston, inventor of the polygraph (or "lie detector") test, was asked to testify for the defense. He used his polygraph machine to conduct a lie-detection test about Frye's new claims of innocence. Using the test, Marston concluded that Frye was telling the truth and that he did not commit the murder. The prosecution objected, questioning the scientific acceptance and validity of this so-called "lie detector" and the judge agreed, throwing the polygraph test results out (Nordberg, 2001). The defense countered with the following brief:

> "The rule is that the opinions of experts or skilled witnesses are admissible in evidence in those cases in which the matter of inquiry is such that inexperienced persons are unlikely to prove capable of forming a correct judgment upon it, for the reason that the subject-matter so far partakes of a science, art, or trade as to require a previous habit or experience or study in it, in order to acquire a knowledge of it. When the question involved does not lie within the range of common experience or common knowledge, but requires special experience or special knowledge, then the opinions of witnesses skilled in that particular science, art, or trade to which the question relates are admissible in evidence."

This was submitted to show that Marston was knowledgeable enough in the field of psychology that he could explain how it could be determined if someone was telling the truth to the layman. The court clarified its stance by stating what is now known as the "*Frye Rule*" by saying, "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 (Nordberg, 2001)."

The court's opinion on the Frye matter set the precedent for the next several decades that any scientific technique - past, present, and future - must become generally considered meaningful and accurate to the experts in the field it comes from before it could ever be used to generate pertinent evidence in a court of law. Although this decision did not have any connection to DNA fingerprinting evidence at the time (since the concept had not been developed), its scope was later widened to include DNA fingerprinting evidence in subsequent court cases. The Frye Rule was invoked numerous times by both sides of the coin: those saying that the Frye Rule validated the use of DNA fingerprinting and those that said it dismissed the use of it.

Over the next several years, the Frye Rule made it very difficult to use highly technical evidence in a court of law. It set the standard that every new scientific discovery to be used in court to provide evidence would have to pass this stringent test and become almost universally accepted in the scientific community before its use. To some, the Frye Rule was too strict to allow timely use of a new scientific technique and too vague to discern what would be admissible.

Federal Rules of Evidence 702, 1975

Federal Rules of Evidence 702, also known as Rule 702, helped clear the air above these matters. Rule 702 is a key part of the Federal Rules of Evidence proposed by the Supreme Court and passed by Congress in 1975 (Coleman and Swenson, 1995).

Although the Federal Rules of Evidence were only supposed to be applied to federal courts, 32 states have evidence codes that mirror the Federal Rules. Rule 702 states as follows:

> "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 (Coleman and Swenson, 1995)."

Since most courts hold the Federal Rules of Evidence or their own evidence codes mirroring them of higher repute, Rule 702 generally supercedes the Frye Rule when applied to technical evidence, including DNA fingerprinting evidence. Rule 702 holds highly scientific evidence to the same standards that more typical evidence is held. This means that matters of probation, materiality and reliability of the evidence outweigh its tendency to mislead, prejudice, and confuse the jury, and that the judge now possesses more leeway pertaining to the admissibility of scientific techniques used to obtain evidence (Coleman and Swenson, 1995). When DNA fingerprinting techniques evolved in the 1980's, Rule 702 was interpreted to include it in many cases. This was done to, among other things, help judges, juries, and any other pertinent personnel understand new scientific discoveries before their inner workings are widely known, understood, and generally accepted in their respective scientific communities, unlike the Frye Rule. This has helped lead to the proliferation of expert witnesses testifying in court cases involving highly scientific issues, including DNA fingerprinting evidence. Expert witnesses testify on the reliability, the authenticity, the security, and the strength of DNA fingerprinting evidence to help clarify those issues to the judge and/or jury.

Challenged in so many ways, the Frye Rule was beginning to get outdated real fast. After the clarification and reconsidering that Rule 702 offered, the ruling on the admissibility of technical evidence still was imperfect and slightly vague. Many expert witnesses had been denied or accepted by judges all over the country with regard to this issue, confusing the point even more.

US v Downing, 1985

In the landmark case of US v Downing, 1985, the issue of admissibility of scientific evidence would get a makeover. John W. Downing and his codefendants, James A. Silva and Richard Piazza, were indicted for mail fraud, wire fraud, and interstate transportation of stolen property (United States, 1985). The three were accused of defrauding scores of suppliers and manufacturers out of goods in 1978 and 1979. They had allegedly run a company called the Universal League of Clergy, ULC, under the assumed names of Reverend Claymore, Malcolm Sloane, Reverend Olson, Paul Eaton, and Richard Thomas (some had multiple assumed names). They went to trade shows to find personnel that represented companies selling products. After ULC placed an order with these various companies, they offered a list containing a plethora of banks and other places of business as references, so as to purchase all of the items on credit. Every institution on the list did not exist, but when the manufacturers investigated the references by sending mail to the given addresses, they got positive reports about ULC's credit rating and history. This happened because ULC had allegedly given false contact information which was fielded by ULC itself, and ULC had in fact sent out the bogus credit reports. ULC then sold or used the merchandise and never made any effort to pay

back the suppliers, even skipping town from Bedford, Massachusetts to Blue Bell, Pennsylvania to avoid capture. Downing, Silva, and Piazza all contended that Downing was not Reverend Claymore as several eyewitnesses had stated, and that they were all tricked by the real Reverend Claymore. Furthermore, they all stated that if the real Reverend Claymore was caught, they would all be proven innocent (United States, 1985).

Downing's attorney tried to call Robert Weisburg, Ph.D. of Temple University to the stand to testify about the possibility that the eyewitnesses could have erred in their identification of "Reverend Claymore" as John Downing. He was to testify about the "forgetting curve," how stress effects memory, how witnesses assimilate information that they've heard into their recollection, how conversing witnesses can distort or adversely reinforce each other's identifications, and that studies have shown that a witness' confidence in their recollection has no direct correspondence with actual fact. The judge denied the witness to testify because he said that it "Is a function of the jury to deal with the credibility of the witness[es] that have appeared here and give whatever weight to that testimony that they see fit and also determine if their evidence is credible (United States, 1985)." Downing's attorney appealed to a higher court.

The appellate court that ruled on the case ruled in favor of Downing, citing the "helpfulness" clause of Rule 702. After examining the ruling of the lower court, how it came to its decision, and Rule 702, the appellate court granted a new trial to the defendants (which they still lost) and announced that "We therefore conclude that the district court erred as a matter of law when it in effect decided that expert testimony on the subject [of eyewitness testimony] is simply not admissible (United States, 1985)." The appellate court in effect also concluded that relevancy is a very important sticking

point when considering evidence. The decision made it clear that the relevance of evidence and expert witness testimony is more important to its admissibility than the Frye Rule's claim for the general acceptance of it.

The ruling in the US v Downing trial of 1985 did not directly involve DNA fingerprinting evidence. It only made the requirements of the admissibility of scientific discoveries more lenient than the very rigid Frye Rule.

Colin Pitchfork, 1986

DNA evidence finally made its way into the courtroom in the mid-1980's in Britain, first in a paternity case, then in two related murder cases. A fifteen year-old British girl named Lynda Mann was raped and strangled in 1983 (Ramsland, 2003). Three years later, a second fifteen year-old British girl named Dawn Ashworth was raped and killed just a mile away from where Lynda Mann was found dead. When a man was arrested he confessed to just the murder of Dawn Ashworth. British authorities wanted to convict him on both accounts, so they employed Dr. Alec Jeffreys to use his new DNA fingerprinting technique - which he had used once before in a court of law to solve a paternity case (Ramsland, 2003) - to match the accused's DNA with both crimes. As it turned out, the DNA taken from their leading suspect matched neither crime scene DNA! Thus not only did the man not commit the crime he didn't confess to, he didn't commit the one he *did* confess to!

A new manhunt ensued for whoever could have committed the two murders. As a trick, the local authorities asked every man with the same blood type in the nearby area to voluntarily submit a blood sample for testing to find the killer. The trick was that they

were going to question anyone who *didn't* submit a blood sample. A woman overheard a man bragging that he had given a blood sample in someone's stead and turned him in. He confessed that he had taken the test for a man named Colin Pitchfork. Pitchfork admitted to committing the murders and his DNA matched that of the man who committed them. The case never went to trial. He became the first person in the world to be convicted for murder based on DNA fingerprinting evidence (Ramsland, 2003).

People v Andrews, 1987

Based on the success of the Pitchfork case in Britain, U.S. attorneys decided to try and use the technology in America. The landmark case of People v Andrews, 1987 did make the connection shortly thereafter, marking the very first case where DNA fingerprinting evidence was ruled to be admissible in the United States (Ramsland, 2003). In 1987, Florida's Assistant State's Attorney decided to try to submit DNA evidence to help solve a serial-raping case.

For six months in 1986, a man raped at least twenty-three women. He was caught, but was very cautious not to leave too much evidence behind and was only convicted of one rape where he left fingerprints at the scene of the crime. Since he was to be in prison for no more than twenty-two years, prosecutors wanted to fight harder and prove he committed the other crimes so as to lock him up for the rest of his life. When DNA samples from the accused, Tommy Lee Andrews, and the twenty-three presumably related crime scenes were sent to the Life Codes lab, it was found that they *all* matched (Andrews v, 1988). Although the pretrial evidentiary hearing was long, complex, and ground-breaking, and even had its share of miscues with the new science, Andrews was

eventually convicted as a serial rapist - in large part due to the DNA fingerprinting evidence - and his sentence was increased from the original twenty-two years to 115 years.

The holdup during the pretrial hearing was caused by the revolutionary kind of evidence submitted and the prosecutorial miscues associated with such new evidence. Before it could be deemed admissible, DNA fingerprinting had to be proven to be scientifically sound in method, theory, and interpretation, and positively reviewed by peers (Andrews v, 1988). The best way to do this, since there were no U.S. court cases with any precedents concerning the matter, was to cite incredible amounts of scientific literature that lauded the practice and endorsed its use in court. This added to the extreme length of the pretrial hearing. Another obstacle in the prosecution of Tommy Lee Andrews occurred when the prosecuting attorney spoke of incredible statistical odds pertaining to the DNA fingerprinting evidence that he could not properly explain. The trial ended in a hung jury and the conviction based on the DNA evidence had to wait until a second trial. The evidence was submitted and examined more correctly and with more clarity, helping the jury come to a guilty verdict, resulting in the lengthening of Andrews' sentence (Ramsland, 2003).

With this new scientific technique would come some stumbling blocks, necessary to ensure justice would be served for both the defense as well as the prosecution. After the Andrews decision, many cases used DNA fingerprinting evidence to convict felons, polishing the tactics that lawyers would have to use to submit such evidence. It wasn't until 1989 that DNA fingerprinting evidence would be *excluded* by a court of law in the U.S. in the landmark case of New York v Castro.

People v Castro, 1989

Although the Federal Rules of Evidence held precedence over the Frye Rule, most courts still looked to the Frye Rule when it applied. In 1976, the inadequacy of the Frye Rule was appended by the decision in the case of the People v Kelly. The previous precedent from the Frye decision stated that it takes two steps for a new scientific technique to gain general acceptance: identifying the particular field(s) and the relevant scientific community into which the scientific principle or discovery falls and determining whether that community accepts the technology, principle or discovery (Coleman and Swenson, 1995). In People v Kelly, a third "prong" was added, stating that "the proponent of the evidence must demonstrate that correct scientific procedures were done in the particular case." This was the angle used by the defense in New York v Castro.

Before the trial of New York v Castro, DNA fingerprinting evidence was in its infancy, and its reliability and position in the courtroom was still being clarified. The power of DNA evidence was so overwhelming that the *practice* of obtaining it was overlooked. There was no universal standard for conducting the tests and that left open the possibility of error, fraud, and other problems. The defense team for Castro noted some of these flaws and objected to the evidence. Using the opinion of People v Kelly, Castro's defense created a parallel three-prong test for DNA evidence. From then on, there would be a burden of proof for any legal team attempting to submit DNA fingerprinting evidence into trial. This would include identifying a generally accepted scientific theory in the relevant scientific community that says that DNA fingerprinting is

reliable; determining whether or not techniques exist that can produce reliable DNA fingerprinting results; and proving that the testing lab performed correct scientific procedures in their test(s) (People v. Castro, 1989). By the end of the trial, the FBI had already set up an organization to clearly define universal standards for procedures that are used to obtain DNA fingerprinting evidence, called the Technical Working Group in DNA Analysis Methods, or TWIGDAM (Standing Committee, 1998). In the end, the Castro case never went to trial, he admitted guilt in 1989. So although the judge would not have allowed DNA evidence if the case had gone to trial, the trial system gained a new 3-prong test for determining evidence admissibility, and gained new standards for performing the tests.

US v Two Bulls, 1990

After errors were found in the DNA fingerprinting technique used at a prominent DNA testing laboratory in People v Castro, the pendulum again swung towards stricter rules for the admissibility of DNA evidence. Once again, this seemed too strict to most, and more clarification was in order. In the case of US v Two Bulls, 1990, the rulings from many cases and multiple rules from the Federal Rules of Evidence were pulled together to further clarify the issue.

With so many different interpretations imposed on DNA fingerprinting evidence taken from different rulings, the admissibility of DNA evidence came into question over a variety of issues time and time again. In the case of US v Two Bulls, attorneys called upon many rulings to create a stronger precedent for further cases. Although Lynette Two Bulls (a Sioux Indian) passed away before her appeal was heard, a landmark

decision was reached that incorporated many aspects of many prior decisions (Hawaii Supreme, 1992). The ruling in US v Two Bulls created a more definitive five-prong test for determining the admissibility of DNA fingerprinting evidence. From the Frye decision, the first prong is to make sure that this kind of DNA evidence is generally accepted by the relevant scientific community. The second and third prongs, taken from modified bits of the New York v Castro decision, pertained to whether or not the technique was properly performed, whether generally accepted testing procedures were used, and whether or not the test(s) were performed properly in this particular instance, respectively. The fourth and fifth prongs, taken from an interpretation of the Federal Rules of Evidence Rule 403, are that the evidence must be more prejudicial than probative, and the statistics related to the DNA fingerprinting evidence must be more probative than prejudicial, respectively (Hawaii Supreme, 1992).

People v Miles, 1991

The new, five-pronged test created by the US v Two Bulls hearing was put to the test and further clarified by the People v Miles case of 1991. Reggie Miles was accused of sexually assaulting and physically abusing a woman. Afterwards, he allegedly forced her to withdraw money from her bank account (People v Morris, 1992). Cellmark (a DNA testing laboratory whose findings had been rejected by courts many times before) was commissioned to test the DNA samples from the crime scene and found a match to the defendant. The defense objected in many ways, including arguing about the procedures used by Cellmark, the value of the expert witnesses presented by the prosecution, and the general acceptance of the statistics used pertaining to the likelihood

of the match. The judge disagreed with the defense and allowed the evidence (People v Morris, 1992).

The ruling in favor of admitting DNA evidence in the case of People v Miles connected several rulings. It legitimized the TWIGDAM guidelines for DNA testing that were set up after the New York v Castro trial, and recognized them as being reliable and a fit standard for future trials. Also, it strengthened the US v Two Bulls decision by using the five-prong test and agreeing with it, as well as using it to allow the expert testimony on the DNA statistics. Thus this trial strongly switched the sentiment to allowing DNA evidence in courts when properly done.

Daubert v Merrell Dow, 1993

As clarifying as it was, the US v Two Bulls decision still held the Frye Rule with too much weight and power, as did the ruling in People v Miles. When two children were born with serious birth defects, their mother looked to a drug she took to fight nausea as the culprit in the case of Daubert v Merrell Dow Pharmaceuticals in 1993. Although the defense in the case showed that no tests had proven the link between the drug, Bendectin, and birth defects in humans, the prosecution called upon knowledgeable witnesses that reinterpreted published data to show links between Bendectin and birth defects in other animals, as well as links between drugs similar to Bendectin and birth defects in humans (Blackmun, 1993). The judge disallowed the testimony of the expert witnesses for the prosecution, saying that these kinds of findings were not "generally accepted" by the scientific community, as the Frye Rule mandates.

The prosecution challenged the ruling, believing the Frye Rule to be too strict. Appeals were filed and lost all the way up to the Supreme Court. The Supreme Court reversed the lower court rulings, and mandated the trial proceed in lower courts allowing the prosecution's expert witnesses. The Supreme Court ruled that the Frye Rule was superseded by Rule 702 of the Federal Rules of Evidence and therefore didn't apply in this particular instance. In part, the Supreme Court stated that "Cross-examination, presentation of contrary evidence, and careful instruction on the burden of proof, rather than wholesale exclusion under an uncompromising 'general acceptance' standard, is the appropriate means by which evidence based on valid principles may be challenged (Daubert v, 1993)." Although the Daubert v Merrell Dow Pharmaceuticals case did not specifically include DNA fingerprinting evidence, the philosophy proposed by its ruling impacted the precedent at the time and helped to finalize a new Daubert standard view of DNA evidence in the courtroom.

Other Cases

Although the rulings in US v Yee (1991) and People v Robinson (2003) did not add anything to the admissibility or understanding of DNA fingerprinting evidence in the courtroom, they did help to show the changing attitudes different sectors of society had of it.

In US v Yee (1991), DNA fingerprint testing moved from the private sector to the federal government. Yee was accused of shooting a man in a van 14 times (Sylvester and Stafford, 1998). When some of the blood found at the scene of the crime did not match that of the victim, police suspected that at least one bullet had ricocheted off the van and

hit one of the gunmen. After capturing a suspect, Yee, FBI testing resulted in a match between his blood and that found at the crime scene. After a six-week long hearing on the admissibility of the DNA evidence, the magistrate recommended that the DNA results obtained through testing by the FBI be admitted, saying that there was "general acceptance in the pertinent scientific community that the procedures developed and implemented by the FBI for determining that the DNA patterns from a known [i.e., a criminal suspect] source match with DNA patterns from a 'questioned' [i.e., crime scene] source are reliable." The evidence was admitted, as well as the statistical evidence, and the defendant was convicted. What was so significant in this case was that it was the first time DNA was ever tested by the FBI (Wooley, 2003). The federal government was now recognizing and utilizing DNA fingerprinting technologies.

Usually, DNA evidence is brought to further incriminate a suspect who already has other evidence against him and only strengthens a case. Even if the nail in the coffin is the DNA evidence, it used to never be the ONLY piece of evidence against a defendant. Nowadays, however, DNA databases are able to solve crimes by taking bodily fluid samples from a crime scene and matching them with someone already in the database.

In 1993 and 1994, a series of sexual assaults occurred in the Cal Expo area of California (Press Release, 2003). The investigators had no real leads and the case seemed to die out. After six years went by, the lead investigator had a "John Doe" warrant filed to stop the statute of limitations from passing by and the case file closed. After this happened, the police were able to run a scan of the California criminal DNA database for DNA matching that of the perpetrator's. They found a match in one Paul Eugene

Robinson. Although he was convicted in some of these cases through the use of other evidence, he was convicted on five counts of sexual assault *solely* on DNA evidence on June 26th, 2003 (Press Release, 2003). This makes the striking statement that DNA fingerprinting evidence is now so highly regarded by every sector of the government that it can actually be the only piece of evidence used in convicting a person of a crime.

From its early days in the 1980s, DNA fingerprinting evidence has come a long way. It started out as a highly controversial and disputed form of evidence. Pretrial hearings would last days, weeks, even months, trying to determine the admissibility of DNA evidence. Through a very detailed and in-depth look at the entire process of DNA fingerprinting, this country has now accepted it as a literal smoking gun that spells doom for any criminal unlucky enough to leave any behind.

Chapter-4: Sensational DNA Cases

After having considered in chapter-3 some of the landmark court cases that established precedents for allowing DNA evidence into the courtroom, let's turn our attention to an amazing case where the public likely got a real education on DNA evidence.

Trial of the Century

On the date of June 12, 1994 a crime occurred which when investigated, was called the infamous "Trial of the Century". Ronald Goldman and Nicole Brown Simpson were the two victims, and the suspect was O.J. Simpson. Some neighbors found the victims through a chain of events involving the Simpson dog. The neighbors noticed the dog was acting weird, and also saw that the dog had blood on the fur of its underside. One of the neighbors attempted to calm the dog down and take care of it, but the dog was just too restless and shaken. During an attempt to calm the dog by taking it for a walk, the dog led him back to the Simpson estate, and stopped down the path in which Nicole and Goldman were both dead in pools of their own blood. The neighbor called the police after peering down the dark path and making out the body of Nicole lying in her own blood.

Figure 4.1: Police investigation of the O.J. Simpson's Estate.
(The O.J. Simpson Trial, 2000)

The police arrived to discover a bloody double homicide scene, with Nicole partially under the fence, and Goldman lying off to her right in a small garden with his eyes still open. The officers who were first on the scene took careful measures to make sure they did not contaminate the area, such as staying six feet away from the bodies at all times, and making sure not to step in any of the blood. When the paramedics arrived, they confirmed that both victims were in fact dead. A short time later, at 5AM, a pair of police officers made their way over to O.J.'s residence to collect and care for his children, who were still asleep in their beds. During the trip to the residence, the officers noticed a 1994 white Ford Bronco parked half on the curb and half on the street, and proceeded to buzz the occupants of the home but received no answer. At this time one of the officers began inspecting the Bronco and found what appeared to be a blood spot within the

vicinity of the driver's side door handle. The officers then received O.J.'s home phone number and began calling it, still receiving no answer. The officers decided they had just cause to enter the premises due to the two bodies a couple of miles down the road, the bloodstains on the Bronco, and the lack of response from the residence at this late hour. As they entered the property, Kato Kaelin was found, but O.J. himself was nowhere to be seen.

The police interviewed Kaelin. They also eventually discovered that O.J. was in Chicago by tracing some of his older daughter's phone calls. O.J. was on the next flight back after a friend called him and filled him in on what the situation at his home was. A glove had been found at the murder scene, and the match to it was located in the garden during the investigation of O.J.'s residence. This glove was not touched, and was left for further inspection and proper collection.

When examined closely, the estate of O.J. Simpson was found to be covered in blood spots leading up to the back of the car, in the car, on the walkways, etc.

Figure 4.2: Photo of the female victim Nicole Brown Simpson.
(The O.J. Simpson Trial, 2000)

Dennis Fung, a LAPD criminalist, and Andrea Mazzola, a SID trainee finally began the proper and sterile collection and documentation of all of the evidence starting at 7:10AM. Their basic instructions were to collect both gloves, document all of the blood spots at the various scenes, and have the Bronco impounded for further investigation and documentation.

The press was arriving in a massive crowd and Detective Tom Lange arranged to have the body covered by a blanket from inside the house. This was one of the critical mistakes that contributed to O.J. Simpson's defense, another involving a video taken of the crime scene. Fung had collected socks prior to the filming of the video, and O.J.'s defense team used the difference with the video as if the police had planted the socks as evidence to frame O.J. By June 14th at noon, both autopsies had been performed and documented, and were witnessed by two lead detectives. Nicole's autopsy showed that she had suffered four fatal wounds, one of which was a slash across her neck from the left to the right. This slash suggests from its direction that the murderer was right-handed. A large contusion on the back of her head was found, along with slash wounds on her hands, which indicates a struggle took place and that she was attempting to fight back against her killer.

Figure 4.3: Photo of the male victim Ronald Goldman.
(The O.J. Simpson Trial, 2000)

Goldman was found to have slashes across his face, as well as a large contusion on the back of his head, very similar to the one Nicole had suffered. These contusions indicated that both victims had been hit in the head from behind. Goldman had a total of nineteen slash wounds, with four of them deep enough to be fatal. It was found that the type of knife that was used in the crime had been purchased just the day before by O.J.

In the eyes of the jury and the public, the bloodspots were the most complex element of the trial. Because the explanation and science behind it is full of details, the jurors had to keep a close eye for technical differences which could be easily misunderstood and misread.

The defense was intent on asserting that the blanket over Nicole could possibly have contaminated the blood on her, which plants doubts about the evidence collected. Another main focus was on how the Bronco hadn't been taken as evidence properly from the very beginning of the investigation. Those points allow for the chance that a person

could have contaminated the scene or planted evidence against the subject, and planted doubt in the minds of the jurors. Another major issue brought up by the defense was why junior criminalist Andrea Mazzola collected most of the evidence rather than Fung himself. Due to the fact that Mazzola was only a junior criminalist, the jury was left with the feeling that her lack of experience left room for error and she could have made a large mistake in the process of collecting the evidence properly. While on the stand, Fung talked of making a "temporary" solution to the collection of evidence by putting bloodstains in plastic bags. Putting the blood in plastic allows the growth of bacteria, which causes an aberration in test results, and plants further doubt into the minds of the jurors as to the value of their validity.

When Andrea Mazzola took the stand, she spoke of Fung not supervising her during the majority of the collection of the evidence. Fung had earlier stated that he had looked over the collection of all of the evidence. These differing statements showed another flaw in the prosecution, and jurors noticed it. Mazzola was shown to not always correctly collect evidence, as she was recorded on video, and showed her dropping cotton swabs, resting her hand on the dirty footpath, and proceeding to wipe off collecting tweezers with that same hand. Mazzola then stated that she did not intentionally alter the evidence and collected it to the best of her ability.

The defense concluded that the collection of the blood as evidence was not carried out properly, and was thus invalid. Procedures were not carried through effectively, and were sloppy. These allowed room for error and time to plant evidence, which led the jury to encounter doubts as to what to believe. Not only did these doubts surface, but the jury

also had only a partial comprehension of what fingerprinting and forensics are and how they operate.

The next person called to the stand was Doctor Robin Cotton. Doctor Cotton worked as the laboratory director for Cell Mark Diagnostics in Germantown, Maryland, which is the largest DNA specialist unit in America. The majority of the DNA testing for the Simpson trial took place at Cell Mark Diagnostics, under Doctor Cotton.

Doctor Cotton explained to the jury all the workings of DNA analysis, including RFLP and PCR analysis. Doctor Cotton testified that the blood found at the crime scene leading away from the bodies matched with O.J.'s blood. He further testified that Nicole's blood was found on the socks that were located in O.J.'s bedroom. Doctor Cotton claimed that the odds of finding another perfect match to the blood samples were one in 1.7 billion.

The defense's response to Doctor Cotton's testimony was that the blood wasn't collected properly, and was contaminated in the process, which could skew the DNA test results. This defense tarnished the impact of the DNA fingerprinting evidence, and caused the jury to have reasonable doubt in the trial.

The testimonials pertaining to the DNA fingerprinting were given over and over again. Statistical odds for DNA matches shot up in some cases to one in 21 billion, and other facts and technical details flew right over the jury's heads, but all the evidence presented was virtually meaningless if the defense's statement that the DNA could have been contaminated was true. The defense strategy was to keep focusing on the fact that the test results could be incorrect if the collection of the evidence occurred improperly and directly caused contamination.

Figure 4.4: O.J. Simpson trying on the gloves found at the crime scene during the trial. (The O.J. Simpson Trial, 2000)

The gloves found at the crime scene and in O.J.'s garden were the most tangible piece of evidence that the prosecution had. They were a very unique pair that Nicole had purchased for O.J. Richard Rubin, president of Aris Gloves, the maker of the gloves, claimed that the gloves were O.J.'s size and should fit his hands. Previous to the trial that morning, the prosecution had a man with the same size and texture of hands as O.J. come in to try on the gloves. The gloves fit the man perfectly, and slid right on and off. The intent of the prosecution was to suggest during the trial that O.J. was to try on the evidence gloves. O.J. attempted to put the gloves on that day while wearing latex gloves, so as to avoid the contamination of the evidence. The gloves appeared to be too small and were unable to be put on by O.J. in front of the courtroom and jury. This image would be a huge symbol for the jury, as one of the main tenements of the prosecution turned out to be apparently physically impossible, and inspired much doubt as to the rest of their case. Later on, while being questioned about the trying on of the gloves, Simpson's main defense attorney stated "I don't think he could 'act' the size of his hands.

He would be a great actor if he could 'act' his hands larger." Rubin then was brought out to tell the jury that the gloves could have shrunk due to the drying blood on them, but the jury already had the scene acted out before them, and the doubt was firmly planted.

EDTA is an agent used to stop the degradation of blood, and is oftentimes used in laboratory testing tubes, as well as in laundry detergent and paint. The blood that was found on the sock, and blood found on the gate of Nicole's home were found to contain EDTA. The blood found on the socks had a higher content of DNA than that of the autopsy and this knowledge proves that the sock could not have been planted. Because the autopsy blood had a dropped value of DNA in comparison with the sock, the socks had to be from the actual crime scene, since the DNA in the sock had a much higher content of DNA.

The jury had a lack of understanding of the technical details of why things were proven, but they did understand that EDTA was present in the samples, which only enhanced their considerations that the crime scene was contaminated.

Overall, what the world learned from this trial of the century was that although the technique of DNA fingerprinting had by now become commonly accepted in the courtroom (unlike some of the trials of chapter-3), the way the DNA evidence is collected is extremely important. The process through which the evidence was collected didn't follow the books and standards of forensic science. The designated procedure was created in order to be followed explicitly, and because it was disregarded a clearly guilty O.J. Simpson was allowed to roam without being brought to justice in the criminal trial where the standard is "without a shadow of a doubt". OJ was subsequently held liable for

the two deaths in a civil trial in which the standard shifted to "a preponderance of the evidence".

Chapter-5: DNA Databases

One of the most important tools in the Forensic Sciences is the DNA database. DNA databases allow investigators to take the results of DNA fingerprinting and compare them to lists of DNA fingerprints to try to find a match. When such matches can be found, cases can be solved which otherwise would take massive resources to solve, or be unsolvable. However, our databases as they currently stand are insufficient.

It is unreasonable using current technology and Molecular Biology methods to expect the whole span of a suspect's DNA to be sequenced for forensics purposes. After all, scientists only recently succeeded in sequencing one human genome (About The, 2003). Such a process would take too much time and money to be practical for the hundreds of thousands of samples ready for forensic analysis. Instead scientists have found short segments of DNA that are highly variable between people. Therefore, by inspecting a few of these variable sights or loci the probability of false positives decrease since the probability of multiple people having the same group of identical segments becomes more and more unlikely when the number of sites inspected increase. The segments used for such analysis are called short tandem repeats. However, with the increased study of population genomics, it has been discovered that the previously conceived methods of calculating the probability of another individual having the same group of short tandem repeats were not accurate (Lewontin and Hartl, 1991).

An individual's genetic information is determined by the genetic information of his/her parents. The probability of an individual's genome occurring is therefore determined by the probability of the two parents coming together and conceiving a child.

It has been determined that although many people consider the process of choosing a mate to be random, it truly is not. Many factors affect the choice of a mate, including religion, ethnicity, and geography. These factors cause the phenomenon known as 'endogamy.' Endogamy is when people have a tendency to marry within a specific group of which they are a part. This effect is well known by the results seen in the examples of Jews having a higher tendency than most people for developing Tay - Sachs disease, and Blacks being more likely than most people to have Sickle Cell Anemia. There is nothing intrinsic about being Jewish or Black that makes a person prone to these diseases. Instead it is the fact that these groups have married within their own circles for so long that the probability of bearing a child homogeneous for a disease increases. This practice of endogamy drastically affects the probability of similar genomes in certain circles and thereby population genomics. Therefore, when scientists calculate the probability of another individual having the same group of short tandem repeats the social group of which the person belongs must be taken into consideration. (Lewontin, 1991).

DNA fingerprinting and DNA databases are very controversial topics. Courts are still in contention over accepting the probability claims of some scientists. By standardizing DNA forensics and fingerprinting, DNA evidence is growing more submissable in court. However, no matter how well the examination of the DNA evidence is performed, no useful conclusions can be drawn until population genomics is properly understood and studied. This increased understanding can only be achieved by obtaining genetic information from a far higher percentage of the population.

In order for scientists to discover which sequences predominate in which communities, and thereby make DNA fingerprinting probability determinations more

accurate, they must have access to the genetic information of numerous people within different social circles. If people would agree to contribute only 1 ml of blood to a DNA database this could be easily accomplished. However, many people are concerned about losing their privacy if they contribute their DNA.

The CODIS Database

The primary action that must be taken to abate these fears is to educate the populace. As a whole, people do not know that guidelines that have already been established concerning DNA databases. The DNA Identification Act of 1994 (United States, 1994) gave the FBI the authority to establish a national DNA index for crime scene evidence and convicted felons for the sole purpose of law enforcement. The FBI then formed a three level indexing called CODIS (Combined DNA Index System): local on the bottom (LDIS), state in the middle (SDIS), and national at the top (NDIS). By having the database set up in such a layered manner, the local agencies can still operate according to their own legislative and legal requirements. The local information flows up into the state level, and then both the local and the state flow into the national database. In this manner the FBI has accumulated more than 210,000 profiles of crimescene evidence and convicted felons from 24 states (The FBI's, 2000). Within CODIS there are two indexes: the Forensic Index and the Offender Index. The Forensic index contains the DNA profiles compiled from crime scene evidence. The Offender Index contains the DNA profiles collected from individuals convicted of crimes as decided by the legislation in each state. By dividing the profiles in this manner, profiles in the Forensic Index can be compared to serial offenders. The Offender Index is helpful to see if any of the

profiles recently found at a crime scene matches a profile of a past offender which could then become a suspect in the case. All in all, this FBI database has become a very powerful tool in linking criminals to their crimes. However, the database is not given free reign. There are many controls and legislations overseeing the databases to protect the public (The FBI's, 2000).

Databases and Privacy

People's fears when it comes to DNA databases are broad and complex. Some people fear being wrongly convicted for a crime either mistakenly, or by being setup, since their information would now be accessible to law enforcement officers performing searches. Others fear that groups such as insurance agencies could gain access to a person's information and refuse to accept a client due to a genetic predisposition to a disease (Williamson, 2002). This fear of illegal access appears to be well founded as seen by the example that a company named Decode negotiated to pay two hundred million dollars for the information in Iceland's genetic database. All of these fears must be addressed before DNA databases can become truly widespread (Kahn, 1999). The DNA Identification Act of 1994, in addition to allowing for the creation of the CODIS DNA database, limits the type of DNA data that may be maintained in the national database, as well as who may access this data and for what purpose. All of the DNA records in The National DNA Index System are protected from unauthorized access through administrative, physical and technical safeguards (Adams, 2002). The Office of the Inspector General even checks up on the FBI to certify that they are in compliance with all such jurisdiction, and indeed the FBI has been found compliant.

Non-CODIS Databases

As useful as this national CODIS database has been, its contributors are not chosen at random from the general population, so it is not of much value for establishing allele frequencies of specific loci. People would be much more willing to donate their genetic information to another database established to help determine probability frequencies if privacy protection guidelines and penalties for anyone who violates these guidelines are implemented. In addition if the privacy requirements are not met, the database would be forcibly terminated. The DNA Identification Act has already been established and is indeed acting to ensure the privacy of all donors (The Combined, 2001).

People also worry that they may be falsely charged for a crime; however, what they do not realize is that the manner in which the DNA database is set up, this would never happen. Scientists require DNA profiles to study for an increased understanding of population genomics. These profiles would not be included in the Offender Index or the Forensic Index. A new database would be created for the sole purpose of researching population genomics, not for law enforcement purposes. Some day it would help law enforcement to have everyone's genetic profile on file to compare crime scene evidence to. Having such a large database would drastically reduce the amount of time required in researching possible suspects for a crime based on DNA evidence. If and when such a complete database is formed, people have to understand that the increased number of donors to the database causes the chance of being falsely convicted to decrease, not increase. With the false probabilities now used in population genomics it is more

probable for a detective to falsely decide that an individual's genetic material is a match to the sample of evidence. When the true population genomics are known, a more accurate probability of a match in DNA profiles will be understood. Scientists will be able to determine the number of sequences that would have to be analyzed to act as an accurate fingerprint for a genome with a very low probability of a false match. Genomics as they stand now has a higher probability of false accusations than if people would agree to form a database and provide an accurate knowledge of allele frequencies.

Some people also fear that the DNA information will be used to determine medical predispositions. However the public does not realize that the type of information on tandem repeats placed in such databases contains little or no useful medical information. Others state that the national databases themselves won't have such information, but the DNA sample left behind will. People fear what might be done with the DNA after it has been profiled. The crime lab does not discard the sample immediately. The databases do not contain the entire sequence of an individual's genetic information. Instead, they only contain the DNA profiles of specific forensic loci. However, once scientists determine accurate allele frequencies, and determine the location of the sites required for unique assessment, and the number of sites required to be inspected; it would be too much work to collect DNA samples again from everyone who is currently in the database. Such an undertaking would take too much time and money. Instead, by having the samples already present, a more efficient succession of analysis could be completed on the samples. These samples are not used for any other purpose but DNA profiling, and therefore should not be feared (Williamson, 2002).

People fear that if they donate their genetic information to the databases it could be used for research purposes. Most people do not understand the complexity of their genetic information. And they feel it contains information which is very private and represents is who they are. Therefore, they fear other people having access to this complexity and what these people might be able to do with this information. In order to abate these fears anyone donating their information to a database should have the option of noting whether they agree to have their information used for research purposes or not. Without the noted consent, scientists would not, and should not, have access to anyone's information for research purposes. In addition, the scientist should not be able to access any identifying information about the individual whose genetic information they have been given for research. With such restraints set in place people could feel more secure in donating to the database (Williamson, 2002).

What the database controversy comes down to is a question of ethics. People want to be sure that criminals end up in jail. People are willing to set up a system to help catch more criminals and have them convicted. However, people are unwilling to set up a system in which they fear that there is some chance that their safety and security might come into danger. What people must decide is whether they find it more important to protect themselves from the off chance that an individual might corrupt the system and accuse an innocent person, or set up a system to help society protect itself from violent criminals. People must understand that society has already set up a system to prevent any such corruption. And people must learn to put their faith in this system which has been set up to protect the innocent. If a person is falsely accused, he/she will still get a fair trial in which he/she will be pronounced innocent. Any person who is discovered to

be corrupting the system will be caught and tried, and all of that person's corruptions will be overturned and brought to trial again. The judicial system has been established to determine the truth and only convict the actual criminals. In the end if people put their faith in the justice system and help establish and promote programs such as DNA databases which can help this pursuit of the truth, the truth will be found.

Chapter-6: Conclusions

Deoxyribonucleic Acid (DNA) is the building block of human life. DNA is unique among every individual on Earth (with the exception of most identical twins) and is a blueprint for the human body. Since it is every bit as much of a personal identifier as fingerprints, yet can not be altered by criminals, scientists have developed the technologies to map DNA - such as restriction fragment length polymorphism and polymerase chain reaction - in order to link suspects to crimes and solve paternity cases, among other uses.

Although there are plenty of ways to identify suspects and connect perpetrators to crimes, DNA fingerprinting has distinct advantages. Most other forensic evidence is fairly circumstantial and can sometimes be chalked up to coincidence, such as in blood typing where a large percentage of the population carries the same type. DNA is more akin to fingerprints - with its likelihood for a match being much greater than in other forensic evidence - but is much more prevalent at a crime scene and harder to distort and contaminate. Although the guidelines for doing so are not uniform, using correct procedures when performing DNA fingerprinting is a daunting task, but the reward is the correct use of the greatest tool in forensic science.

Using DNA fingerprinting, many criminals have been apprehended and convicted of crimes in U.S. courts. However, the admission of DNA evidence into courts was not always a straightforward task. The admission of DNA evidence was tightly coupled to the evolution of a series of landmark court cases addressing the admission of any new technologies. At first, attention was paid to whether the new technology was generally

accepted in the scientific community, and this standard evolved to include determinations on whether the technology was reliable, and performed correctly. Chapter-3 of this IQP summarized several key landmark cases.

The public is not generally aware of the landmark court cases for admitting DNA evidence into courts, but instead has more likely heard of DNA testing in a variety of sensational cases that were highly publicized. Of these sensational cases, the so called "trial of the century" the O.J. Simpson murder trial introduced the public to DNA fingerprinting like never before, and pointed out problems that can occur in DNA evidence collection procedures. The trial dragged on for months and swept up the entire nation. Despite mounds of forensics evidence, including DNA, O.J. Simpson was found not guilty in the double murder trial. Although this seemed to be a huge blow to DNA fingerprinting evidence, it wasn't: many things were learned from the O.J. Simpson trial, especially concerning the handling and preservation of evidence. Without trials and tribulations such as these, DNA fingerprinting evidence would not be where it is today.

One of the most important tools to come out of DNA fingerprinting is the DNA database. The FBI CODIS database contains DNA profiles for violent felons that is used to screen forensic samples from current crime scenes for "cold hits", to see if a previously convicted felon has committed a new crime. In addition, smaller databases exist for the purpose of more accurately assigning allele frequencies to forensic STR loci. These latter databases help more accurately assign probabilities of a match. While DNA databases have incredible advantages, including providing more accurate DNA statistics and catching criminals, the public is suspect to the technology and none too willing to provide their own DNA into *any* database. Their fears are understandable, but need to be

overcome. The type of information on STR lengths that goes into DNA databases contains no medical information for denying someone health coverage, or new job employment. However it is a good idea that the original DNA sample (that could be used to obtain such personal medical information in the future) be destroyed after entering STR data in the database. Donors to the "frequency determination" databases should be kept anonymous. On the other hand, it is also very important for the government to continue to put laws into place to protect people's privacy concerning their DNA. If the government continues to enact laws protecting people's privacy and the general public can get past their fears, DNA databases could be the last monumental step in protecting society from violent criminals.

Bibliography

"About The Human Genome Project." (2003) National Human Genome Research Institute. http://www.genome.gov/10001772

Adams, D.E. (2002) Congressional Statement: "The FBI's CODIS Program". Federal Bureau of Investigation, U.S. Department of Justice. http://www.fbi.gov/congress/congress02/adams051402.htm

(ADEAR) Alzheimer's Disease Education & Referral Center. (2003) http://www.alzheimers.org/unraveling/images/large/DNA-HIGH.jpg

ADEAR Center. (1995) "Chromosomes and Genes." http://alzheimers.org/gene.html

Andrews v. State of Florida. (1988) District Court of Appeal of Florida, Fifth District, 533, Southern Series, 2d, pp. 841.

Association for Biology Laboratory Education. (1999) http://www.zoo.utoronto.ca/able/volumes/vol-12/1-karche/fig1-7.gif

Blackmun, H. (1993) "Daubert v. Merrell Dow Pharmaceuticals (92-102), 509 U.S. 579 (1993)." http://supct.law.cornell.edu:8080/supct/html/92-102.ZO.html

Brinton, K. and Lieberman, K-A. (1994) "Basics of DNA Fingerprinting." University of Washington. http://www.biology.washington.edu/fingerprint/dnaintro.html

CNN. (1995) "O.J. Simpson Trial News." http://www.cnn.com/US/OJ/evidence/index.html

Coleman, H. and Swenson, E. (1995) "DNA in the Courtroom." http://www.genelex.com/paternitytesting/paternitybook5.html

Daubert v. Merrell Dow Pharmaceuticals, Inc. (1993) Supreme Court of the United States, 113 S. Ct. pp. 2786.

Della Manna, A. and Montpetit, S (2000) "A Novel Approach to Obtaining Reliable PCR Results from Luminol Tested Bloodstains." *Journal of Forensic Sciences* **45**(4): 886.

Gaytmenn, R., and Sweet, D (2003) "Quantification of Forensic DNA from Various Regions of Human Teeth." *Journal of Forensic Sciences* **48**: 1.

"Handbook of Forensic Services" (1999) Federal Bureau of Investigation, U.S. Department of Justice. http://www.fbi.gov/hq/lab/handbook/examsdna.htm

Harris, T. (2003) "How Luminol Works." HowStuffWorks, Inc.
http://people.howstuffworks.com/luminol1.htm

"Hawaii Supreme Court Case No. 15302." (1992)
http://64.29.92.28/RW/Legal_Research/Hawaii/members/sc/15302.HTM

Huskey, R.J. (1999) "DNA Fingerprinting Using VNTRs." University of Virginia.
http://www.people.virginia.edu/~rjh9u/vntr1.html

Inman, K. and Rudin, N. (1997) An Introduction to Forensic DNA Analysis. New York: CRC Press.

Jones, T.L. "O.J, Simpson and the Trial." The Crime Library.
http://www.crimelibrary.com/classics4/oj/index.htm

Kahn, J.P. (1999) "Attention Shoppers: Special Today – Iceland's DNA". Center for Bioethics, University of Minnesota.
http://www.cnn.com/HEALTH/bioethics/9902/iceland.dna/template.html

Kobus, H.J., Silenieks, E., and Scharnberg, J. (2002) "Improving the Effectiveness of Fluorescence for the Detection of Semen Stains on Fabrics." *Journal of Forensic* Sciences **47**: 1.

Lewis, S.W., Dr. (2003) "The Luminol Test."
http://www.deakin.edu.au/forensic/Chemical%20Detective/Luminol_test.htm

Lewontin, R.C. and Hartl, D.L. (1991) "Population Genetics in Forensic DNA Typing." *Science* **254**: 1745.

Linder, D. (2000) "Crime Investigation Scene."
http://www.law.umkc.edu/faculty/projects/ftrials/Simpson/INVEST.jpg

Linder, D. (2000) "Famous American Trials: The O.J. Simpson Trial 1995."
http://www.law.umkc.edu/faculty/projects/ftrials/Simpson/simpson.htm

Linder, D. (2000) "Nicole Simpson."
http://www.law.umkc.edu/faculty/projects/ftrials/Simpson/NICOLE.jpg

Linder, D. (2000) "O.J. Trying On Glove."
http://www.law.umkc.edu/faculty/projects/ftrials/Simpson/OJGLOVE5.jpg

Linder, D. (2000) "Ronald Goldman."
http://www.law.umkc.edu/faculty/projects/ftrials/Simpson/RONG.jpg

Lorente, M., Entrala, C., Lorente, J.A, Alvarez, J.C, Villanueva, E., and Budowle, B. (1998). "Dandruff as a Potential Source of DNA in Forensic Casework." *Journal of Forensic Sciences* **43**: 901.

"MIT Biology Hypertextbook." (2001) http://web.mit.edu/esgbio/www/dogma/images/dna.gif

Nordberg, P. (2001) "The Frye Opinion." http://www.daubertontheweb.com/frye_opinion.htm

People v. Castro (1989) Supreme Court, Bronx County, New York, Criminal Term, Part 28, 545 New York State Series, 2d, pp 985.

People v. Morris (1992) Appellate Court of Illinois, Second District, Vol. 603 Northeastern Series, 2d ed., pp. 1196

"Press Release: People v. Paul Eugene Robinson." (2003) Sacramento County District Attorney. http://www.da.saccounty.net/pr/030626_robinson.htm

Ramsland, K. (2003) "All About DNA in Court." http://www.crimelibrary.com/criminal_mind/forensics/dna/6.html?sect=21

Ramsland, K. (2003) "Serology: It's In The Blood." http://www.crimelibrary.com/criminal_mind/forensics/serology/3.html?sect=21

Redway, K. "Analysis of DNA." University of Westminster. http://users.wmin.ac.uk/~redwayk/lectures/analysis.htm

Scully, J. (2003) "Case: the People v. Paul Eugene Robinson." http://www.da.saccounty.net/pr/030626_robinson.htm

"Standing Committee on Justice and Human Rights." (1998) http://www.parl.gc.ca/InfoComDoc/36/1/JURI/Meetings/Evidence/JURIEV36-E.htm

Sylvester, J. and Stafford, J. (2003) "Judicial Acceptance of DNA Profiling." http://www.phreak.org/archives/The_Hacker_Chronicles_II/lawnt/judna.txt

Tanaka, M., Yoshimoto, T., Nozawa, H., Ohtaki, H., Kato, Y., Sato, K., Yamamoto, T., Tamaki, K., and Katsumata, Y. (2000). "Usefulness of a Toothbrush as a Source of Evidential DNA for Typing." *Journal of Forensic Sciences* **45**: 674.

Texas A&M University. (2003) http://ntri.tamuk.edu/immunology/southern-blot.gif

"The Combined DNA Indexing System; Statement of Compliance with Laws and Regulations." (2001) Office of the Inspector General. http://www.usdoj.gov/oig/audit/0126/laws.htm

"The FBI's Combined DNA Index System Program." (2000) FBI, U.S. Department of Justice. http://www.fbi.gov/hq/lab/codis/brochure.pdf

"The Polygraph and Lie Detection." (2003) The National Academies Press. http://www.nap.edu/books/0309084369/html/291.html

Toburen, A. (2002) "Genomic Gibberish?" http://whyfiles.org/075genome/images/dna.gif

United States Public Law, PL 103-322, 1994 HR 3355, Title XXI - State and Local Law Enforcement, Subtitle C - DNA Identification, Sections 210301-210306.

United States v. Downing (1985) United States Court of Appeals, 3rd Circuit, Vol. 753 Federal Series, 2d, pp. 1224.

University of Washington. (1994) http://www.biology.washington.edu/fingerprint/vntr02.gif

Walsh, D.J., Corey, A.C., Cotton, R.W., Forman, L., Herrin, G.L., Jr., Word, C.J., and Garner, D.D. (1992). "Isolation of Deoxyribonucleic Acid (DNA) from Saliva and Forensic Science Samples Containing Saliva." *Journal of Forensic Sciences* **37**: 387.

Webb, L.G., Egan, S.E., and Turbett, G.R. (2001). "Recovery of DNA for Forensic Analysis from Lip Cosmetics." *Journal of Forensic Sciences* **46**: 1474.

"What Every Law Enforcement Officer Should Know About DNA Evidence" (1999) National Institute of Justice. http://www.ncjrs.org/nij/DNAbro/intro.html

Williamson, R. and Duncan, R. (2002) "DNA Testing For All." *Nature* **418**: 585.

Wooley, J. (2003) "This is the Statement of Before the Senate Judiciary Committee." http://www.senate.gov/~judiciary/oldsite/6132000_jw.htm

Zamir, A., Springer, E., and Glattstein, B. (2000). "Fingerprints and DNA: STR Typing of DNA Extracted from Adhesive Tape after Processing for Fingerprints." *Journal of Forensic Sciences* **45**: 687.