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DNA FINGERPRINTING

An Interactive Qualifying Project Report

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By:

Nicholas Mercurio Alex Pittera Peter White

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APPROVED:

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

ABSTRACT

DNA fingerprinting has had an enormous technological impact on society. This IQP seeks to describe this effect and demonstrate its magnitude in several ways. First, the procedures for performing DNA fingerprints are explained. Next, methods for effectively collecting and storing DNA samples are described. Then, an analysis of landmark DNA courtcases reveals how this subject has changed the legal system by setting standards for admitting complex evidence. Two sensational DNA courtcases then show the power that DNA fingerprinting has on the outcome of trials, perhaps even decades after the crime has been committed. Finally, a discussion of the ethics of DNA databases shows the controversial nature of the technology, and the authors draw conclusions about this powerful and expanding technology.

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PROJECT OBJECTIVES

This project was undertaken to display the technological effect that DNA fingerprinting has on society, as well as to investigate the controversial nature of this expanding and cutting-edge technology. The purpose of Chapter-1 is to describe how the fingerprints are actually performed, and provide general background knowledge to help understand DNA fingerprinting. Chapter-2 explores effective methods for the collection and storage of DNA, which if not performed properly negate the evidence in court. Chapter-3 investigates landmark court cases to show the great impact that DNA fingerprinting has had on the legal system. Chapter-4 describes two sensational DNA cases to further offer an understanding of the power in DNA forensics, even for crimes committed decades ago. Chapter-5 describes the purposes and ethics behind DNA databases, and dispels some popular myths. Finally, the authors of this IQP draw conclusions based on their research about this effective and expanding technology.

CHAPTER-1: INTRODUCTION TO DNA FINGERPRINTING TECHNOLOGY

Alex Pittera

Introduction to DNA Fingerprinting

DNA was first discovered in 1868 by the Swiss biologist Freidrich Miescher (Biotechnology Industry Organization, 2010). Since that time, many new revelations concerning DNA have been uncovered and have guided us to today's ideas and technology concerning DNA. These include the discovery of the double helical structure of DNA in 1953, and the unraveling of the genetic code in 1961-1965 (Biotechnology Industry Organization, 2010). DNA carries important genetic information. Today, this genetic information can be used to precisely identify individuals from trace information left at crime scenes. DNA in cells comes from such things as a person's blood, semen, saliva, urine, hair, teeth, bone, or tissue. Although DNA fingerprinting is most often associated with human DNA, it can also be used to identify other organisms such as plants and animals. The purpose of this chapter is to introduce the *technology* of DNA fingerprinting, describing the main ways DNA fingerprints are obtained and the main uses. The technology, however, is only the beginning of this story, and in later chapters we will discuss ethical and legal issues associated with DNA analysis and its storage in databases.

DNA Terminology

Deoxyribonucleic acid (DNA) is the genetic material that dictates the properties of the cell containing it. DNA is inherited from its parent organisms, and for organisms that reproduce sexually, the result makes each organism different from one another. Structurally, a DNA molecule looks like a double helix (**Figure-1**) and consists of *nucleotides*. Each nucleotide is

composed of a deoxyribose sugar, one phosphate group, and one of four different bases: adenine, guanine, thymine, and cytosine. These different nucleotides are linked together in a sugar phosphate backbone, and their order spells out genetic words or genes that tell cells what to do. An organism's DNA is a combination of the parent male and female DNA, and naturally will have half of each of the parents' DNA.

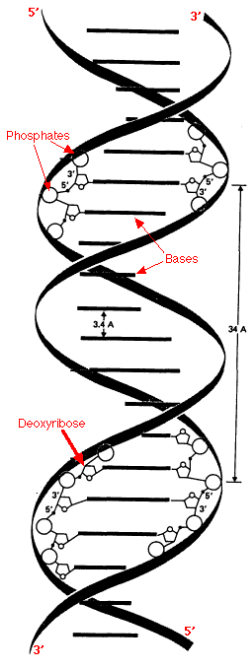

Figure-1: Structure of a DNA Double Helix. Shown are the two complementary strands of the DNA double helix. The strands are composed of alternating deoxyribose sugar and phosphate groups. Nitrogenous bases (shown as rungs on the ladder) and hydrogen bonded to each other to anneal the two strands together. (The Double Helix, 2010)

During DNA analysis, *cells* from an organism are needed. Cells are the basic building blocks of all living matter. These cells can come from a number of different tissues, such as hair, nucleated blood cells, sperm, or skin flakes. In the collected cells, DNA is mostly found in the cell's *nucleus*, where almost every cell in that organism has the exact same DNA. Nuclei are found in almost every cell in the body (with the exception of red blood cells). Within the nuclei are *chromosomes* which are condensed structures containing DNA molecules folded into tight shapes that aid their separation during cell division. Chromosomes are made up of DNA coiled

tightly around histone proteins. These proteins provide strength and structure to chromosomes. Humans contain twenty three pairs of chromosomes in most cells; twenty three chromosomes come from the female parent, and the other twenty three come from the male parent (How Many Chromosomes, 2010). Although DNA is mostly found in the nucleus of a cell, it is also found in *mitochondria*. Mitochondria are the organelle in a cell that produces a form of energy that the cell can actually use. Mitochondria are maternally inherited (there is no paternal contribution to mitochondria), therefore mitochondrial DNA (mtDNA) is more conserved from generation to generation, and can be used to analyze ancient tissue samples.

Repetitive DNA Sequences

Some DNA sequences encode useful proteins that keep the cell alive and provide the cell with its specific properties. These coding sequences (genes) are fairly conserved between all human beings, and these are the sequences that make us all human. All human DNA is approximately 99.9% identical. But not all DNA is conserved between humans; 0.1% varies from human to human. Although initially this may seem like a small percentage, it is more than enough to differentiate one persons' DNA from another. Maternal twins are the only exception, having mostly identical DNAs. These *variable* DNA sequences are the ones analyzed during DNA fingerprint analysis. The variable sequences often do not encode proteins, so over time their sequences have been allowed to change with no consequences to the individual. In the past, these variable sequences were termed "junk DNA" as scientists believed they had no real function, but we now know this junk DNA serves to help control cellular functions.

During DNA analysis, an individual's entire DNA *genome* (summary of all chromosomal sequences for that individual) is not analyzed. Full genome sequencing has only been achieved a

few times in history. Instead, during DNA analysis specific locations (*loci*) are analyzed that have been proven by scientists to vary from individual to individual. For DNA profiles entered into the FBI's CODIS database, 13 core loci are analyzed. These loci differ from individual to individual by the number of repeat sequences present. Variable number of tandem repeat sequences (**VNTRs**) are relatively long repeats that require a Southern blot method for analysis. Short tandem repeat sequences (**STRs**) are shorter loci that can be analyzed by amplifying type techniques (see below) (University of Arizona, 2000; Background Information, 2010).

Non-Amplifying-Type DNA Fingerprints

Two main techniques are used for DNA fingerprint analysis; restriction fragment length polymorphism (RFLP) and short tandem repeat (STR) analysis. Each type has its own pros and cons. RFLP is the primary technique used for analyzing DNA (RFLP, 2010). RFLP was the first type adapted by Alex Jeffreys in England (Jeffreys et al., 1985a) from an earlier 1970's Southern blot technique. RFLP was the first type of analysis used in a court case; a paternity case involving immigrants to prove a mother/son relationship (Jeffreys et al., 1985b).

RFLP analyzes the length of specific DNA fragments produced by cutting DNA with restriction enzymes. The DNA is cut with restriction enzymes which cut at specific sequences. For example, if DNA is cut with the restriction enzyme EcoRI, the result is the production of EcoRI DNA fragments whose lengths may vary depending on the number of VNTRs present. The steps for completing this procedure are as follows:

1. Separate white and red blood cells using a centrifuge.

2. Extract nuclear DNA from the white blood cells. This is done by bathing the cells in hot water, then adding salt, and putting the mixture back into the centrifuge.

3. Cut the purified DNA into fragments using a restriction enzyme.

4. Separate the DNA fragments by size using agarose electrophoresis. Place the fragments into one end of a bed of agarose gel with electrodes in it. The agarose gel is made from agar (agar, is a type of seaweed that turns into gelatin when dissolved in boiling water and is basically food for many types of cells). Use an electric current to sort the DNA segments by length. This process is called agarose gel electrophoresis. Electrophoresis refers to the process of moving the negatively-charged molecules through the gel with electricity. The shorter segments move farther away from their original location, while longer ones stay closer. The samples are compared in parallel rows or lanes.

5. Use a sheet of nitrocellulose or nylon to blot the DNA pattern to the membrane.

6. Add a radiolabeled probe to the membrane. The probe represents a DNA molecule with a complementary sequence to the locus of interest. The probe hybridizes to the complementary DNA fragment on the membrane, identifying its location and its size.

7. Identify the location of the radiolabeled probe using x-ray film.
An autoradiograph is created, which is an image on x-ray film left by the decay pattern of the radiation. The autoradiograph, with its distinctive dark-colored parallel bands, is the DNA profile.

(Freeman, 2010)

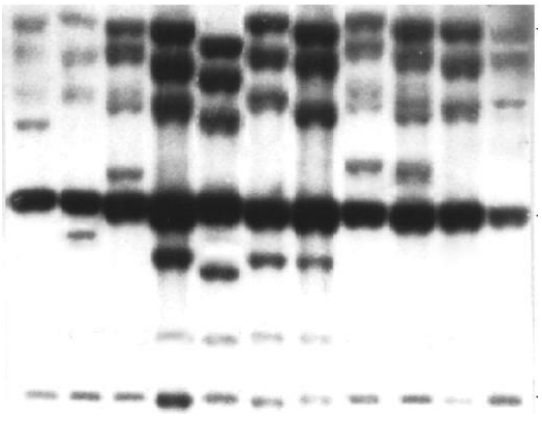

Figure-1: Example of RFLP-Type DNA Autoradiograph. Note that the banding pattern in lane-4 matches that in lane-7, so are derived from the same DNA. (Freeman, 2010)

The photograph in **Figure-1** shows an example of an RFLP type DNA fingerprint. The dark bands in each lane represent restriction fragments of different lengths. Note that the pattern of bands in lane 4 matches that in lane 7. RFLP analysis requires a relatively large amount of

DNA, as much as twenty five strands of hair, or a nickel size bodily fluid sample. This is because the process is non amplifying. RFLPs are typically too long to be amplified by polymerase chain reactions (PCR) (discussed below). But because it does not involve PCR, the technique is not as prone to contamination as the STR/PCR type analysis. The RFLP is also a very time consuming process. The procedure can take from a week to a month to complete when done correctly. This technique also requires examining multiple locations, which is also a time consuming process. Additionally RFLPs need to be done manually, and this can lead to human error. Due to the extensive time required for RFLP analysis, the second technique STR/PCR has mostly replaced RFLP in many labs.

Amplifying-Type DNA Fingerprints

The second type of DNA fingerprint technology analyzes short tandem repeats (STRs). STRs are short enough to be amplified by polymerase chain reaction (PCR), which is their main advantage. PCR was discovered by Kary Mullis (Mullis et al., 1986) who was subsequently awarded the Nobel Prize in chemistry in 1993. The development of this important technique of amplifying DNA has been said to be one of the most important scientific advances in all of molecular biology (Brown, 1995). Typically thirteen different loci are analyzed to make the DNA profile. This type of analysis can analyze very small DNA samples, and can even analyze partially degraded DNA (STR Analysis, 2010).

PCR amplifies the locus for analysis using an automated thermocycler that cycles between different programmed temperatures (Brown, 1995; Rice, 2010). PCR essentially takes a small piece of DNA and replicates it to create more DNA, therefore increasing the size of the sample. In order to start this process the DNA must first be heated to about 94ºC to denature and

separate the DNA strands. Next, the temperature is lowered to about 55ºC to allow a pair of primers to anneal to the area surrounding the locus to act as starting points for DNA replication. Then the temperature is raised to about 72ºC, the optimum temperature of Taq DNA polymerase. Taq is an enzyme isolated from thermal bacteria that is capable of replicating DNA at elevated temperatures. Taq polymerase synthesizes two new strands of DNA using the original strands as blueprints and the primers as start sites. This procedure is repeated 30-40 times making one billion copies of the original DNA. This may seem like a complicated procedure, but fortunately it is automated by a machine called thermocycler, and can be completed in just a few hours. The procedure for completing the STR/PCR analyses is as follows:

1. Extract nuclear DNA from cells in the tissue sample.
2. Amplify specific loci by PCR.
3. Use gel electrophoresis or column chromatography or capillary electrophoresis to determine PCR fragment length, and thus how many repeats are present at that locus.
4. Dyes are applied to help visualize the DNA. (RFLP, 2010)

The diagram in **Figure-2** shows an example of an STR type DNA fingerprint *(*Schilz et al., 2006). In this interesting case, STR PCR was performed on eight different loci (Amelogenin, D13S317, D5S818, VWA, CSF1PO, D351358, D21S11, and FGA) from DNA isolated from the bones of a Bronze Age family. From the amelogenin locus, we can see that the child (middle panel) was a female (X chromosome only). From the D13S317 locus, we see that the daughter's genotype is [9,12], the father's genotype (upper panel) is [12], and the mother's genotype is [8,9]. Thus, the daughter received the 9 genotype from the mother and the 12 genotype from the father. This analysis, when repeated for each locus, proves the familial relationship of the three individuals *(*Schilz et al., 2006).

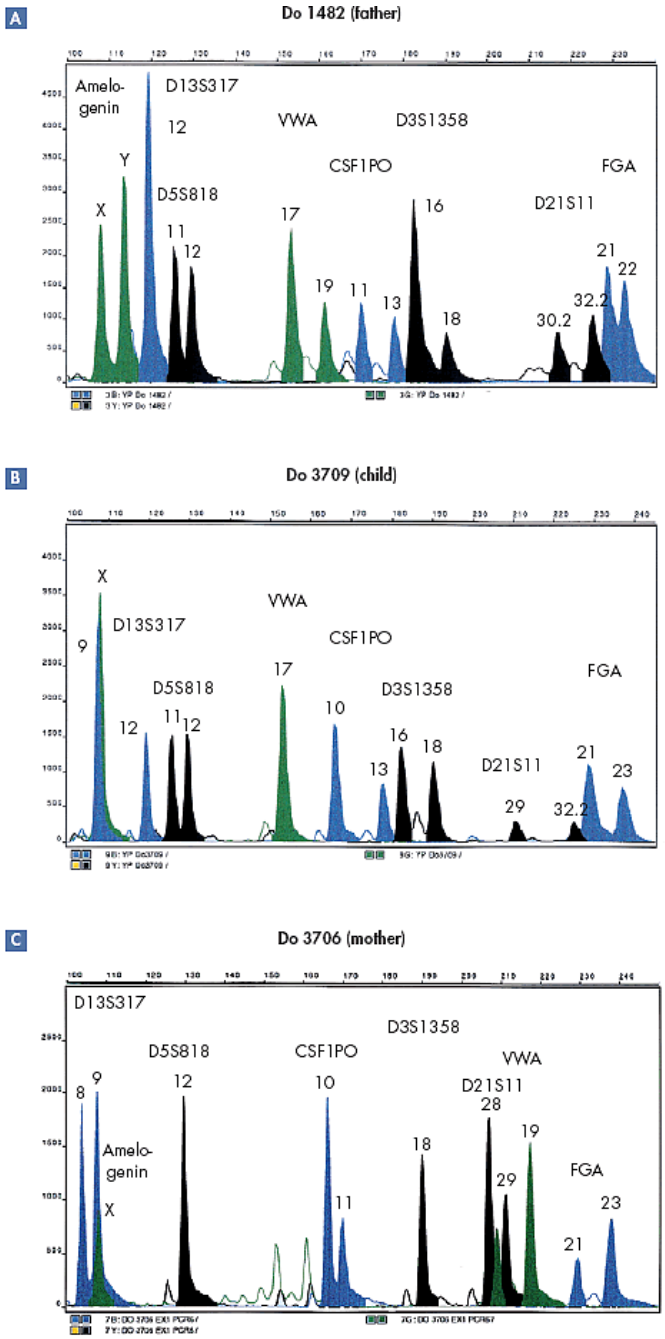

Figure-2: Example of an STR/PCR Type DNA Fingerprint. STR analysis was performed on DNA from 3000 year old bones of a Bronze Age family. The panels, upper to lower, represent DNA from the father, child, and mother, respectively. For the last sample, the position of the VWA allele differs as slightly different primers were used. The analysis shows the familial relationship of the three individuals tested. (Schilz et al., 2006)

DNA Fingerprint Applications

RFLP and SLR analyses provide a plethora of valuable information. The common uses of this information include paternity testing, predicting genetic diseases, criminal forensics, anthropology, wildlife management, crop management, and the monitoring of organ transplant recipients to make sure the body will not reject the new organs.

Paternity testing is currently the most common application for DNA fingerprint analysis. As mentioned earlier, this was the very first court application for DNA testing (Jeffreys et al., 1985b), and it is now done hundreds of times each day to prove not just paternity, but all forms of familial testing (mother/son, mother/daughter, father/son, father/daughter, siblings). **Figure-3** shows two examples of paternity testing. In the left panel (paternity exclusion), the child's pattern contains no bands derived from the alleged father, so the male is excluded as father. In the right panel (paternity inclusion), note that the child's upper band is derived from the father, and the lower band from the mother, establishing paternity.

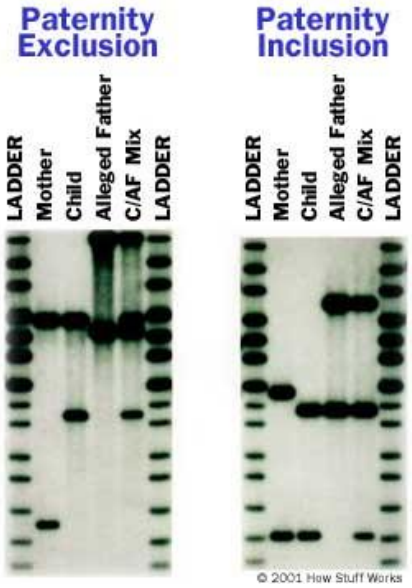

Figure-3: Example Data of a Paternity Test. This test shows paternity exclusion (left panel) and paternity inclusion (right panel). Note that in the left panel, neither the child's upper or lower bands are derived from the alleged father, so he is excluded. (Harris, 2010)

More recently, DNA testing has been improved statistically to detect *familial* hits in databases, such as the recent solving of the Grim Sleeper case in Los Angeles, where a serial killer was identified by a familial hit to his son in a database (Miller, 2010).

When testing for genetic diseases, scientists often look for patterns of DNA sequences in patients known to have a specific disease. This has already been applied to diseases like cystic fibrosis, Huntington's chorea, and sickle-cell anemia. Testing for sickle-cell anemia is an example of using an RFLP to diagnose a mutation. Sickle cell anemia can be caused by a single nucleotide mutation in the β-globin gene in which thymine is replaced by adenine. This T→A mutation renders the DNA sequence at that site uncuttable with MstII. Thus, sickle cell patients at this locus have longer MstII restriction fragments (RFLP, 2010). Predicting future health using DNA technology can also be done by pre-natal screenings. This procedure has already been done successfully for cystic fibrosis; PCR was used to amplify the DNA from one cell of an 8-cell IVF embryo to determine whether the embryo was normal, and if so, was implanted into the uterus.

DNA uses in forensics have been rapidly increasing in the past decade. DNA samples collected at crime scenes are compared to the DNA of a suspect or entries in a database. Although this procedure of matching DNA evidence to a suspect is extremely powerful, DNA databases include only previously convicted criminals, so some states are considering including all *arrested* persons profiles in the CODIS database (this topic will be discussed in Chapter-5).

DNA analysis combined with anthropology can be very useful in determining the likely place of origin of mummies or ancient artifacts such as the Dead Sea Scrolls. For example, the DNA from Otzi the Iceman was analyzed to determine he originated in the Italian alps (Handt et al., 1994), and has more recently been used to identify a new ancient human species (Brown,

2010). For the Dead Sea Scrolls, they were written on different kinds of skin such as sheep or goatskin, so when comparing the DNA of the different scrolls to each other, scientists could put the pieces of scrolls most closely related together.

Wildlife preservation can also benefit from DNA analyses. Endangered animals being illegally killed and sold can be tracked using DNA evidence. Such activities include the tracking of the illegal sale of whale meat or elephant ivory, where the DNA profile of the poached item can be compared to an animal carcass, allowing justice officials to take appropriate action against the poachers, ultimately protecting the endangered species.

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Chapter-2: DNA Forensics

Peter White

Introduction

Evidence containing DNA is very useful because it can link a person with another individual, object, or location (Lee, 2008). Because DNA is such a powerful tool for identification, the use of DNA in court cases has become much more prevalent in recent years. It is difficult for a criminal to avoid leaving a DNA trail behind at a crime scene, and once DNA is left behind its sequence cannot be altered. Although DNA forensics was initially a loosely regulated non-standardized science, now highly trained investigators use strict standardized methods for collecting, transporting, storing, and analyzing DNA evidence. The technology attracts much attention in the media, including TV series such as *CSI* and *NCIS*. Although, the media may sometimes distort the technology's capabilities, DNA forensics indisputably increases the accuracy and validity of court verdicts if the evidence is handled properly.

Types of DNA Evidence

Several different types of human tissues contain DNA which can be used as physical evidence, including blood and bloodstains, semen and seminal stains, tissues and cells, bones and organs, hairs with follicles, and urine and saliva with nucleated cells. The types of biological evidence that do not contain DNA are tears, perspiration, serum, and other bodily fluids, because they are found without cells, so they contain no nuclei or mitochondria (the two sources of DNA).

The amount of DNA present in each type of evidence varies, making some types of evidence more valuable than others (Kaye and Sensabaugh, 2000). For example, semen may hold forty times the DNA content of the same volume of saliva (**Table-I**). The more DNA found in the sample, the higher the rate of accuracy during analysis, which helps ensure the validity of the evidence in a courtroom.

Table-I: Types of Forensic Samples, Their DNA Content, and PCR Success Rates.

Sample	DNA Content	PCR Success Rate
Blood 1. stain 1 cm x 1 cm 2. stain 1 mm x 1 mm	20,000–40,000 ng/mL ca. 200 ng ca. 2 ng	> 95%
Semen 1. on post-coital vaginal swab	150,000–300,000 ng/mL 0–3000 ng	>95%
Saliva 1. on a cigarette butt	1000–10,000 ng/mL 0–25 ng	50–70%
Hair 1. root end of pulled hair 2. root end of shed hair 3. hair shaft	 1–750 ng 1–12 ng 0.001–0.040 ng/cm	 >90% <20%
Urine	1–20 ng/mL	
Skin cells 1. from socks, gloves, or repeatedly used clothing 2. from handled objects (e.g., a doorknob)		30–60% <20%

ng = nanogram, or 1/1,000,000,000th of a gram; mL = milliliter; cm = centimeter; mm = millimeter

Securing the Crime Scene

In order for DNA to reach the courtroom uncompromised, precautions are necessary at every level of investigation to ensure safe passage. These should begin upon the arrival of the first officer at the crime scene. He or she should secure the scene by setting up boundaries defining the level of caution needed, and defining where authorized personnel can enter. Greg Dagnan, Assistant Professor of Criminal Justice at Missouri Southern State University wrote an article entitled *Increasing Crime Scene Integrity by Creating Multiple Security Levels* (2006). He developed a three tiered security system (**Figure-1**). The first zone completely engulfs the crime scene and all possible evidence. The second zone surrounds the first and acts as a buffer. This zone allows an area for officers to talk, set up work stations, park vehicles and remain unbothered by the public and the media. Also, if a piece of evidence is eventually found in the secondary containment, it is still considered to be in a protected area, which helps when this evidence is brought forth in the courtroom. The third tier is the perimeter containment. This is where the filtering out of unauthorized persons and vehicles takes place (Dagnan, 2006). Utilizing this three tier containment system goes a long way in protecting the integrity of DNA samples. It keeps out unnecessary people who may contaminate evidence, and leaves only the experts in the first containment level to collect samples.

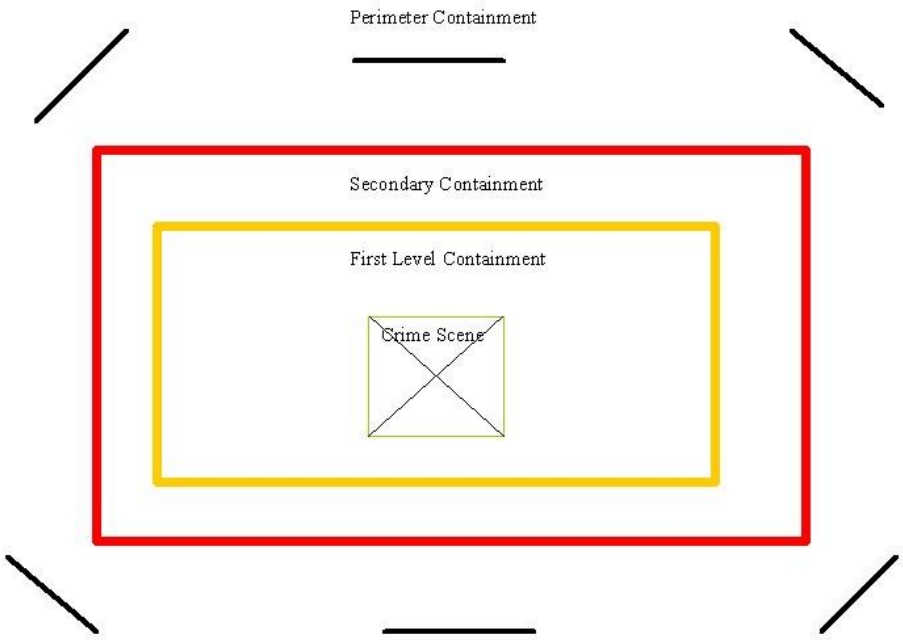

Figure-1: Diagram of Greg Dagnan's Three Tiered System Securing a Crime Scene. (Dagnan, 2006).

Contamination Prevention

Throughout the investigation, new protocols help prevent the contamination of DNA. Some of these protocols repeat Dagnan's system, such as limiting the number of people with access to evidence, designating paths of entrance and exit, and defining an area for trash and equipment. But in addition to Dagnan's system, other methods can reduce the risk of contamination. Use personal protective equipment (PPE) to decrease the risk of contamination of personnel and evidence. Clean and sanitize (or dispose) of tools and equipment between collections and scenes, using single-use tools whenever possible. These protocols may seem elementary, but they have not been followed many times in the past resulting in unfortunate issues in the court room (Crime Scene Investigation, 2000).

One of the hardest jobs for an investigator is preventing sample-to-sample contamination. This can easily be prevented with the help of a few inexpensive items. Using swabs with wooden

shafts instead of plastic can help considerably, as the wood is stronger and less likely to break. And the wooden swabs can be stabbed into Styrofoam blocks they are being dried. To ensure that the blocks do not tip over, it is suggested that a double-sided adhesive be attached to the bottom of the Styrofoam block. The blocks should be clearly labeled with an evidence number on a sticker. Lastly, once the swabs are completely dry, they should be put into separate paper envelopes for packaging (Kramer, 2002).

These procedures are necessary for the evidence to be admissible in court. Prosecutors depend on the fact that investigators are being properly trained and follow protocol. If one possible source of contamination exists, the defense could have the evidence thrown out. This problem displays the fragility of DNA forensics and the importance of a professional controlled crime scene.

Evidence Collection

Now that the crime scene is secure and the proper precautions have been taken, the delicate process of evidence collection begins. Regulations define how to properly collect evidence, and if these are followed, this dramatically reduces the risk of contamination. Different procedures should be followed depending on the state the evidence is found in. For example, if there is a wet stain containing DNA located on an immovable object, the investigator should soak up the stain with sterile cotton tip swabs or clean cotton, allow it to air dry, seal it in clean paper in a manner that would make tampering evident with initials over the seal, and clearly label the outer packaging. If there is a dry stain, the investigator should moisten the swabs with sterile water. Then, rub the stain until it is picked up, then follow other procedures outlined above (Evidence Collection in Forensic Biology, 2002). General collection instructions

include always keeping in mind procedures for preventing sample-to-sample contamination or contamination from collector to sample (Kramer, 2002).

One of the best ways to collect DNA is to take the entire object, or if possible cut-out a piece of the object, with evidence on its surface. This ensures that the investigator takes as large a sample as possible, increasing the chance of getting a useful piece of evidence. Also effective is tape-lifting where the investigator takes a standard piece of tape normally used to collect fingerprints and places it on the dried stain, being careful not to touch the sticky side of the tape. After pressing on the non-sticky side with a blunt object to ensure that a strong contact has been made between the tape and the stain, the investigator lifts the tape and places it on vinyl acetate backing. Another simple method of collection is to scrape the stain with a sharp instrument, then place the evidence in a paper container. A paper container is more desirable than plastic because plastic holds a static charge that would make the pieces cling to the sides of the container (Schiro, 2001). Plastic also retains water more than paper, increasing the chance of DNA degradation.

The Police Executive Research Forum offers a table of all types of DNA forensic evidence an investigator may come across in all its forms (**Table-II**). The table also displays the methods of collection, the risks involved for that particular method, and other special considerations the investigator should keep in mind.

Table-II: DNA Evidence Collection Methods, Risks and Special Considerations (Turner et al, 2002).

Evidence		Collection Method	Risks	Special Considerations
Type	**Form**			
Blood	Dried (Small Items)	If possible, wrap the item in clean paper, place the article in a brown paper bag or box, and seal and label container. Send the whole stained object to the laboratory after labeling and packaging.		
Blood	Dried (Large Items)	*Preferred Method:* Cover the stained area with clean paper and seal the edges down with tape to prevent loss or contamination.	More work for the serologist: bulky items require more storage space.	Requires a minimal amount of interaction with the bloodstains by the investigator and allows the serologist to make the decisions involved in collecting the samples.
		Alternate Method #1: Cut out the part of the item with the bloodstain(s). A control sample should also be cut out if available. Both cuttings should go into separate paper envelopes.	Investigator must use discretion to determine which stains and controls to collect. Some materials are difficult to cut through.	Dilution and contamination potential eliminated by not using water as the collection medium. Investigator has minimal interaction with the bloodstain, and evidence does not take up much storage space.
		Alternate Method #2: Use fingerprint tape to lift bloodstain. Place tape over bloodstain and surrounding negative control area. Lift the bloodstain and place the tape on a vinyl acetate backing.	Investigator must decide which stains and controls to collect. Bloodstains do not lift well off certain surfaces.	A fairly easy technique in which the control sample is readily collected. Dilution and contamination potential minimized by eliminating the use of water as the collection medium. Requires little storage space.
		Alternate Method #3: Scrape bloodstains into a paper packet with a clean, sharp instrument.	Investigator must decide which stains to collect; when scraped, bloodstains break into small, difficult-to-handle flakes; flakes are easily lost.	Dilution and contamination potential minimized by eliminating the use of water as the collection medium. Requires little storage space.
		Alternate Method #4: Absorb stains onto ½" long, number 8 white cotton threads moistened with distilled or deionized water.	Dilution and contamination potential is increased due to using water; investigator must use discretion as to which stains and controls to collect.	Stain is concentrated onto a relatively small surface area, requiring little storage space.

		Alternate Method #5: Absorb stains onto moistened ½" x ½" cotton squares, following the same procedure as with threads.	Dilution and contamination potential is increased due to using more water.	Stain is concentrated onto a relatively small surface area; easier to handle than threads; requires little storage space.
Blood	Wet (Small Items	Place small stained items in paper bag (or plastic bag to prevent contamination of other objects). In a secure spot, take item out of bag, and allow the evidence and bag to thoroughly air dry.	Evidence should be refrigerated or frozen immediately, then delivered to the laboratory as quickly as possible. Delays beyond 48 hours may increase the chances of decomposition. More work for the serologist; bulky items use more storage space.	Requires a minimal amount of interaction with the bloodstains by the investigator; allows the serologist to make the decisions involved in collecting the samples.
Blood	Wet (Large Items)	Absorb the stain onto a 1" x 1" square of cotton muslin. Package it in paper (or plastic to prevent contamination of other objects).	Evidence should be refrigerated or frozen immediately, then delivered to the laboratory as quickly as possible.	Requires little storage space; fairly easy technique to perform; stain is concentrated onto a relatively small surface area.
Semen and Seminal Stains	On Fabric	Allow any stains to air dry. If damp, allow fabric to dry completely before packaging in paper.		Often found on clothing, blankets, and sheets.
	On Victim	If victim shows evidence of sexual intercourse, use PERK. If necessary, oral, vaginal, or anal swabs should be taken from the victim. Swabs should be air dried under a fan or moving air source for at least one hour.	The body begins breaking down the various components in seminal fluid through drainage, enzyme activity, pH, etc. Moisture in the swabs allows microorganisms to grow, which can destroy the evidentiary value of the swabs.	Take swabs as soon as possible. Evidence collected and subjected to testing may reveal results from biological material left by other consensual sexual partners unrelated to the offense investigated or other contact with victim by other individuals.
Saliva		Use sterile gauze pad or swabs; allow to air dry. Place in paper, not plastic, containers. Sources of saliva can include envelopes, bottles, cans, gum, food, etc.		
Clothing	Wet	Hang articles in a room with adequate ventilation and allow to air dry. Label, roll in paper, then store in brown paper bag or box; seal and label container.		Handle fabrics as little as possible.

Hair	With root sheath	Collect 15-20 representative hairs from the suspect. Place in paper packet and then in an envelope.		If a root sheath is attached, DNA analysis using PCR technology can provide information on the likelihood that this hair came from a certain percentage of the population to which the suspect belongs.
Hair	Without root sheath	Collect 15-20 representative hairs from the suspect. Place in paper packet and then in an envelope.		If there is no root sheath, microscopic analysis can reveal whether the hair has the same characteristics as the suspect's hair.
Stain evidence on nonabsorbent materials		On materials such as plastic and metal, shifting the material from a cold to a warm environment may create condensation, destroying the forensic value of the sample. Samples must be packaged so the stain portion is protected. Keep evidence at room temperature and deliver to lab as quickly as possible.		

Evidence Transportation and Storage

Once DNA evidence is collected, it is essential that the samples are placed in the correct transportation and storage conditions. The evidence should be placed into a sealed paper container, labeled with the investigator's initials over the seal, a serial number, the date and time it was collected, and where it was found. This container not only assures that the DNA will not be damaged chemically, but also makes tampering nearly impossible.

The investigators have worked hard to make sure the sample was not contaminated during the process of collection, so now they must make sure its integrity remains throughout transportation and storage. DNA can be damaged very easily if kept in the wrong conditions. It must remain out of direct sunlight and high temperatures, such as an outdoor crime scene during

the summer time, or sitting in a police car without air conditioning (President's DNA Initiative, 1999). Long term storage also requires a cool place with ample room for filing systems.

Storing DNA correctly has emerged as a problem for many agencies. They do not have the proper space or facilities to store DNA evidence in its abundance and fragility. Not only does this lead to storing DNA in undesirable conditions, which may contribute to contamination and the elimination of its usefulness in the courtroom, but also it leads to not collecting the proper amount of DNA in the first place for fear that they will not have ample room for storage. Naturally, this creates many setbacks for prosecutors. Also, DNA collected from unsolved crime scenes should be kept because there may be developments in the case at a later date. Some agencies barely have room for evidence for current cases, let alone cases from the past (Lovrich et al., 2003). It has been estimated that 79% of law enforcement agencies keep collected and unanalyzed evidence in a centralized storage area. 61% of law enforcement agencies do not have sufficient space for long term evidence storage, and 70% find the need for more storage space to be "critical" or "highly critical" (Lovrich, 2003) (**Table-III**).

Table-III: Storage Locations for Unanalyzed Evidence and Long-Term Storage Needs (Lovrich, 2003).

Storage Issue for Local Law Enforcement Agencies	Law Enforcement Agencies Responding (%)
Where unanalyzed evidence is stored	
Centralized storage area	79.0
Decentralized storage areas/various district locations	3.1
Prosecutor's facility	2.0
Crime laboratory facility	22.2
Other	5.6

Does agency have sufficient space for long-term evidence storage?

Yes 39.0
No 61.0

Is the need for more storage space "critical" or "highly critical"?

Yes 70.3
No 29.7

The investigator's job is not finished once sample collection is complete. It is crucial that they follow procedures pertaining to transportation and storage so that the DNA evidence is admissible in court. This stage of DNA forensics is as important as any, and advancements in DNA forensic science are being held up due to lack of storage space for evidence.

Chapter-2 Conclusions

The power of DNA fingerprinting only works if the DNA samples are collected properly from a crime scene. Mistakes in collection can lead to DNA contamination, degradation, or mislabeling. Thus, DNA forensics is the centerpiece of this new identification technology, and its popularity has grown exponentially over the past two decades. Caution and standardized techniques must be used at every step of the forensic process. As our DNA technological capabilities expand, the value of DNA profiling to society will continue to grow.

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CHAPTER-3: LANDMARK DNA COURT CASES

Alex Pittera

In the previous chapters we discussed the *technology* of DNA fingerprint analysis, including the main types of fingerprints, and the methods used to minimize DNA contamination and degradation. In this chapter, we go beyond the technology to discuss several landmark court cases that set precedence's for entering new technologies in US courts.

James Alphonzo Frye vs. United States

James Alphonzo Frye vs. United States proved to be a highly significant court case in United States history for many reasons. On November 25, 1920, James Frye was accused of murdering a physician, Dr. Robert W. Brown. Although Frye originally admitting murdering the victim early in the investigation, his lawyer Richard V. Mattingly told James Frye to retract his statement and take a lie detector test. At the time, a lie detector test or polygraph test was a new invention in crime prosecution. The test, developed by William Marston, consisted of a stethoscope and a standard medical blood pressure cuff to monitor Frye's heartbeat and blood pressure immediately after each question. Marston looked for elevated blood levels to determine whether Frye was lying or telling the truth. After viewing the results, Marston was convinced that Frye was telling the truth and that he did not kill the physician. Although Marston was convinced of Frye's innocence, as soon as the trial began his lie detector test was thrown out by Judge McCoy due to the invention not being *generally accepted* in the scientific community. Many scientists thought that just being nervous could elevate a person's blood pressure or that if a person was a good liar the test could be fooled. Without the lie detector results allowed, and

based on the earlier confession and other physical evidence, Frye was convicted of second degree murder with a life sentence in jail. Frye's lawyer, Mattingly, appealed his case to the Supreme Court on the grounds that the polygraph results were not allowed, but in 1923 the Circuit Court of Appeals in the District of Columbia upheld Judge McCoy's decision of not allowing the lie detector test in court.

The significance of this court case was that it provided a *Frye Standard* used for decades of subsequent cases when judges came across new scientific inventions. Such new technology would be allowed only if *generally accepted* in the scientific community. The precise citation usually used in court when denying new scientific evidence is:

> "Just when a scientific principle or discovery crosses the line between the experimental and demonstrative stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have *general acceptance* in the particular field in which it belongs."
>
> "We think the systolic blood pressure deception test has not gained such standing and scientific recognition among physiological and psychological authorities as would justify the courts in admitting expert testimony deduced from the discovery, development, and experiments thus far made." (Fisher, 2010)

Federal Rules of Evidence 702 (Rule 702) and the Daubrt vs. Merrel Case

Although the *Frye Standard* for decades played a major part in US case history, the standard did not address whether particular evidence was actually analyzed correctly with appropriate controls, or whether the technique is *reliable*, or what is the known *error rate* for the technique. The *Federal Rules of Evidence 702* (Rule 702) was created in 1975, and gave more insight into the *Frye Standard* by setting more relaxed guidelines (Mahle, 1999). *Rule 702* gave the courts the capability of using expert witnesses with specialized understanding, skill, training,

or education, the ability to assist courts in interpreting complex evidence, and expanded the standard to focus more on *reliability*, peer review, *and known error rate*, than general acceptance (Moenssens, 2010).

Rule 702 came to surpass Frye in 1993 during the *Daubert vs. Merrel Dow Pharmaceuticals*, Inc. series of trials. In this case, two boys, Jason Daubert and Eric Schuller, were born with serious birth defects after their mothers were treated for anti-nausea with a drug called Bendectin while pregnant. The mothers made claims saying their sons, and 1,700 other people, were born with defects caused by the Bendectin during the 1980's. Although there was no concrete proof that this drug caused birth defects, prosecutors looked at alternative forms of evidence to prove the drug likely caused birth defects. Their evidence involved live animal tests, a re-interpretations of existing published data on the drug, and an analysis of how this drug is chemically similar to other drugs known to cause birth defects. When this evidence was submitted in district court, it was denied due the Frye standard, as the evidence had not been peer reviewed.

The case was eventually considered by the Supreme Court who wanted to clarify and update the criteria for expert testimony admissibility. The Daubert case became a debate on which standard, Frye or Rule 702, superseded. In the end, Rule 702 was declared to be a better standard, and the Daubert evidence was allowed into court. The Supreme Court stated that the *Frye Standard* no longer governed the admissibility of scientific evidence, and that *Rule 702* allowed evidence only if the debated technology was reliable, peer-reviewed, and had a known error rate. The new *Daubert Standard of Evidence Admissibility* uses four criteria:

1. Whether the theory or technique has been *reliably* tested
2. Whether the theory or technique has been subject to *peer review* and publication
3. What the known or potential *rate of error* of the theory or technique used
4. Whether the theory of method has been *generally accepted* by the scientific community (Mahle, 1999; Atlantic Legal, 2010)

Colin Pitchfork Case (1986)

The Colin Pitchfork case began on November 22, 1983, when a fifteen year old girl, Lynda Mann, was discovered murdered in Narborough, Leicestershire England (Batt, 1999). Lynda was raped, murdered and dumped on an abandoned path. Unfortunately, police only found a small amount of crime scene evidence, and only a small semen sample was collected. Although small, the sample gave authorities the blood type and an enzyme profile that only matched 10 percent of males. Although this evidence narrowed the search, the case went cold until 1987 when another 15 year old girl, Dawn Ashworth, was murdered, raped, and dumped on an untraveled path. As with the first case, semen was also found and matched the first semen sample from the Lynda Mann murder with respect to blood type and enzyme profile, so the same man appeared to kill both girls.

A tip was eventually received by the police, and a suspect Richard Buckland was arrested. Buckland admitted to killing the second girl but refused to admit to killing Lynda Mann. This was crucial in this case, since police knew that one man had committed both crimes. So the police resorted to a then new DNA test invented by Alex Jeffreys (Jeffreys, 1985a) that had previously been used to solve a paternity case (Jeffreys, 1985b), but which had not yet been applied to a murder case. To everyone's surprise, the DNA profile from the crime scene evidence did not match that from Buckland, proving his innocence in both crimes. This was the first time DNA testing was used to prove innocence. But who was the murderer?

Once the authorities were aware of Buckland's innocence and the power of DNA testing abilities, they began testing all males in three local villages. Over 5,000 men gave blood and were tested for DNA matches, but none of the samples matched the DNA found at the crime

scenes. This would have been the end of this case, if a man named Colin Pitchfork had not bragged to his friend that he had paid someone to give blood in his name. A local bakery manager heard this, and Pitchfork was arrested (**Figure-1**). Although he admitted to committing the murders and rapes, Pitchfork's DNA was still tested and was found to be a match to crime scene evidence. Pitchfork was sentenced to life imprisonment on concurrent terms for rape and murder. He appealed his case in May 2009 and won, granting him 2 years less than previously. Convicting Pitchfork from DNA for murder was another first in DNA history, and provided the beginning of using this technology worldwide in courts. Crime scene items that previously contained no evidentiary value could now be the most crucial piece of evidence collected.

Figure-1: Picture of Colin Pitchfork. (Wikipedia, 2010)

Paul Eugene Robinson Case (1994, 2000, 2003)

On August 24, 2000, Police Detective Peter Willover of the Sacramento Police department was desperate. A serial rapist was about to get away with his disturbing crimes due to the six year statute of limitations. Once the statute had expired, all evidence collected from the rapes would be destroyed and useless. Willover had no desire to destroy this evidence but needed

a way to extend the statute. Hope came for the victims and Det. Willover when a call was made by Anne Marie Schubert, a sexual assault prosecutor, who had a brilliant idea about a new technique being applied to cases with DNA evidence nearing the statute of limitations. She told Willover about a prosecutor in Milwaukee named Norman Gahn who had filed a warrant under the name John Doe in order to extend a case nearing the statute of limitations. Gahn was the first person to file a warrant not based on a person's physical characteristics, but based on someone's genetic DNA code. This John Doe warrant granted authorities more time to collect evidence and over rode the mandate to destroy evidence. So Detective Willovers with the help of Schubert filed the warrant as seen below:

> Number 00F06871, "THE PEOPLE OF THE STATE OF CALIFORNIA vs. JOHN DOE." The charges listed the suspect as an "unknown male with Short Tandem Repeat (STR) Deoxyribonucleic Acid (DNA) Profile at the following Genetic Locations, using the Cofiler and Profiler Plus Polymerase Chain Reaction (PCR) amplification kits: D3S1358 (15,15), D16S539 (9,10), THO1 (7,7), TPOX (6,9), CSF1PO (10,11), D7S820 (8,11), vWa (18,19), FGA (22,24), D8S1179 (12,15), D21S11 (28,28), D18S51 (20,20), D5S818 (8,13), D13S317 (10,11), with said Genetic Profile being unique, occurring in approximately 1 in 21 sextillion of the Caucasian population, 1 in 650 quadrillion of the African American population, 1 in 420 sextillion of the Hispanic population. (Delsohn, 2001)

The case lay dormant until an unlucky man violated his parole in November of 1998. Paul Eugene Robinson (**Figure-2**) was arrested for violating his parole. Originally Robinson was arrested for several burglaries and was now caught snooping around private properties by sheriff's deputies. Although pleading no contest to his arrest, a background check showed spousal abuse, and authorities wanted to compare his DNA profile to the state's database. But because Robinson's record only showed the spousal abuse conviction, a misdemeanor, a felony conviction was needed to take DNA samples.

Figure-2: Paul Eugene Robinson. (Delsohn, 2001)

Although taking DNA samples under these misdemeanor conditions is illegal, California state law allows for mistakes when the DNA is taken in good faith, so Robinson's DNA was processed. Just three weeks went by after Robinson's DNA collection, and a "cold hit" occurred to the rape crime scene evidence, so a warrant was issued for Robinson's arrest. This was the first time a John Doe warrant was actually used in court. Although the Fourth Amendment is sketchy on allowing an arrest with no actual physical evidence, prosecutor Schubert remained confident that the DNA evidence by itself would be strong enough to bring Robinson to court and successfully convict him. Schubert's approach was questioned because California law normally requires an individual's identifying information (name and address) to be listed on the face of the warrant. This warrant identified the suspect only as a John Doe, male, and black, and included his DNA profile. This lack of identifying information gave Robinson's attorney hope to have the warrant declared inadmissible. At the pre-trial hearing, Robinson's lawyer claimed any black male could have been arrested with the warrant, and he noted the extension of the statute of limitations, and this would be the first time an extension of the statute of limitations would be tested in court.

But prosecutor Schubert argued the John Doe warrants would only be created for stranger rapes, not for date rapes or consensual sex cases where personal ID information would still be required. This distinction was important since the statute of limitations was normally in place to prevent the testimony of witnesses in old cases that may have become distorted over time, but there were no witnesses in the John Doe case. Shubert also stated that although the genetic coding information was not on the warrant's front page, there were directions to a "remarks" section where the genetic code was located.

Judge Tani G. Cantil-Sakauye denied Robinson's lawyer Griffin the motion to dismiss the John Doe warrant, so Robinson was convicted in the rape cases based solely on his DNA profile. The judge ruled that with advances of forensic science, DNA was unalterable making it a conclusive piece of evidence. Griffin tried appealing the case to the Supreme Court, failed again, making Robinson the first person in U.S. history to be arrested and brought to justice using strictly DNA evidence.

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Chapter-4: Sensational DNA Cases

Peter White

Introduction

DNA forensics offers a powerful identification tool for the courtroom. In the previous chapter, we discussed various landmark court cases that set legal precedents for allowing new technologies in US courts, but those cases likely are not familiar to most readers. In this chapter, very well known court cases will be used as examples for showing how DNA can be powerful if used properly. In the first case, DNA forensics would have been a useful tool for investigators at the time of the murder, but since the crime occurred prior to the advent of this technology, it was used years later to solve the crime. In the second case, DNA forensics was used throughout, but did not deliver the appropriate verdict. In both cases, DNA forensics played or could have played a big role in their outcome.

Dr. Sam Sheppard

Dr. Sam Sheppard and his wife Marilyn **(Figure-1)** hosted their neighbors for dinner on the evening of July 3, 1954. Dr. Sam, as he was called, and his wife seemed to be themselves throughout the entire night. After their guests left, Dr. Sam fell asleep on the couch downstairs, while Marilyn, who was four months pregnant, went to bed along with their seven year old son, Chip. At 5:40 a.m. Spencer Houk, the mayor of a small

Figure-1: Dr. Sam Sheppard and his wife Marilyn. (Cleveland Press, 1954)

community on the shore of Lake Erie, received a phone call from Dr. Sam, his neighbor: "I think they've killed Marilyn" was all that Dr. Sam said. Houk immediately ran to the Sheppard residence and found Marilyn's lifeless body on the bed half naked and severely beaten on the head **(Figure-2)**. The walls of the room were sprayed with blood, and Dr. Sheppard stood with no shirt, soaking wet pants, and a bruise on the side of his face (Kelly, 2006).

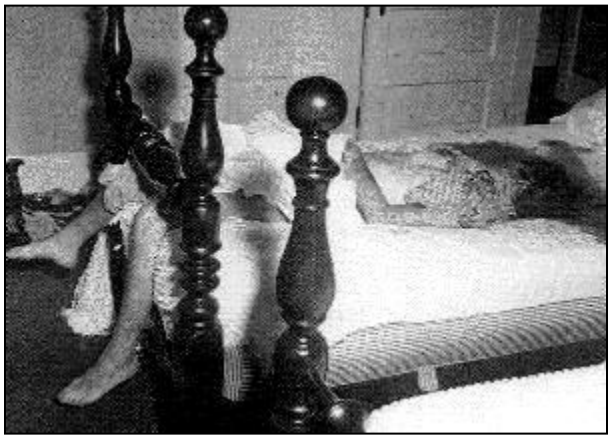

Figure-2: Marilyn Sheppard's Body as Found by Investigators. (Linder, 2006)

When the police arrived that morning, Dr. Sam Sheppard's side of the story was first heard. He was awakened by the sounds of a struggle and his wife's screams from upstairs. He immediately ran to her aid, but upon running upstairs he saw the form of a man who knocked him unconscious without hesitation. When Dr. Sheppard regained consciousness, he heard the intruder downstairs and pursued him outside to the shore of the lake where there was a struggle. Once again, Dr. Sheppard was knocked unconscious. When he regained consciousness once more he found himself lying half in the lake, which explains his soaked clothes. It was then that he phoned his neighbor, Spencer Houk (Kelly, 2006). Dr. Sam was only able to give investigators a very brief description of the intruder. The most notable feature Dr. Sam could give investigators was the suspect's bushy hair **(Figure-3)**.

Figure-3: A Police Sketch of the Bushy-Haired Intruder as Described by Dr. Sam Sheppard. (McGunagle, 2004)

To the misfortune of Dr. Sam, Dr. Samuel Gerber, the county coroner, took over the investigation. Gerber hated him because Dr. Sam and his brother and father were osteopaths. He had even previously stated, "I'm going to get them someday." Traditional medical practitioners despised osteopaths, the only other physicians licensed to practice medicine and surgery. To add Dr. Sam's misfortune of Gerber's bias, it was general practice to target the husband in domestic violence cases. To no one's surprise the coroner said, "It's obvious that the doctor did it." He then ordered detectives to go the hospital where Dr. Sam was being treated to get a confession (Kelly, 2006).

The media originally entertained the idea of a burglar or drug addict killing Marilyn, but quickly had a change of heart and now followed Gerber's lead. Gerber held an inquest in a school gymnasium that would hinder Dr. Sam's case immensely **(Figure-4)**. There was an audience of over two hundred, mostly housewives, who were clearly against Dr. Sam. Early in the process Dr. Sam's lawyer was removed from the room for demanding that outbursts be put on record. Unfortunately, Dr. Sam endured five hours of questioning without legal counsel. Without much surprise, Gerber issued a "coroner's verdict" stating, "the injuries that caused this death were inflicted by her husband." The only evidence that the coroner possessed was nothing worthy of a conviction. First, Dr. Sam stated that he was faithful to his wife; however one witness claimed otherwise. One may wonder how this connects the case, but it certainly persuaded the housewives in the gymnasium that Dr. Sam was guilty. Also, Sheppard's story was possible but unlikely, and he failed to fully cooperate with the police. Lastly, Dr. Sam "called in two lawyers," which displayed guilt to some people.

Figure-4: Dr. Samuel Gerber Questions Dr. Sam Sheppard at the Normandy Elementary School Coroner's Inquest. (Cleveland Press, 1954)

For twenty five days, the Bay Village Police remained on the fence as to whether or not to arrest Dr. Sam. On July 29, the Cleveland Police offered an ultimatum stating that if they did not arrest him, they would withdraw from the case. The next day the doctor was arrested. On October 18, 1954, the case of the *State of Ohio vs. Sam Sheppard* began. Throughout the trial witnesses were called to the stand not to offer physical evidence found, but rather to give character references. The courtroom seemed to be more interested in the Sheppard's marital status, than the forensic evidence of the case. One newspaper later stated that Dr. Sam was tried for murder and convicted of adultery. The reason for this lack of forensic evidence is due to the shoddy manner in which the police constructed their investigation. There were no samples or notes taken from the victim's body or wounds. Investigators never checked for evidence of rape. There were cigarette butts floating in the toilet (none of the Sheppards smoked), and no one found it necessary to collect them for evidence. Overall, no attempt was made to collect forensic evidence whatsoever. Because of these poor investigative procedures, Dr. Sam Sheppard was sentenced to life in prison (Kelly, 2006).

In November of 1959, a man named Richard Eberling was arrested for burglary in the Cleveland area. In his possession was Marilyn Sheppard's ring. He claimed that he had stolen this ring from Sam's brother, Richard's house, and during police questioning Eberling volunteered some curious information. He worked as a window washer for Dr. Sam, and days before the murder he cut himself while working and dripped blood inside of the Sheppard house. Many questioned why he would account for his blood being in the house unless he was worried that investigators would make the connection to the murder. However, Eberling did not fit the description of the bushy haired man so police remained confident that they had the right man, Dr. Sam, behind bars (McClish, 2002).

After ten years of imprisonment and numerous denied appeals, Judge Carl Weinman issued a blockbuster ruling ordering Dr. Sam released from prison. Judge Weinman added that, "If there ever was a trial by newspaper this is a perfect example." He found five separate violations of Dr. Sam's constitutional rights, and called the trial "a mockery of justice" (McGunagle, 2004). So in 1964, Dr. Sam Sheppard was a free man. However, his happiness would be short-lived as he would be back in the court room for a second trial.

On November 1, 1966, the case of the *State of Ohio vs. Sam Sheppard* commenced for a second time. In this trial, a pivotal piece of evidence that served the prosecution well in the first trial, an imprint of what Dr. Gerber said was most-likely a surgical instrument, was shown to be something different. F. Lee Bailey, Dr. Sam's new lawyer, showed the court that this imprint was most-likely not a surgical instrument. On November 16, 1966, the jury found Dr. Sam not guilty of all charges (McGunagle, 2004).

In 1970, Dr. Sam Sheppard died of liver failure. His family wishing to cleanse the Sheppard name took the case back to court to get an innocence ruling rather than "not guilty".

With further investigation it was found that Eberling's DNA was found on the stairs of Sheppard house. This was believed to be the result of Marilyn biting her attacker. Compounding this evidence was a combination of DNA found on Marilyn's teeth. Blood found on Marilyn's teeth belonged to Eberling and Marilyn. There was also a combination of DNA found in a vaginal swab taken from Marilyn. It belonged to Eberling and Sheppard, but Sheppard had stated that he and his wife had sex the Friday night before the murder (McClish, 2002).

The Sheppard family was never able to get the innocence ruling they were looking for. As Dr. Sam's son said, only history will tell who the killer was. There have been multiple books published on this case, with many proposed suspects. There has even been a movie and television series, *The Fugitive,* based on this case in which a wealthy doctor is wrongfully convicted of killing his wife. These show the attention the case attracted across the country.

DNA forensics has developed substantially since the 1950's. If investigators at the time of Marilyn Sheppard's murder had the crime scene and analytical training available now, the real killer would have been discovered. Instead, the police did not properly investigate the crime scene, and an innocent man went to prison.

O.J. Simpson

On Sunday June 12, 1994, in the Brentwood area of Los Angeles, an Akita dog was found covered in human blood. This dog then led its finder to the home of Nicole Brown Simpson, ex- wife of former pro-football star Orenthal "O.J." Simpson. Around 10:00 p.m. the bodies of Nicole and her friend, Ronald Goldman, were found brutally murdered. Nicole's neck had been slashed so deeply that her head almost was severed from her body. Goldman's neck had been slashed as well, but he had an additional thirty stab wounds to the body and upper thigh

area. O.J. Simpson, Nicole's ex-husband and living only minutes away, was immediately a suspect (Jones, 2004).

At 5:00 a.m. on Monday morning, four detectives went to Simpson's house. There, detectives found a white ford bronco with blood on its door. This car was the property of the Hertz Corporation for whom Simpson was a spokesperson. With the discovery of blood on his property and the fact that his wife lay murdered less than two miles away, detectives found it necessary to enter the premises. They still had no success when ringing the door bells until they went around to a row of three bungalows. In the first was Kato Kaelin, a friend and house guest of Simpson. In the second was Arnelle Simpson, O.J.'s daughter. Detectives interviewed Kaelin and learned that the night before, he and Simpson went to a McDonald's. Then, Kaelin retired to his bungalow. Then around 10:45 p.m. he heard commotion outside. When he went out to investigate he saw a limousine waiting to take Simpson to the airport to catch a "red eye" flight to Chicago. Kaelin and the driver loaded Simpson's luggage except for a small black bag Simpson held (Jones, 2004).

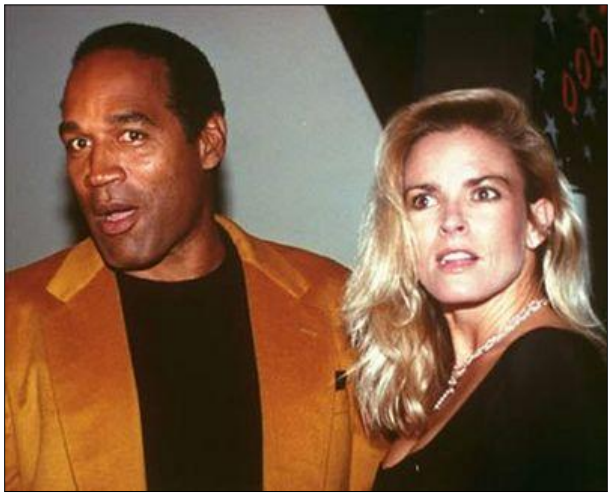

Figure-5: O.J. and Nicole Brown Simpson. (News One, 2010)

When detectives were able to get in touch with Simpson in Chicago, he seemed very distraught to hear about the death of his ex-wife. He broke a glass after hearing the news, however he never asked questions such as where, when, who, and how. O.J. caught a flight back to Los Angeles. While still at the home of O.J. Simpson, detectives found a brown leather glove that matched another found at the scene of the murder **(Figure-6)**. Now the detectives would

have no problem getting a warrant to fully search and seize any evidence in the Simpson residence (Jones, 2004).

Figure-6: Glove Found at the Residence of Nicole Brown Simpson. (Potter, 2010)

Police took Simpson into the station for questioning. Throughout this interview Simpson contradicted himself on many accounts, including facts concerning the timing of his use of the Ford Bronco, the way he injured his hand, which shoes he was wearing the night of the murder, and what he was doing that evening at his estate. Many feel that investigators did not pry enough answers out of Simpson at this time; however, they claimed that Simpson was not yet under arrest, and was not even the prime suspect. They felt that they needed to be cautious because Simpson could choose to leave at any time (Jones, 2004).

Before Simpson left the police station, very important evidence was taken from him. They took his fingerprints, a photograph of his wounded hand, and a blood sample. This blood sample would turn out to play an important role in the case. The nurse that took the sample claimed to have drawn 8cc of blood from Simpson. When it was discovered later that there were only 6.5cc of blood in the vile, the defense claimed that investigators took blood to plant as evidence to incriminate Simpson (Jones, 2004).

On June 17, police arrested O.J. Simpson, and the "Trial of the Century" began on Tuesday, January 24, 1995. During the first ninety nine days of the trial, the prosecution called seventy two witnesses. The first third of the witnesses served to show that the defendant had the motive to kill, and the second third showed his opportunity to kill, the third portion showed that

Simpson did in fact use his motive and opportunity to kill his ex-wife and Ronald Goldman (Linder, 2000).

The prosecution did their job reasonably well at many points of the trial. When trying to display the violent and corrupt nature of the defendant, they called witnesses such as Nicole's sister, Denise Brown, and a friend of Simpson's, Ron Shipp. Here the courtroom was told of an abusive and possessive husband. Denise Brown told of a dinner attended by Nicole and O.J. where he grabbed Nicole by the crotch and said "This is where babies come from, and this belongs to me." She later told of an incident where he picked up Nicole and threw her against the wall. Ron Shipp told the courtroom of a time Simpson admitted to him, "I've had dreams of killing Nicole" (Linder, 2000).

Another successful witness called by the prosecution was limousine driver, Allan Park. He testified that he arrived at the Simpson residence at 10:25 p.m. the night of the murder. When there was no answer at the house, he proceeded to wait in the car. Shortly before 11:00 p.m. he saw a tall black man weighing about 200 pounds enter the house. A few moments later Simpson emerged claiming that he overslept (Linder, 2000).

The last set of useful evidence for the prosecution was DNA profiles from blood found on numerous objects. Two sets of restriction fragment length polymorphism (RFLP) tests (discussed in Chapter-1) served the prosecution well (**Figure-3**). The first was taken from blood found at the murder scene. The test showed that the sample could only have come from one out of every 170 million sources blood. This sample matched Simpson's profile. The second profile was taken from the blood-drenched socks found in Simpson's bedroom. This test concluded that the sample could only have come from one out of every 6.8 billion sources of blood and matched Nicole's DNA profile (Linder, 2000).

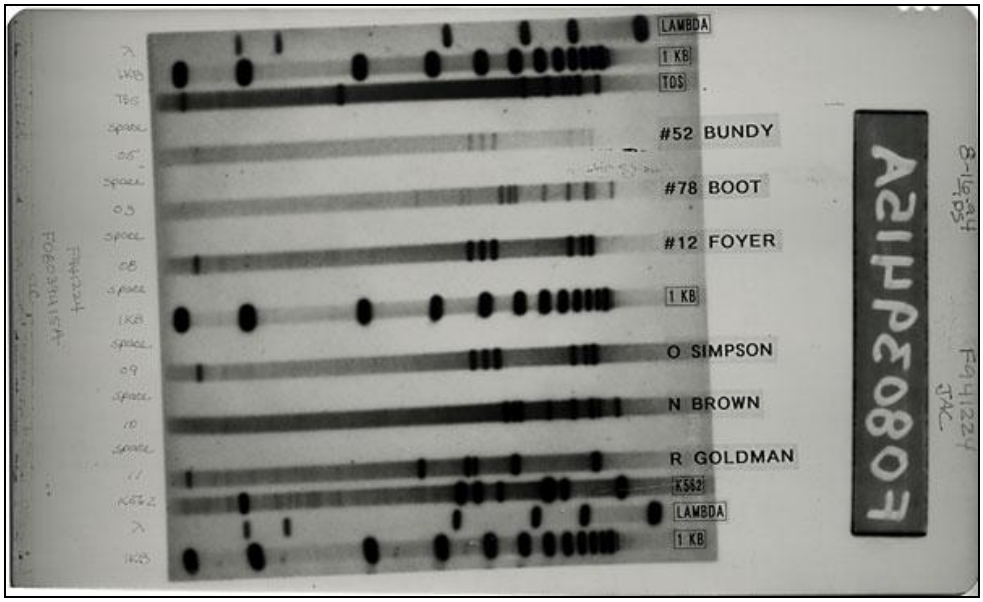

Figure-7: O.J. Trial Blood Evidence DNA Fingerprint Analysis. (National Anthropological Archives, 2002)

Although the prosecution put together a solid case in some respects, their mistakes outweighed their victories. The first mistake came before the trial even began. They decided to file the case in the downtown district instead of the district in which the crime occurred which is normal protocol. They did this to avoid the all white jury they would most likely impanel in Santa Monica, the district where the crime was committed. They feared that a conviction under these circumstances could give way to racial protests. Second, a mistake was made when the prosecution did not seek the death penalty. If they had sought the death penalty they would have received a "death-qualified" jury, which is one that excludes those whose opposition to capital punishment might prevent them from imposing a death sentence. Those that would have been excluded are typically black and female, and that exclusion would have served the prosecution well (Linder, 2000).

Detective Mark Fuhrman played a big role in the prosecution's failure. He was the detective who found the glove outside of Kato Kaelin's bungalow. When he took the stand, the defense took this opportunity to ask whether he had used the "n word" in the past ten years. They knew that he had, as they had in their possession a taped conversation of Fuhrman using that word. When Fuhrman denied using the word, the defense played the tape recording discrediting him. The defense's plan was to discredit the evidence by saying it was either contaminated, planted, or both. They used Fuhrman's alleged racism as motive for planting incriminating evidence against Simpson. In addition, the police used beginning-level technicians to handle some of the evidence, who were not properly trained in using chain of custody documentation for crime scene evidence, and this further opened the door to potential evidence tampering. And in one of the most infamous scenes in all of US trial history, to the defense's delight, the prosecution accidently assisted them in discrediting glove evidence, when in front of the judge and jury, the prosecution asked Simpson to try on the glove found at the crime scene, but the glove did not fit the defendant **(Figure-8)** (Linder, 2000).

Figure-8: O.J. Simpson Shows the Courtroom Gloves as Requested by the Prosecution. (Gardner, 2008)

When the defense took the floor, they did their best to continue to discredit all evidence presented by the prosecution. Although many say Mark Fuhrman was the key to the defense's case, forensic expert Henry Lee may have gotten Simpson the acquittal. Lee suggested that evidence in the form of shoe prints offered the possibility that there were two assailants. He also made the simple observation regarding the prosecution's DNA tests: "Something's wrong." This may not be a very technical observation, but it made a difference. Christopher Darden, the prosecution lawyer who asked Simpson to try on the gloves, stated after the case that Lee was the witness that gave the jury "permission" to acquit, which is what they wanted to do anyway (Linder, 2000). The jury took only three hours to reach the verdict to acquit (Cable News Network, 1995).

In a case where there was such an abundance of DNA evidence, the defense painted a picture where there was still was room for error. Although no proof of evidence tampering was ever provided by the defense, the defense provided a scenario of "reasonable doubt", so the mountain of forensic evidence was not enough to achieve a guilty verdict. O.J. was subsequently found liable for the two deaths in a civil trial, where the outcome is based on the "preponderance of evidence", not the "beyond all doubt" standard for criminal trials. DNA forensics played a huge role in the OJ criminal case; however it did not serve justice well. The outcome of this case was a toughening of standards for evidence handling and technician training.

Chapter-4 Conclusions

DNA plays a great role in helping solve cases, even when the crime occurred decades ago. Then and now, when crime scenes are managed correctly, and evidence is collected and

stored properly, DNA has the power to identify or exonerate suspects. As DNA forensic technology continues to grow, the accuracy of verdicts in the courtroom grows with it.

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Chapter 5: The Ethics of DNA Fingerprinting and DNA Databases

Nicholas Mercurio

Since April of 1995, DNA samples have been stored in computer databases to aid in the prosecution of criminals. The United Kingdom was the first to begin building a library of convicted criminals with their development of the United Kingdom National Database (NDNAD). By 1998, the United States began construction of their own Combined DNA Index System (CODIS), which by October 2007 contained at least 5,000,000 offender profiles, and today has over 8,332,712 offender profiles, making it the largest DNA database in the world (FBI.gov, 2010). However, with the advent of DNA databases came legal challenges about privacy concerns and potential citizens rights violations. In this chapter, we go beyond a discussion of DNA fingerprinting *technology* itself to discuss the ethics of DNA databases, as an example of the impact of DNA technology on society.

Whose Profiles Should be Entered?

In the US, individual states determine whose DNA profiles should be entered into databases (State Laws, 2010). **Table I** shows a list of the 50 states and their laws mandating DNA profiles. For example, the state of Massachusetts passed legislation on February 10, 2004, requiring all convicted felons to submit a blood sample to the Massachusetts State Police Crime Laboratory for entrance into CODIS. These felons include kidnappers, rapists, murderers, larcenists and burglars.

State	All Felonies	Some Juveniles	Some Misdemeanors	Some Arrestees	Not Guilty By Mental Defect or GBMI	Other
Alabama	X					
Alaska	X	X		X -- Violent felonies.		
Arizona	X	X		X -- Many serious felonies.		Includes residential and criminal burglary.
Arkansas	X	X -- Violent crimes only.	X -- Some sexual offenses.		X	
California	X	X		X -- Expansion to all felon arrestees starts in 2009.		Includes those convicted of terrorist activity in violation of weapons of mass destruction provisions; and those convicted of a qualifying offense in another state.
Colorado	X	X				Includes any person who has a duty to register as a sex offender, including probationers, habitual offenders as condition of parole, and those released without parole supervison.
Connecticut	X				X	Includes persons on probation or parole prior to discharge from supervision.
Delaware	X		X -- Certain child endangerment or abandonment crimes.			
Florida	X	X			X	Includes persons on probation, parole, release or supervision following conviction of certain offenses.
Georgia	X	X				Includes probationers convicted of qualifying offense.
Hawaii	X	X			X	Includes qualifying persons in prison, on probation or parole, parole violators.
Idaho		X				Most felons are included.
Illinois	X	X	X -- Any person required to register as a sex offender, includes some misdemeanors.			Includes people held under civil commitment law, those found guilty but mentally ill for a sex offense, persons seeking transfer to state under interstate compact, stalking and residential burglary.
Indiana	X					Includes qualifying offenders on probation or parole.
Iowa	X	X	X Any person required to register as a sex offender. Any criminal offenses against minors included.		X	Includes qualifying parolees and offenders on work release and offenders receiving a deferred judgment of felony.
Kansas	X	X		X -- Felony or drug grid level 1 or 2; expands after June 30, 2008 to include all persons arrested for a felony.		
Kentucky		X				Includes those convicted of unlawful transaction with a minor, promoting sexual performance of a minor, Burglary I and II and Class A and B felonies involving death or serious injury to the victim.
Louisiana	X	X		X --If funds authorized.		
Maine	X	X	(May include a lesser included offense if a qualifying offense was originally charged.)			Includes all Class A, B, C serious crimes and Class D and E convictions if the person had prior felony conviction for which DNA not collected.
Maryland	X	X	X	X -- Violent crimes, burglary and breaking and entering of a motor vehicle.		
Massachusetts	X	X				
Michigan	X	X		X -- Violent felonies.		
Minnesota	X	X	(May include offenses "arising out of same set of circumstances.")	X -- Specified serious crimes upon judicial finding of probable cause.		
Mississippi	X					
Missouri	X					
Montana	X	X				
Nebraska						
Nevada	X		X -- Failure to register as a convicted person.			
New Hampshire		X				Includes violent crimes.
New Jersey	X	X	X -- Any crime for which a sentence of imprisonment of 6 months or more is imposed.		X	
New Mexico	X	X		X -- Specific violent felonies.		
New York	X		X -- Many misdemeanors.			
North Carolina	X				X	Includes persons on community supervision.
North Dakota	X			X -- All felonies – effective 01/09.		Many serious felonies, including burglary.
Ohio	X	X	X -- Certain child victim offenses.			

Oklahoma	X					2001 law requires planning to incrementally add qualifying felonies to the database, to include all felony offenses by 2006.
Oregon	X	X				
Pennsylvania		X				Includes violent and sexual offenders.
Rhode Island	X					
South Carolina	X	X	(May be required by court order for any offense.)	X -- Violent felonies punishable by more than 5 years in prison.		Includes qualifying offenders on community supervision.
South Dakota	X	X		X -- Violent felonies punishable by more than 5 years in prison.		
Tennessee	X	X		X -- Violent felonies, upon finding of probable cause.		Includes those persons seeking transfer to the state under interstate compact who have committed qualifying offense.
Texas	X	X	(May be required by court order for any offense.)	X -- Post-indictment only in certain sex crimes.		Expanding to all felons contingent upon federal funds.
Utah	X	X	X -- Class A misdemeanors. Others may qualify if convicted on lower degree of qualifying offense.		X	Includes persons convicted in another state of a qualifying offense.
Vermont	X		(Only if as part of a plea agreement.)			
Virginia	X	X		X -- Violent felonies, including attempts.		
Washington	X	X				Includes those who have been convicted out of state or under federal law of a violent offense.
West Virginia	X					
Wisconsin	X	X	X -- Some misdemeanors for which sex offender registration is required.		X	
Wyoming	X	X				Includes all persons required to register as a sex offender.

Table-I: List of the US States and Their Requirements for Database Entries. (State Laws, 2010)

Currently, over two-thirds of US states have enacted laws requiring DNA profile submissions for burglary. And all states except four (Kentucky, Nebraska, New Hampshire, and Pennsylvania) now collect DNA samples from all *convicted* felons (State Laws, 2010). Fifteen states even require some *arrested* individuals to submit DNA; these states argue the more entries in the database the better the probability of solving crimes. However, the author of this chapter disagrees with entering all arrested individuals, for which reasons I will explain further. Massachusetts CODIS accounts for 281,446 profiles, which have aided over 2,800 investigations. These profiles act as a justice catalyst; the more DNA fingerprints on file, the easier it is to link suspects to crime scene evidence, or to link related crimes to bring the case to justice.

Database Size and Match Probabilities

One advantage of the increasing size of DNA databases is their large size allows more accurate determinations of specific allele frequencies in various populations. As discussed in Chapter-1, the current CODIS entry contains information on 13 core loci for an individual's DNA. At each locus, the fingerprint analysis determines the number of repeat sequences, either variable number of tandem repeats (VNTRs) or short tandem repeats (STRs). For example, an individual's DNA at locus-1 might have 11 repeats at that location. So we need to know how often in the population does 11 repeat sequences occur, 1 in 10, 1 in 100, 1 in 1000, etc. The larger the database, the larger the sample size for determining how frequent that genotype is in that population. And in response to earlier critisisms, the analysis has even be extended to include various ethnic groups. So for example if a suspect is hispanic, scientists now have a better idea of the frequencies of each core locus in the hispanic population relative to the total population, to make a more accurate match.

With respect to current match probabilities, scientists multiply the frequency of the genotype at each locus together to generate a total probability. Mathematicians currently believe the likelihood of two individuals (excluding identical twins) having the same CODIS profile is about one in a quintillion (1 followed by 18 zeros). However, in real court cases the DNA is sometimes partially degraded, so information may not be available for some loci, so the probability number can vary from case to case. In this case, we calculate the probability of a match with the remaining accurate loci, and in most cases it is low enough to be used in the case. As time progresses and DNA databases grow larger, our picture of allele frequencies will grow even more accurate.

Database Ethics

When debating database ethics, a few tangible arguments surface. One of the most controversial topics is medical predispositions and permanent DNA sample storage. Contrary to popular belief, the current CODIS entry for 13 core loci does not include medical predisposition data. So one cannot hack into CODIS to determine whether a convicted felon is predisposed to cancer then deny that individual medical insurance. However, it is true that further testing *beyond* the 13 core loci might reveal medical predispositions for specific diseases. For example, scientists can currently assay for cystic fibrosis, early onset Alzheimer's disease, or Tay Sachs disease through genetic testing. Although medical predisposition information does not lie within CODIS, if the original DNA sample still resides in some person's freezer, it could be further analyzed to obtain this information. So the author of this chapter argues for tight control of DNA samples, and their destruction once CODIS identifying information has been obtained. Technology has allowed us to peel back the first few layers of understanding of DNA. The chemical makeup of DNA holds information about the individual's genealogical, psychological, and medical makeup. Such information, in my opinion, is private. Who your ancestors are, where they came from, whether or not you have Attention Deficit Disorder, HIV, or other medical information, in my opinion, is private information.

Do United States privacy laws protect such information from unlawfully entering the hands of the government? "Parents in Texas sued the state health agency when they discovered that blood taken from their newborns, to be screened for genetic disorders, had been made available to scientists without the families' authorization. Some samples, they later learned, had also been provided to federal law enforcement officials for research aimed at improving the interpretation of forensic DNA evidence" (NY Times, 2010).

When a sample of DNA is donated for forensic evidence, can it later be legally subject to further testing? In the case of donated DNA, when researchers begin testing for one specific piece of information, any other information overturned must remain undisclosed unless "informed consent" is granted by the donor. In other words, if DNA is *donated* for the use of forensic testing, it can not be tested further for medical information unless the donor consents. But regulations aside, what guarantees that your DNA will not undergo further testing? Although there currently is no guarantee, a destruction of the DNA is the most reasonable solution. Thus, in order to retain scientific integrity, DNA samples obtained from felons for CODIS information should be destroyed after the DNA has been fingerprinted for that identification information.

Familial Database Searches

One of the more recent ethical and legal challenges facing US courts is familial DNA searches. Familial DNA searches allow investigators to identify imperfect DNA matches to immediate relatives. Familial searches are possible because immediate relatives are more likely to have several matching loci than two unrelated people. So for example, familial testing might allow a guilty father to be identified from an imperfect match of crime scene evidence to his son's profile in a database. This is precisely what happened recently with the solving of the "Grim Sleeper" serial murder case in Los Angeles (Miller, 2010). In this infamous case, Lonnie David Franklin Jr. aka the "Grim Sleeper" (**Figure-1**), left some forensic DNA evidence behind at several of his 10 murder scenes. Investigators profiled this DNA, and linked the murders to each other, but had no suspect. It wasn't until the Lonnie's son Christopher Franklin was incarcerated on a weapons felony conviction that the DNA left behind at the crime scenes

became useful. Using a familial DNA search, a weak match was found between the crime scene DNA and Christopher's DNA profile in the database, so it became clear the killer was closely related to Christopher. On July 7th 2010, Christopher's father Lonnie David Franklin Jr. was arrested and pleaded guilty to killing nearly a dozen women in Los Angeles over a period of 25 years.

Figure-1: Photograph of the Grim Sleeper, Lonnie David Franklin, Jr. This infamous case was recently solved by familial testing in which crimescene evidence DNA made an imperfect DNA match to Lonnie's son DNA profile. (Miller, 2010)

Although familial DNA testing opens the door to potentially solving more crimes, it also opens some serious ethical questions regarding racial discrimination, privacy, and legality. With respect to race, because more black offender profiles are entered into CODIS from convicted felons, it is more likely that black suspects will be identified in familial testing. "Race is a big issue; it's a legitimate question to address, and it's a troubling fact," Sanford University Law School professor Hank Greely said in a CNN interview. "We can talk all day long about why it is that more African-Americans are arrested, but the fact is that the database reflects that. Inevitably

that means familial DNA matching will net more African-Americans than any other group of people" (Greely, 2010).

These statements, though true, should have no influence on the decision whether to keep familial searches. The bottom line is that the entered profiles still come from convicted felons, black or not. The more important issue here touched on by Erin Murphy of the University of California, Berklee School of Law, is the subject of privacy and involuntary involvement. "We in a free society work on the premise that you have a right to go about your business without answering questions from the government unless they have a reason to suspect *you* of an offense." She then goes on to mention, "It's sending a message to the relatives of convicted people that their privacy is less valuable somehow than that of other law abiding citizens." (Murphy, 2010)

For these reasons, legislators should act quickly to regulate familial DNA searches to ensure they are carefully done, and to ensure the relative receiving the imperfect DNA match is treated fairly. Critics contest the legality of familial searches arguing a violation of the 4th amendment in that "family members aren't actually in CODIS—but they are nonetheless "reachable" through their profiled relative" (Zetter, 2010).

Chapter-5 Conclusions

The current laws in the state of Massachusetts most closely match the author of this IQP chapter for mandating DNA entries into CODIS. I believe that felons, upon committing a severe crime, should lose certain rights, including any privacy right to withhold their identity. If your own child fell victim to assault, rape, or murder would you want your son or daughter's assassin to get released from jail, and continue committing such heinous crimes? DNA profiling and

databases help reduce repeat offences, and keep criminals from living recklessly. If one cannot live a lawful life, then he should not be granted the same freedoms as the rest of us. If an individual's DNA is sampled and stored in CODIS, the criminal will think twice before committing a repeat offense. Some individuals believe that DNA fingerprinting gives state and federal authorities too much power, but after reviewing the list of current felonies that Massachusetts requires for profiling, I believe the punishment fits the crime. But the author of this chapter does not want to tip the balance too much away from privacy rights, and does not agree with states currently requiring some *arrested* individuals to provide DNA samples.

Over the last two decades, DNA databases and DNA fingerprinting have proven extremely valuable for solving crimes, however certain restrictions need to be established to control the original DNA sample once it has been obtained to prevent its use beyond CODIS analysis. As we have seen, with the development of new biological research comes knowledge of how to assay for specific medical predispositions, so the DNA sample needs to be destroyed following a successful CODIS analysis for identification purposes. On this point, legislators need to act quickly. Without restrictions on DNA testing, you could end up in some DNA database without even knowing about it, after you donate blood, get a blood sample taken at the hospital, get a throat culture, or leave a hair behind on a hospital bed pillow.

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PROJECT CONCLUSIONS

Discovered long ago in 1868, our knowledge of DNA and its power for identification has grown exponentially with advances in technology to a point where DNA may actually reveal too much information. DNA is obtainable from a person's blood, semen, saliva, urine, hair, teeth, bone, or other tissue. Since Sir Alec Jeffreys' original 1984 adaptation of earlier DNA molecular biology assays to determine personal identification, forensic scientists have harnessed DNA's information to "fingerprint" individuals. But because DNA is so intricate, for DNA fingerprint analysis, scientists only analyze 13 core locations, the entire molecule is not analyzed.

Forensic science's prevalence in the media, television, and more importantly, the courtroom, is constantly increasing. Forensic evidence, when handled properly, is a heavy hitter in the court system, and finally has the track record to prove it. In order to successfully assay genetic information from DNA, a quality sample must be taken while preventing contamination and degradation. Not all tissues are equal, skin cells from handled objects are difficult to sample with a success rate of less than 20%, while DNA samples taken from blood or semen show greater than 95% success. But such success rates don't come easily. In order to ensure uncompromised evidence in the courtroom, crime scene integrity must be followed. DNA at crime scenes can easily be contaminated. For example, a doorknob with skin cells of the victim can be wiped away instantly. To insure such crime scene integrity Greg Dagnan, Assistant Professor of Criminal Justice at Missouri Southern State University, developed the three-tiered security system, which allows organization of the entire crime scene area, while keeping unauthorized personal a safe distance away from a crime scene.

As discussed in Chapter 3, technology such as the polygraph test and DNA sequencing is not easily accepted as evidence in a courtroom. In the *Frye v. United States* case, the polygraph (lie detector) was declined because at the time (and still today) it was not "generally accepted" in the scientific community, helping to establish a general acceptance standard for admitting technological evidence. Over the years in other cases, this *Frye Standard* was modified to include DNA technology. The *People v Daubert* case helped establish a 5-prong test to be applied by a judge in a pre-trial hearing. The *Daubert Standard* includes determining the reliablity of the testing used, its error rate, and whether it was performed correctly in the trial being considered.

DNA databases are the backbone of DNA fingerprinting technology, as they store information on previous offenders (offender index) and previous crimescenes (crimescene index). Hits to these databases help determine if different crimes are related, and help identify the perpetrator if he committed a previous crime. DNA fingerprinting is a probability game, and to more accurately determine the chance of random matches (false positives), the more accurate we need to know the specific frequency of each genotype in the population. The larger the database, the more accurate we know these frequencies, including for different ethnic groups.

But for databases, one serious challenge is whose DNA should be sampled? In the US, this information is determined by individual states. Most states have decided that all *convicted* felons should be required to submit their DNA, including kidnappers, rapists, murderers, larcenists, and burglars. The authors of this project agree with the state of Massachusetts that currently requires all *convicted felons* to provide DNA samples, but not individuals *arrested* of crimes. The authors also agree with the state of Wisconsin, the only state that currently requires destruction of the original DNA sample following the assay of CODIS identifying information.

This sample destruction will prevent anyone from further analyzing the DNA beyond CODIS identifying information to obtain medical predisposition information.

DNA is an extremely powerful tool if used properly. If used improperly, it can reveal an abundance of private information about an individual. To assure the future of DNA fingerprinting in forensics, we must not abuse it.