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DNA FINGERPRINTING

An Interactive Qualifying Project Report

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ABSTRACT

This IQP analyzed DNA fingerprinting technology, including the various methods used to perform tests, and how this amazing new technology has overcome considerable opposition to make advances in the field of forensic science. The earlier chapters focus on the technical portion of the topic, describing what DNA is, how DNA fingerprints are made using different procedures, and which methods are used for collecting, storing, and processing DNA evidence. The function of DNA databases and their ethics was also investigated. The chapters on landmark court cases examined how legal precedence was established for admitting technical evidence into US courts. Finally the authors make their own conclusions about the technology based on their research.

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PROJECT OBJECTIVES

The objective of this project was to examine the technology of DNA fingerprinting, the different methods of DNA analysis, recent advances in DNA collection and storage techniques, as well as the ethical and legal aspects of using this new technology in solving cases. The secondary purpose was to explain in layman's terms why DNA fingerprinting has become the greatest forensic tool in that science's history. The discussion of landmark court cases serves as a model for how precedence was set in US courts for allowing technical information as evidence. The discussion of sensational court cases pointes to the power of the technology to solve decades old crimes. Although DNA fingerprinting is now nearly universally accepted in legal proceedings, the use of DNA databases causes ethical controversies. Overall this project will help the layman understand the science and techniques of DNA fingerprinting, investigative procedures for acquiring evidence, methods of collecting and storing DNA evidence, landmark court cases that set a precedence of admitting DNA evidence in US courts, the ethics of DNA databases, and a clearer understanding of our human genetic uniqueness.

Chapter-1: DNA Fingerprinting Technology

Archana Reddy

DNA fingerprinting is a DNA-based identification system that relies on the genetic differences among individuals or organisms. This technology has been called the greatest tool in the history of forensic science, and although it is relatively new, it has had an amazing impact on society. But as is typical of any powerful new technology, the impact on society has been complex. The aim of this chapter is to introduce you to this amazing technology of DNA fingerprinting, as a prelude to subsequent chapters documenting its effects on the U.S. legal system and on population databases.

DNA

Genetics (meaning *origin*) is the science of hereditary and variation in living organisms. The fact that living things inherit traits from their parents is common knowledge, and has been exploited since pre-historic times with ingenuity to enhance crop and animal quality through selective breeding. The modern science of genetics which seeks to understand the process of inheritance only began in the mid nineteenth century with the work of Gregor Mendel, who observed that organisms inherit traits via discrete units of inheritance, which are now called genes. The molecular basis for genes is DNA (deoxyribonucleic acid). Every cell contains DNA, a biochemical molecule found in the nucleus (nuclear DNA) and also in the mitochondria (mitochondrial DNA, mtDNA). Either type of DNA can be analyzed in DNA fingerprinting assays.

DNA contains genetic information which can be described as a blue print of life, carrying the instructions to construct cell components like protein, RNA, and other molecules necessary for cell function. In 1952, Watson and Crick discovered that the DNA structure has two sides, or strands and that these strands are twisted together like a ladder -- the double helix (**Figure-1**). The helix is composed of two polymer strands (blue in the figure), joined by "rungs on the ladder" which are paired nucleotides (shown as different colors in the figure). Human DNA is a macromolecule made up of nearly 3 billion of these nucleotides. The DNA strands contain four types of repeating nucleotides, adenine (A), thymine (T), guanine (G), and cytosine(C), which are strung together in a sequence that is unique to every individual. The sequence of these nucleotides in humans can be found in more combinations than the total number of humans on the planet. DNA typing techniques used in forensics focus on the differences between individuals for the order and type of these nucleotides (Freudenrich, 2007).

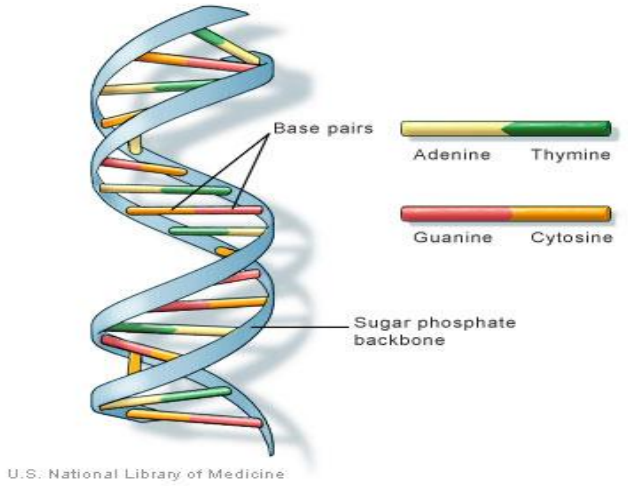

Figure-1: Diagram of the DNA Double Helix Structure. Note that the "rungs" on the ladder consist of different nucleotides (shown as different colors), and their order is different between individuals. Photo courtesy (U.S. National Library of Medicine)

Nucleotides (**Figure-2**) are composed of nitrogen bases (colors in the figure) attached to a backbone of sugar and phosphate groups (black in the figure). The bases join each other by weak hydrogen bonds (dotted lines in the figure) in between each strand to form the 'rungs' of the ladder (Freudenrich, 2007). Each base will bond only with one other type of base, Adenine with Thymine (upper basepair in the figure), and Guanine with Cytosine (lower basepair in the figure).

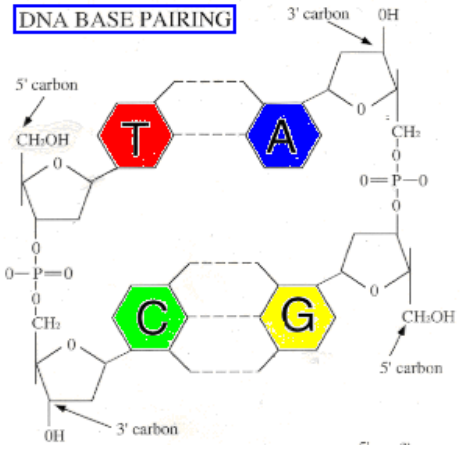

Figure-2: Diagram of DNA Base Pairs. This figure shows a closeup of the "rungs" on the ladder for DNA structure. T pairs only with A, and C with G. (DNA-101, 2009)

Thymine and cytosine are known as pyrimidines, whereas adenine and guanine are known as purines (**Figure-3**). Pyrimidine molecules form 6 cornered rings, and purines are a combination of a 5 cornered and a 6 cornered ring. Thus, purines then are much larger than pyrimidines. Two purines do not bond in a DNA strand, because they are too large, and pyrimidines do not bond with each other because they are too small. This ensures that one pyrimidine will match with one purine, and vice-versa.

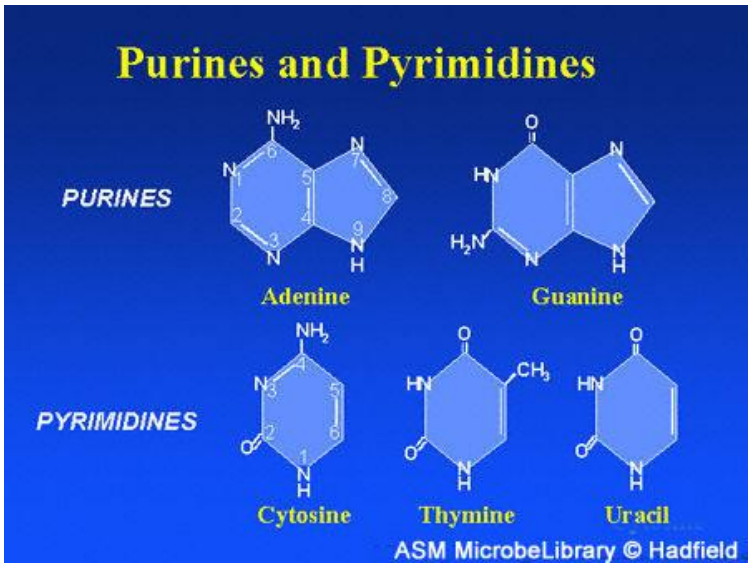

Figure-3: The Two Main Types of DNA Bases. This figure shows the chemical structures of purines (top row) and pyrimidines (bottom row). These structures help ensure that only certain types of bases pair with other specific types. (Hadfield, 2004)

The molecular structure of DNA can be best understood by imagining it as a zipper (**Figure-4**), with each tooth representing one of the 4 nucleotides (A, C, G, or T), and with the opposite teeth forming pairs of either A-T or G-C.

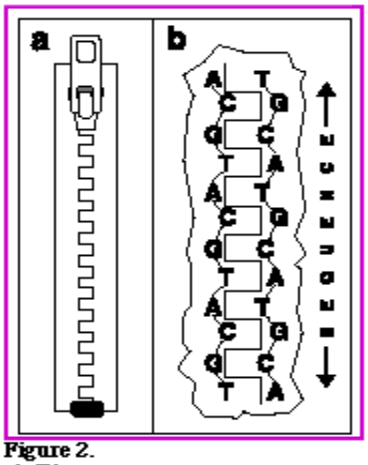

Figure 2.
a) Zipper
b) DNA

Figure-4: A Zipper Model for DNA Structure. This figure represents the two strands of a DNA molecule as two joined strands of a zipper. Such a model helps visualize DNA replication which requires the strands to separate. (Betsch, 1994)

Because the two strands in DNA are only held together by hydrogen bonds, a sufficient force, or even a high temperature, can easily unzip the DNA molecule. This feature is important

to DNA replication. Guanine and cytosine have three hydrogen bonds, while adenine and thymine have only two hydrogen bonds. Therefore, chains of DNA that have many AT pairs (each joined by only 2 hydrogen bonds) are easily unzipped, while chains that have more GC pairs (each with 3 hydrogen bonds) are harder to separate.

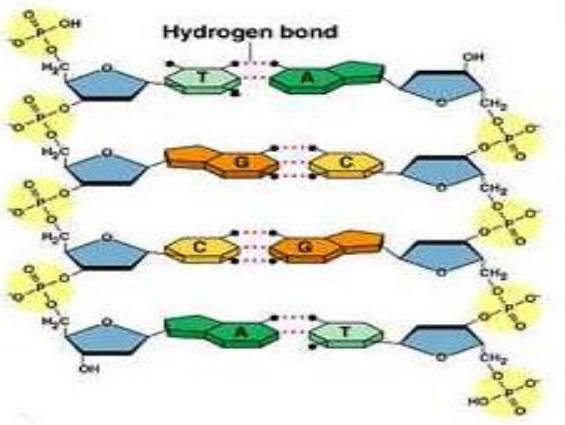

Figure-5: Hydrogen Bonding Between DNA Base Pairs. This figure shows the hydrogen bonds (H-bonds) that join the bases of two DNA strands together. GC pairs have three H-bonds, while AT pairs have only two. (Cuny.edu, 2009)

The information contained in DNA is determined primarily by the sequence of letters (nucleotides) along the zipper. For example, the sequence ACGCT represents different information than the sequence AGTCC, in the same way that the word 'POST' has a different meaning from 'STOP' or 'POTS' even though they use the same letters (Betsch, 1994). So every trait in an organism is the result of a particular DNA sequence. There are so many differences in the order of DNA base pairs, that every person on the planet has a different and unique sequence.

DNA replicates itself at the time of cell division. The amplifying type of DNA fingerprinting (which is especially well suited for analyzing small quantities of crime scene DNA) makes use of this replicating feature of DNA replication. This can be explained by using the previously mentioned zipper illustration where the DNA strands unzip, splitting the base pairs at their weak hydrogen bonds, so the two single polymer strands can serve as templates for adding new nucleotides. Each strand then adds on free floating nucleotides (A, C, T, and G) to

pair with the template base at each position. The result is two perfect copies of the original DNA molecule.

Within a cell, DNA is tightly packed and located inside the nucleus in structures called chromosomes (**Figure-6**). A piece of that DNA within the chromosome (a gene) dictates a particular trait. A gene is made up of a series of exons (coding regions) and introns (non coding regions). Exons are responsible for the instructions on how to produce a particular protein. The non-coding regions function to help regulate gene expression. The non-coding sequences are less conserved between individuals than exons, so these introns sequences, and other non-conserved sequences that *differ* between individuals, are used in DNA profiling.

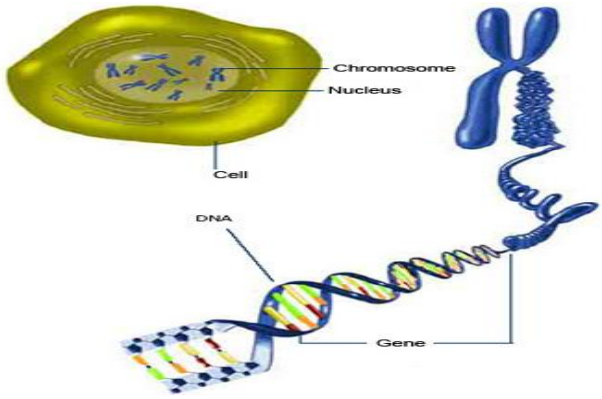

Figure-6: Chromosomes and DNA. This figure shows the nuclear location of chromosomes, and chromosome structure. Cells also contain mitochondrial DNA (not shown). (NIGMS, 2006)

A gene encodes a single genetic instruction, usually proteins, and an allele is one variant of a gene. Alleles are a way of identifying the two members of a gene pair which produce opposite contrasting phenotypes. An allele of a gene is its partner gene, for example b is an allele of B and vice versa. When alleles are identical, the individual is homozygous for that trait. If the pair is made up of 2 different alleles, the individual is heterozygous. A homozygous pair can be

either dominant (AA, BB) or recessive (aa, bb) where as heterozygous are made up of one dominant and one recessive allele (Aa, Bb). In heterozygous individuals, only one allele (the dominant) gains expression, while the other recessive allele is hidden but still present. Phenotype is the term used to describe visible expression of the trait, and the genotype is the actual gene makeup. Extensive use is made of this genetic information in the study of hereditary diseases (Library.thinkquest.com, 2009).

DNA Fingerprinting Methods

The methods for DNA fingerprinting are mainly of two types: RFLP type and the PCR-type. RFLP is non-amplifying, while PCR is amplifying.

RFLP Type Fingerprinting

Restriction fragment length polymorphism (RFLP) is a molecular biological technique used to compare differences in DNA molecules. This technique was invented in England in 1985 by Sir Alec Jeffreys (Jeffreys et., 1985a), and was first used in a courtroom for a paternity case (Jeffreys et al., 1985b). Because it was adapted from earlier reliable Southern blot techniques, it quickly became the standard technique for DNA testing. In this technique, restriction enzymes that cleave the DNA at specific sequences (depending on the enzyme used) are used to digest DNA. Because DNA sequences vary between individuals, the DNAs will contain different restriction sites, thus two different DNAs will produce different cut DNA profiles. Electrophoresis is then used to separate the strands according to their lengths.

For example, consider the strand of DNA from one individual with the sequence GCGCAAGGCGAATTCGCGC. Assume restriction enzyme EcoRI is added to the DNA.

EcoRI recognizes the DNA sequence GAATTC, and it cleaves the bond between guanine and adenine (**Figure-7**) (Lerner et al., 2006).

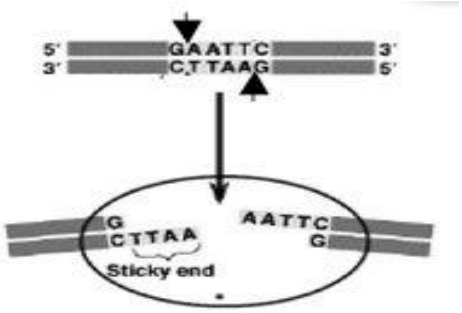

Figure-7: Cleavage of DNA by EcoRI Restriction Enzyme. This figure shows the cutting of DNA at the sequence GAATTC, to produce two fragments with AATT overhangs. (OpenWetWare, 2007)

So EcoRI treatment of the original sequence would produce two fragments GCGCAAGGCG (10 nucleotides in length) and AATTCGCGC (9 nucleotides in length). If a second individual has a different sequence GCGCAAGGCGATTTCGCCC, EcoRI would *not* cut that sequence to produce a 19 nucleotide fragment. If the resulting fragments are separated by electrophoresis (**Figure-8**), individual-1 would show shorter fragments (Lerner et al., 2006).

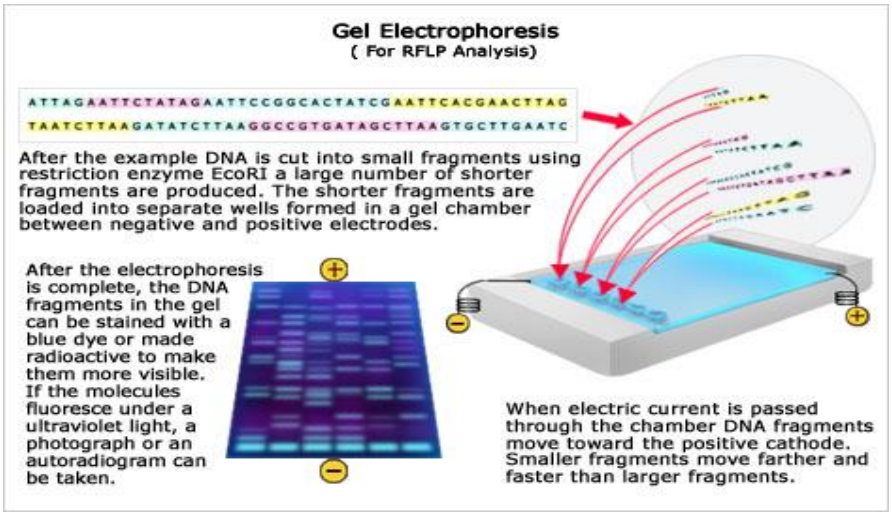

Figure-8: Electrophoresis. This technique is used to separate DNA fragments by size. DNA samples are loaded onto a gel, then an electric current is applied. Since DNA is negatively charged (due to its phosphates), DNA migrates towards the positive anode. Shorter fragments move faster than longer fragments, providing the basis of separation. (Bio.davidson.edu, 2001)

After the gel is run, the DNA is denatured to single strands by treatment with sodium hydroxide which breaks hydrogen bonds, and then the DNA is blotted to a membrane. This blotting process maintains the original separation pattern (profile) of the DNA fragments, while allowing hybridization probes to be added to label specific fragments of interest. The probes bind to complementary DNA sequences present in specific fragments on the membrane. Probes usually are radioactive or contain fluorescent tags, to allow their position to be determined. The position of the hybridized probe on the membrane is then located using x-ray film, which changes color in the presence of radioactivity or fluorescence. The locations of the fragments of DNA show up on the film as dark bands (**Figure-9**). Different samples can be loaded onto the gel in different lanes so that the banding patterns can be compared side by side.

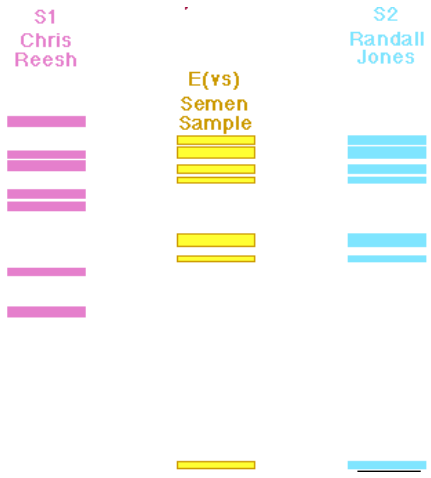

Figure-9: Example of an RFLP Type DNA Fingerprint Analysis. RFLP analysis of a semen sample collected from a raped woman (yellow) versus blood samples of two suspects (left and right lanes). Note that the crime scene DNA matches the suspect on the right. (Bio.davidson.edu, 2003)

RFLP analysis has been an important tool in genome mapping, locating genetic disease genes, forensic fingerprinting, and paternity testing. The advantage of this technique is it is relatively immune to DNA contamination. However, it requires a relatively large amount of sample DNA, and the combined process of probe labeling, DNA fragmentation, electrophoresis, blotting, hybridization, washing, and autoradiography can take a week to complete. The amplifying method or PCR method of DNA fingerprinting is currently preferred because of the above mentioned reasons (Bio.davidson.edu, 2001).

PCR Type Fingerprinting

The other main type of DNA profiling is the polymerase chain reaction (PCR) technique. This method was developed in 1983 by Kary Mullis (formerly of the Cetus Corporation) for establishing hereditary authentication, and it won a Nobel Prize in 1993. PCR analysis amplifies portions of DNA molecules using very small amounts of DNA template, generating millions of copies in an hour. This method uses a thermocycler (**Figure-10**) to place a DNA sample at different temperatures for specified time periods. The thermocycler is programmed to run through cycles of repeated heating (which denatures the DNA), and cooling (which allows primers to anneal, and DNA replication to occur). Primers complementary to DNA regions of anneal to the DNA during the cooling periods to act as sites of DNA replication. Two primers (sense and antisense) flank the region of interest, so the amplified DNA lies between the primer sites.

Figure-10: Picture of a Thermocycler Used for PCR. This machine is used to cycle DNA samples between alternative periods of heating (to denature DNA strands) and cooling (to allow primers to anneal to the DNA, facilitating DNA replication). This process rapidly amplifies portions of DNA between the primers, allowing DNA profiling at specific forensic loci. (Rice, 2006)

A PCR vial contains all the necessary components for DNA duplication: a piece of template DNA, large quantities of the four nucleotides, large quantities of the two primer sequences, and Taq DNA polymerase. The polymerase is the Taq polymerase, named for *Thermus aquaticus*, from which it was isolated at high temperature vents on the ocean floor. The enzyme is stable at high temperatures, so it remains active throughout the thermocycling process. The three parts of PCR (**Figure-11**) are performed in the same vial, but at different temperatures. The first part of the process separates the two DNA chains in the double helix. This is done by heating the vial to 90°C for 30 seconds. But the primers cannot bind to the DNA at such a high temperature, so the vial is then cooled to 55°C. At this cooler temperature the primers bind or 'anneal' to the ends of the DNA strands. This takes about 20 seconds. The final step of the reaction is to make a complete copy of the templates. The temperature of the vial is raised to 72°C. This is the optimal temperature of Taq polymerase, and the enzyme rapidly begins adding

nucleotides to the primer to eventually make a complementary copy of the templates. If the template contains an A nucleotide, the enzyme adds a T nucleotide to the growing strand. If the template contains a G, it adds a C to the new chain, and so on, to the end of the DNA template. This completes one PCR cycle. One cycle takes less than two minutes, and each piece of DNA in the vial has been duplicated. The cycle is then repeated 30 or more times, with each newly synthesized DNA acting as a new template. After 30 cycles, 1 billion copies of a single piece of DNA can be produced! Taking into account the time it takes to change the temperature of the reaction vial, 1 million copies can be ready in about 3 hours (Access Excellence, 1992).

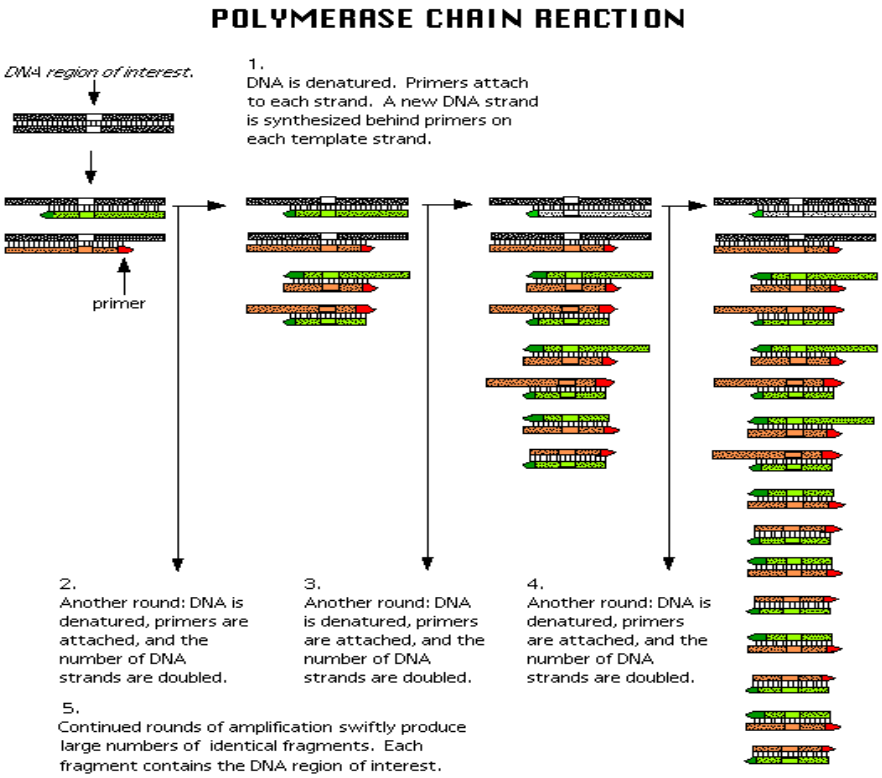

Figure-11: Diagram of PCR. This figure shows the PCR process of DNA amplification. Note that at the end of the process (diagram lower right), only the DNA between the two primers has been amplified. (Access Excellence, 1992)

The advantage of the PCR technique (especially as applied to STRs, see below) is that it is fast, and can analyze trace amounts of DNA, including DNA from a single cell. The disadvantage is it is sensitive to DNA contamination. Because of its ease of use and speed, today most labs run PCR based assays first, then if enough DNA sample is present or contamination is suspected, an RFLP type analysis is run.

AmpFLP PCR

A new technique has been devised that uses components of both RFLP and PCR, termed amplified fragment length polymorphism polymerase chain reaction (AFLP–PCR), a relatively cheap, easy, fast, and reliable method to generate hundreds of informative genetic markers. It relies on variable number tandem repeat (VNTR) polymorphisms (see below) to distinguish various alleles, which are separated on polyacrylamide gels using an allelic ladder. Amplified bands can be rapidly visualized by silver staining the gel. As with all PCR based methods, highly degraded or very small amounts of DNA may cause allelic dropout (false negatives for certain alleles), and because the analysis is done on a gel, very high number of repeats may bunch together at the top of the gel, making it difficult to resolve individual loci. Because of their high replicability and ease of use, AFLP markers have emerged as a major new type of genetic marker with broad application in systematics, pathotyping, population genetics, DNA fingerprinting and quantitative trait loci (QTL) mapping (Mueller and Wolfenbarger, 1999).

STR Analysis

The short tandem repeat (STR) methodology is based on the features of PCR, as these regions of DNA are short enough to analyze by PCR. STRs are regions in DNA that are relatively short, and contain nucleotide patterns repeat within the locus. STR analyses visualize how many times a pattern repeats itself at a particular location. The more repeats, the longer the PCR band amplified. The most common form of STR typing uses laser-induced fluorescence detection of dye- labeled polymerase chain reaction (PCR) products following capillary electrophoresis (CE) size-based separation. These STR loci are targeted with sequence specific primers conjugated to fluorescent markers, and are amplified using PCR. The DNA fragments that result are separated by capillary electrophoresis, and directly visualized by fluorescence.

The polymorphisms displayed at each STR region can by themselves be common, typically each polymorphism will be shared by 5-20% of individuals, thus several different STR loci are analyzed to produce a thorough analysis. The current FBI-approved procedure for submitting a DNA sample into the CODIS database includes 13 core loci (**Figure-12**). This rapid analysis can be used for paternity testing, missing persons identification, and disaster investigations. When looking at multiple loci, it is the unique *combination* of allele frequencies that makes this method highly discriminating as an identification tool (Butler, 2004). The thirteen core loci used in CODIS analyze STRs that involve repeats of about 4 base pairs (Farkas, 2004).

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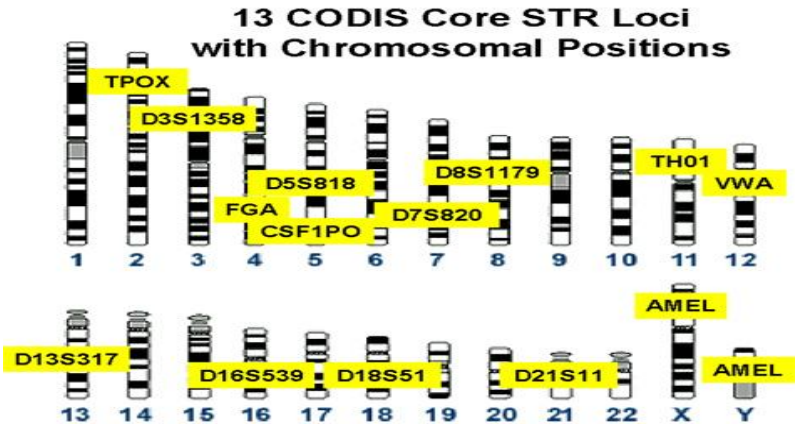

Figure-12: The Current Standard 13 Core Loci for STR Analysis. This figure shows the 13 core loci representing the current standard DNA STR analysis. Also shown on the right are two additional loci used for sex determination. (Chemical Science, 2009)

VNTR Analysis

A variable number tandem repeats (VNTR) locus is a short nucleotide sequence organized as a tandem repeat in the genome. These loci are found on many different chromosomes, and show variations in length between individuals. Each variant acts as an inherited allele and can be used for personal or parental identification. There are two main families of VNTRs: microsatellites and minisatellites. The former are repeats of sequences less than 5 base pairs in length, while the latter involve longer blocks. VNTRs with very short repeat blocks may be unstable di-nucleotide repeats, and may vary from one tissue to another within an individual so are unsuitable for forensic testing, while the longer tri-nucleotide repeats have been of great use to forensics (Chantler, 2004).

SNPs

Sometimes DNA samples differ by a single nucleotide at a locus, not by the length of repeating domains. A Single Nucleotide Polymorphism (SNP) is a small single base change at a specific location. For instance AAGCCTA to AAGCTTA contains a difference in a single nucleotide (underlined), in this case we say that there are two alleles C and T. Most common SNPs have only two alleles. Quite often, SNPs involve cytosine being replaced with thymine (as shown in the example). SNPs do not seem to alter major functions of the genome, but may greatly affect how people respond different diseases and medications. Hybridization of complementary DNA probes is a common method to examine SNPs. In this method, if the DNA sequence does not hybridize to the probe under stringent conditions the sequence likely has a SNP relative to the probe. Melting point temperatures are used in other methods to breakup mismatched nucleotides in the probe relative to the template DNA. PCR is sometimes used along with probe hybridization methods (Just the Facts, 2007).

Mitochondrial DNA Testing

Mitochondrial DNA (mtDNA) is located in the mitochondria of our cells. This type of DNA is passed on from mother to offspring without much variation, and is useful in the study of family lines through female members. Most cells contain many mitochondria, but only one nucleus. So mtDNA is often present at a crime scene sample even if nuclear DNA is not. mtDNA analysis is sometimes used when analyzing old material like hair and bones that no longer have cells with intact nuclei, but contain mitochondria (Powell, 2009).

Y-Chromosome Analysis

This type of analysis is often made use of when testing for the parentage of male offspring. The Y chromosome is passed directly from father to son, so analyzing DNA sequences on this gene can determine relatedness, and can help discriminate between various male DNA samples (Powell, 2009).

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Chapter-2: DNA Forensics

Khushbu Patel

In 1985, British geneticist Sir Alec Jeffery, developed a technique to perform a human identity test which would eventually transform the field of forensic science. The test, discussed in chapter-1, is known as a restriction fragment length polymorphism (RFLP) assay, and was based on earlier assays by Edward Southern (Southern blots) to identify specific DNA fragments in a mixture. The test allows a visualization of the differences between DNA samples, and has enormous applications in forensics (Burns, 2006). The fact that no two person's DNA are the same, other than identical twins, makes DNA evidence a powerful crime solving tool. It is difficult for a criminal to be at a crime scene and not leave some DNA, and once left, its sequence cannot be altered. DNA collected from a crime scene can either link a suspect to the evidence, or eliminate a suspect. It can be a key to solving a residential burglary, sexual assault, or murder case. It also can be the evidence that can link different crime scenes to each other. The investigation begins at the crime scene where evidence is collected, preserved, and documented. These are very crucial steps in an investigation, as the rest of the proceedings rely on their being correctly performed. Since 1985, our knowledge has grown considerably in this area of evidence handling, and the purpose of this chapter is to discuss some of this key information.

DNA Evidence Collection

Evidence is defined as all the means by which any alleged matter of fact whose truth is investigated at judicial trial is established or disproved. So, where do investigators look for

DNA evidence, which is invisible to naked eyes? DNA evidence can be collected from virtually anywhere. It can be from saliva on cigarette butts, postage stamps, a single hair, or blood stains at the crime scene. Samples that are not suitable for DNA isolation based on current technology include: embalmed bodies (with the possible exception of bone or plucked hairs), pathology or fetal tissue samples that have been immersed in formaldehyde or formalin for more than a few hours (with the notable exception of pathology paraffin blocks and slides), and urine stains.

Recognizing and locating the different types of biological evidence is not a simple task. It requires strong observation skills to find small evidence like hair, nail scrapings, and blood stains. Using traditional methods, it can be a very tough job and lots of evidence can be lost. To prevent the loss of evidence, investigators can use a forensic light source. As body fluids are naturally fluorescent, they will glow under UV light illumination. This makes it easy to locate a tiny stain of fluid on carpet, wall, or floor at a crime scene (**Figure-1**). A tiny piece of hair in a carpet will glow under the light too so it makes it easier for investigator to locate it to collect more evidence (Yvon , 2009).

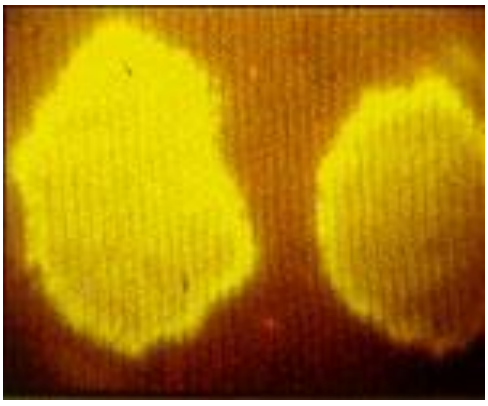

Figure 1: Photograph of a Blood Stain Under Ultraviolet Light Illumination. (Yvon, 2009)

It is very important for an investigator to be very careful while collecting DNA evidence to avoid contamination of evidence. Investigators should always wear Personal Protective Equipment (PPE), as a single hair or drop of sweat from the investigator can leave a sample of

DNA at the crime scene. Cross contamination can be avoided by changing gloves and forceps after collecting every sample. Investigators should also be very careful while collecting them as poor specimen quality can result in degraded DNA which is potentially difficult to analyze.

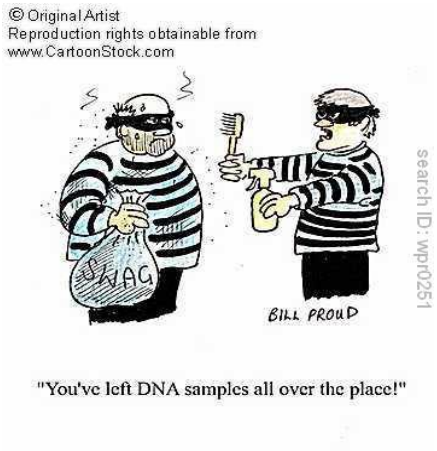

Figure 2: DNA is Easily Left at Crime Scenes. (Proud, 2009)

Several different methods can be used in collecting DNA samples. One of the most commonly used practices is *swabbing*. This method comes in handy when a body fluid like a blood stain on a floor needs to be submitted to the lab for testing. Cotton swabs or cotton tip swabs are preferable while collecting the samples. The process is very simple, first moisten the cotton swab using clean water, and swab the stain. Air-dry it, package it in a paper container, and store it carefully. Try to avoid any sort of cross-contamination during this process.

Another method of evidence collecting is the *tape lift*. This method is used to collect a *dried* blood sample. Evidence can be collected using conventional fingerprint tape from a non porous surface, and should be placed sticky side down on white clean taping paper, and stored in a separate envelope (Kramer, 2002). **Table 1** shows different ways of collecting DNA evidence from a variety of samples.

Evidence		Collection Method	Risk	Special Consideration
Type	From			
Semen and seminal stains	On fabric	Allow any stains to air dry. If damp, allow fabric to dry completely before packaging. Wrap in paper and place in paper, not plastic, bag. Label and package each stained item separately		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. Samples should be stored refrigerated. Do not freeze samples as freezing and thawing can rupture sperm cells.	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. Reasonable attempts should be made to take evidence from all viable suspects (including family, friends, etc.). 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 or not completely dry	Hang articles in a room with adequate ventilation and allow to air dry. Label, roll in paper,		Handle fabrics as little as possible.

		then store in brown paper bag or box; seal and label container.		
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.
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.			

Table 1: Common Procedures and Considerations When Collecting and Storing DNA Evidence. (Turner et al., 2002)

Control samples are equally important when collecting evidence, because when the DNA analysis starts the controls are compared to the suspect evidence to show that no contamination of test solutions has occurred. It is impossible nowadays to conduct investigation without control samples. The controls must be collected with same caution as all other evidence. For instance investigator should use the same water for the control and the suspect evidence in the swab

method. This requires the investigator to be alert and use commonsense (Kramer, 2002).

Collected evidence is sent to a laboratory for testing. **Table 2** shows the main locations where law enforcement agencies currently send DNA evidence for testing. The vast majority (80.1%) are sent to sate laboratories.

Location to Which DNA Evidence is Sent	Law Enforcement Agencies Responding (%)
State Agency Laboratory	80.1
FBI Laboratory	1.1
Private Laboratory/Commercial Laboratory	2.9
Local Agency Laboratory	11.7
Other (regional, medical examiner, county)	4.2

Table-2: Primary Locations Where Law Enforcement Agencies Send DNA Evidence for Testing. (Lovrich et al., 2003)

Storing DNA Evidence

After collecting DNA evidence, its proper storage is also very important. Most of the evidence should be collected in clean, unused paper containers to prevent the contamination by other evidence. It is ideal to use paper containers since paper breathes, which allows the item of evidence to remain dry. Plastic containers should never be used, as plastic bags will retain damaging moisture. Each container should have the collecting person's initials, the date and time the evidence was collected, a complete description of the evidence and where it was found, the investigating agency's name, and the file number. It is very important to maintain a chain of custody to avoid the possibility of evidence tampering. The collected evidence should be properly stored to avoid DNA damage. Direct sunlight and warmer conditions may be harmful to evidence. Officers collecting evidence should be careful to not put evidence in a room or police car without air-conditioning. The evidence should be stored in laboratory conditions only

(in cool, dry climate, free of moisture), and sent to a laboratory as soon as possible. If stored in these conditions, all the samples collected could be kept for five years and safely retain their viability. A frozen sample should last indefinitely. **Table 3** shows a summary of the main ways for storing DNA evidence. Most (79%) are stored in centralized storage areas in local police stations prior to being sent for analysis.

Storage Issue for Local Law Enforcement Agencies	Law Enforcement Agencies Responding (%)
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

Table 3: Storage Locations for Unanalyzed Evidence. The table summarizes where DNA evidence is usually stored prior to DNA analysis. (Lovrich et al., 2003)

DNA Analysis

Once all the evidence has been collected, stored, and sent to a lab for analysis, the real research can begin. As discussed in chapter-1, DNA analysis can include: restriction fragment length polymorphism (RFLP) analysis, polymerase chain reaction (PCR) analysis, short tandem repeat (STR) analysis, mitochondrial DNA analysis, and Y-chromosome analysis (DNA Forensics, 2002). Most DNA results today are stored on a DNA database, which makes it easier to manipulate and locate matches. The world's largest DNA database is the US FBI database called CODIS (Combined DNA Index System), which is a system of connected local, state, and federal databases that help solve crimes by containing the DNA profiles of convicted criminals and crime scene evidence. This topic will be discussed in more detail in Chapter-5.

DNA analysis takes a lot of time. Shown in **Table 4** is the average analysis time and

output for local and state laboratories in U.S. The average analysis time is about 6 months for regular non-priority samples.

Laboratory Type	Ave. Analysis Time (Weeks)	Avg. Annual Output Capacity
Local Laboratories	30.0	771.4
State Laboratories	23.9	1,284.5

Table 4: Average Analysis Time and Output Capacity for State and Local Crime Laboratories. Note: Average analysis time is based on a non-priority, none rape sample. Average annual capacity is measured in samples per year. (Lovrich et al., 2003)

Basic Considerations

There is a lot of equipment brought to a crime scene. Each tool possesses the capabilities needed to help the investigator remain organized and in control. Having control and organization over a crime scene is necessary. All professionals are responsible for making sure to use all tools properly, change gloves frequently, and to not reuse the same equipment multiple times. Some of the most common devices used are the ones used for packaging, barrier tape, tweezers, scalpels, swabs, tape, and others. The crime scene barrier tape is used to make sure all civilians stay away from the crime scene to help ensure that the evidence is not tampered with. This is one of the first measures taken to prevent contamination. To safely package the evidence, the investigators make sure not to physically touch the scene without gloves on. This prevents contamination of the evidence by the investigator. It is very important to prevent the contamination or alteration of the evidence because it weakens a case. To avoid such predicaments the professionals use tweezers, swabs, scalpels, gloves, and anything to help extract the evidence without leaving behind their own DNA. Once they have hold of the material they sought, they place it into bags, containers, and tubes.

A proper chain of custody must be followed to avoid later allegations of misconduct. A chain of custody refers to a chronological documentation showing the seizure, custody, control, transfer, analysis, and disposition of evidence, physical or electronic. Documentation is of great importance and a requirement. All discoveries have to be documented, if anyone came into contact with the object it has to be noted, and this helps the investigation progress easier. Having notes on all actions and procedures is important because it can help clear up later misunderstandings with cross contamination, or help an investigator remember what they had seen and experienced. It's also helpful for anyone reviewing a case to know everything that had happened at a crime scene during collection.

DNA Analysis in Crime Solving

The first application of DNA testing to a crime case came one year after RFLP analysis was invented. In 1986, Dr. Alec Jeffrey of Leicester University in England (**Figure-3**) was asked by police to perform his new DNA analysis on a suspect to two rape-murders in the England midlands. A local kitchen porter became the first person in the world to have his innocence proven by DNA testing on November 21, 1986, as his DNA profile did not match DNA from the crime scene evidence. Police started collecting blood samples from other men in the location, but they too tested negative. The police had no further leads until a woman in a bar reported she overheard a man bragging he gave blood for Colin Pitchfork. When the police tested Pitchfork's DNA, a match occurred to both rape/murders, making Pitchfork the first person convicted of a crime on the basis of DNA evidence (Pitchfork, 2007).

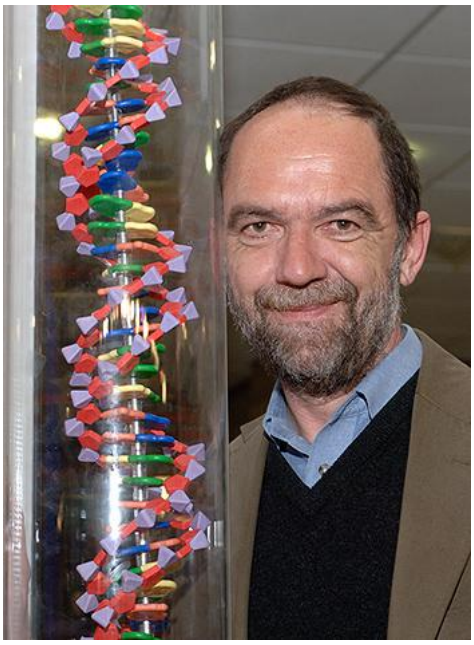

Figure 3: Photograph of Sir Alec Jeffreys.
(University of Huddersfield welcomes 'Father' of DNA fingerprinting to give public lecture**)**

Thanks to DNA forensics, crimes are being solved more easily and at a faster rate. Crimes can even be solved when no other evidence exists except DNA. Statistics show that for every 4438 profiles uploaded into the CODIS DNA database there are 846 cold hits (Cold Hit Statistics, 2009). In 1996, DNA was used in more than 17,000 court cases. But even though DNA analysis has solved lots of cases, there are still lots of cases to be solved. As of January 1, 2002, there were at least 49,000 unsolved murder cases, and 470,000 unsolved rape cases in the U.S. (Lovrich et al., 2003). And crime labs cannot keep up with all the incoming DNA evidence, so there is a sample backlog. The federal government needs to approve the creation of more testing labs, and provide money to train professionals to test the evidence to allow more crimes to be solved.

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Chapter-3: Landmark DNA Court Cases

Jerome Kirkland

Whether it is to prove an individual's guilt or innocence, "science has assumed an increasingly important and powerful role in the decision making process of our judicial branch" (Biancamano, 1996). Ever since the first onset of DNA evidence in the courtroom, this powerful technology has gone through trials and tribulations of becoming the cornerstone for physical evidence. DNA profiling was initially seen as "an infallible tool for putting criminals behind bars as it could pinpoint and narrow down matching a suspect to a crime at an extremely high probability" (Shellem, 2003). However, the technology initially was not standardized or properly controlled, and the probabilities of a random match were not accurately known. So the path for DNA becoming the gold standard of physical evidence was not straightforward, and a discussion of its landmark court cases teaches important points about the acceptance of complex technological information into the courts. This chapter aims to examine the standards brought about by key cases involving the admittance of DNA evidence and techniques. Not all of the cases mentioned in this chapter involve DNA, but they did set precedence and institute new and/or amended guidelines for how technical DNA evidence will be utilized in determining the outcome of a case.

Frye v. United States, 1923

In 1920, it was alleged that James Alphonzo Frye had murdered a wealthy physician, named Dr. Robert Brown, in his office. Although Frye had been seen shooting Brown by another physician, the police had no idea who the killer was because the witness did not know

Frye. Seven months later, Frye committed an armed robbery and was arrested. Upon questioning by the police of the robbery, Frye confessed to both the robbery and the murder of Doctor Brown (Fisher, 2008). After receiving counseling from his court appointed attorney, Frye later retracted his earlier confession, and created an alibi that he had been visiting his girlfriend at the time.

The murder trial began in 1922 in Washington D.C. Prior to the trial, the inventor of a then new deception test (today more commonly known as a polygraph or lie detector test) William Marston, of Harvard University was called by the defense to administer the test to Frye.

> *At the time this was a primitive method that involved nothing more than a standard medical blood pressure cuff and a physician's stethoscope. After each question put to Frye, Marston simply took his blood pressure. Compared to other tests at the time, Marston's test was crude and unreliable* (Fisher, 2008).

Following his tests on Frye, Marston concluded that Frye was innocent and that his confession to the murder was a lie from the start. But the court refused to let Frye enter the evidence of the polygraph test, arguing the test was not *generally accepted* in the scientific community, so the court did not allow him to introduce an expert witness to testify about the test. Without this evidence Frye did not have much of a defense, and within hours of deliberation the jury found him guilty. James Frye was not found guilty for murder in the first degree which would have condemned him to death, but was found guilty for murder in the second degree which was punishable by a life sentence. In hindsight it is believed that since the argument over the admissibility of the deception test was in front of the jury that, "no jury could help being influenced by the knowledge that Frye's test had been proved truthful by the lie detector" (Marston, 1938).

In 1923, James Frye and his attorney appealed his conviction for second degree murder on the grounds that he was not granted permission to admit the lie detector evidence. Frye argued that:

> *Systolic blood pressure rose in a predictable curve when a subject was being deceptive and afraid that the falsehood could be detected. The curve, maintained Frye, corresponded "exactly to the struggle going on in the subject's mind, between fear and attempted control of that fear, as the examination touches the vital points in respect of which he is attempting to deceive the examiner* (Law Library, 2009).

However the court asserted that, "blood pressure is influenced by change in the emotions of the witness and that the systolic blood pressure rises are brought about by nervous impulses sent to the sympathetic branch of the autonomic nervous system" (Law Library, 2009), implying that a person's own emotions could control his own blood pressure, not just his guilt or innocence. Frye insisted that the deception test could be explained by a witness who was an expert in the field, but the court rejected this with these now-famous words:

> *Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the 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 gained* ***general acceptance*** *in the particular field in which it belongs (Frye v. United States, 1923).*

The impact of this case was monumental in that the *general acceptance* criterion was used for decades by other court cases to follow as guidelines. What would eventually become known as the *Frye Standard* or *Frye Rule* set the bar to determine whether evidence had a valid scientific basis, and whether the relevant community which surrounds the scientific technique generally accepts the technique. However, the Frye standard was not perfect, it was difficult to

achieve it with real court cases. "Whether the practice or procedure was generally accepted by the scientific community would eventually become too difficult for the courts to manage as the scientific community expanded" (Law Library, 2009), thus a more lenient standard surfaced in 1975.

Federal Rules of Evidence 702 (Rule 702), 1975

In 1975, Congress approved a proposal drafted by the Supreme Court a decade prior. The rules of evidence for federal courts previously created by an advisory committee would later officially become the *Federal Rules of Evidence* or *Rule 702*. Before these rules were in place, federal courts had relied on common law practices and precedence set by preceding cases. In accordance with testimony by an expert witness, *Rule 702* mandates that:

> *If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of* ***reliable*** *principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case (Rule 702, 2000).*

This new rule helped lighten the more strict and difficult to abide by Frye Standard. Under Rule 702, even if the evidence is not generally accepted by the scientific community in which it belongs, the judge may still admit evidence if it is found to be *reliable and useful* by the jury in determining the outcome of the case. With Rule 702 in effect, courtrooms willingly adopted its more lenient and forgiving standards, as opposed to the stringent requirements of the Frye Standard.

It later turned out that the 1975 *Rule 702* played a key role in the evolution of DNA fingerprinting techniques in the 1980's. Had it not been for *Rule 702*, then the *Frye Standard* and its general acceptance approach would not have allowed DNA to enter the courtroom. The relative swift acceptance of DNA evidence as we know it today can be heavily attributed to *Rule 702*.

Colin Pitchfork, 1986

The technique for creating DNA profiles was "invented" by Dr. Alec Jeffreys of Leicester University in England, as a logical application of the previously invented molecular biology Southern blot assay. Dr. Jeffreys, and two other fellow doctors published the first paper on DNA profiling in forensic science. Equally important, they were the first to demonstrate that DNA could be obtained from crime scene stains (Forensic Science Service, 2007).

Coincidentally, the first DNA profiling conviction in history took place in the small town of Narborough in Leicester, England, where "two schoolgirls were murdered in 1983 and 1986. This murder sparked a hunt that was only to be resolved by an intelligence-led screen, eventually leading to the conviction of a local man - Colin Pitchfork" (Forensic Science Service, 2007). In 1983, Lynda Mann, a fifteen year old girl was found raped and murdered. A semen sample was taken from her body and it was determined that it belonged to a person with type A blood group, and an enzyme profile, which matched ten percent of the adult male population (Forensic Science Service, 2007). The Mann case would eventually turn cold, as there were no other leads at the time.

Unfortunately, three years later another body of a 15 year old girl, named Dawn Ashworth, was found strangled and sexually assaulted in the same town. Semen samples recovered from Dawn's body revealed the same blood type and enzyme characteristics as that of

Lynda (Forensic Science Service, 2007). Therefore police were convinced the same person had committed both murders.

A prime suspect, John Buckland, was apprehended by the police. Upon questioning, Buckland revealed details about Dawn Ashworth's case that had not been released to the public. Further questioning would lead to a confession by Buckland for Dawn's murder; however he denied any participation in the death of Lynda Mann. Using the new DNA techniques provided by Jeffreys and his partners, they compared semen samples from both murders against a blood sample from Buckland. The testing concluded that a match did not exist between Buckland's samples and the samples recovered from the bodies of the two girls, and therefore the charges against him were dropped. Thus, in hindsight, the first court application of DNA profiling was to grant a man's innocence rather than to prove ones guilt.

In an effort to capture the real murderer, the police decided to undertake the world's first DNA intelligence-led screen, in which they had five thousand men volunteer and provide blood or saliva samples (Forensic Science Service, 2007). DNA profiling was performed, but initially there was no match. However, a male was overheard in a bar claiming that he had taken the blood test for his friend, Colin Pitchfork, in an effort to conceal his identity. Pitchfork would later be arrested, and his DNA matched both murders. With the evidence stacked against him, Pitchfork confessed to the murders, so the case never actually made it to trial. He was sentenced to life in prison for his heinous acts. The Pitchfork case was so influential because it was the first time in history in which a conviction was made based on DNA evidence, and the first time a man was exonerated of a crime due to DNA evidence.

Andrews v. Florida, 1988

After hitting groundbreaking strides in the legal system in England, it was now time for DNA evidence to impact the legal system in the US. In 1988 this occurred in Orlando, Florida following a string of rape incidents in which a man named Tommy Lee Andrews was arrested, charged, convicted, and sentenced to 22 years for one of the rapes. Investigators wondered if there was a connection between all of the rapes, and looked to utilize DNA evidence to determine if the same perpetrator committed each rape. DNA profiling was performed on crime scene samples, and it was shown that the women in each rape were a victim of the same man. Once this was determined, samples of DNA from the victims were compared to DNA taken from Andrews, and they matched, so Andrews was charged for all of the rapes.

In order for the charges to uphold in court, and because the DNA methods used were a fairly new technique, a pretrial hearing was called to determine if the evidence was valid and *reliable* enough to be admitted into the courtroom. Using the *Rule 702* standard for *reliability*, and a Downing case for *relevancy* (not discussed here), after a long and arduous pretrial hearing, the judge ruled that the DNA evidence was admissible, setting a huge precedence for admitting DNA evidence in the U.S. court system. Andrews was convicted on all counts, and instead of facing what was initially a 22 year sentence, he would now be in prison for 115 years. DNA evidence acceptance was off to a fast start in the U.S., but this would only last one year.

People v. Castro, 1989

Although the *Andrews v. Florida* case of 1988 proved to be a success for the admittance of DNA in the U.S. legal system, DNA technology was still in its infancy. Just one year later in 1989, the *People v. Castro* case would put DNA evidence to an ultimate test. Joseph Castro, a thirty-eight year old Hispanic, was accused of murdering his pregnant neighbor, twenty-year old

Vilma Ponce, and her two-year old daughter (*People v. Castro*, 1989). A bloodstain discovered on Castro's watch was concluded to match the DNA of the victims.

Overlooking the ruling of the Andrews case a year prior, which was based on the *Rule 702* reliability standard and the Downing relevancy standard, the New York Supreme Court decided to further investigate the admissibility of DNA testing in the Castro case. During a pretrial hearing that lasted 12 weeks, and contained expert testimony that was exhaustively considered, the presiding judge eventually established a three prong approach test to outline the procedures necessary for the acceptable admittance of DNA evidence. The test said that DNA evidence would be admissible with affirmative answers to the following:

1. Is there a generally accepted scientific theory stating that DNA testing can be reliable?
2. Do techniques exist that can produce reliable DNA results?
3. Did the testing lab perform these accepted DNA tests in this trial?

In August of 1989, the court ruled that in the case of *People v. Castro* only the first two criteria were met. The third criteria failed to be met because Lifecodes Corporation did not use generally accepted scientific techniques for obtaining their results (*People v. Castro*, 1989). If it had not been for Castro's confession, the DNA evidence against him would not have made its way into the courtroom.

The three prong test resulting from the Castro case would serve as a standard for other cases using DNA evidence. It called for the need for more thorough, accurate, and careful DNA testing. Shortly after the case, the U.S. Federal Bureau of Investigation (FBI) created the "Technical Working Group on DNA Analysis Methods" (TWGDAM) charged with preparing guidelines that were more defined and universally received (Miller, 1991).

Two Bulls v. US, 1990

Following the 1989 Castro case, it still remained that DNA profiling was fairly new and was a subject of controversy for both the scientific field and legal system. The case of *Two Bulls v. The United States* would soon aid in the matter. In 1990, Matthew Sylvester Two Bulls was charged with aggravated sexual abuse and sexual abuse of a minor, arising out of the rape of a fourteen-year-old girl on the Pine Ridge Indian Reservation in South Dakota. The police seized the underwear worn by the victim before and after the incident, which was turned over to the FBI laboratory for DNA analysis. Upon isolating the stain on the underwear and comparing its DNA to the DNA of Two Bulls' blood sample, it was concluded that there was a very high probability that the semen on the underwear came from Two Bulls. Before the trial, Two Bulls challenged the admissibility of the evidence against him. However, after hearing the testimony of the government's first witness, the district judge ruled that it had been sufficiently established that DNA evidence was generally accepted by the scientific community so that the evidence could be presented to the jury (*Two Bulls v. United States*, 1990).

After the hearing, Two Bulls would enter a conditional guilty plea, and was sentenced to 108 months in prison followed by two years of supervised release. The sentence was delayed and he was released on bond pending his appeal (*Two Bulls v. United States*, 1990).

During the appeal, two Bulls argued that an error was made on his behalf by the trial court because it applied the liberal *Federal Rule of Evidence 702* in determining the admissibility of the DNA evidence against him, rather than using the more stringent *Frye Test* or Castro three prong test. Two Bulls asserted that a five step test should be used to determine the admissibility of DNA evidence, similar to the three step test used in the case of *People v. Castro*. In preparing the five prong test, the court merged the *Frye Standard*, *Rule 702 Standard*, and the Castro Three

Prong Standard into a hybrid standard bundled into one package. This would create what is known as the *Five-Prong Test* to be performed at a pre-trial hearing:

1. Is DNA testing generally accepted?
2. Is the testing procedure used here generally accepted?
3. Was the test performed correctly here?
4. Is the evidence more prejudicial than probative, and if so, disallow it.
5. Is the statistics of the DNA match more prejudicial than probative? If so disallow it.

The first prong originated from the *Frye Test*, and its purpose centered on identifying whether or not DNA profiling has gained general acceptance by the scientific community in which it belongs. Both the second and third prongs came about from the Castro case but are less rigorous in this instance and only aim to prove that the acceptance of test procedures of the DNA evidence in question are both technically and scientifically accurate and applicable for the case at hand. The fourth and fifth prongs stem from *Rule 702*, and were set in place to ensure the DNA evidence being tested has not been prejudicially influenced but instead are probative.

Miles v. Illinois, 1991

The 1991 case of *Miles v. Illinois* would call upon the new TWGADM guidelines that were established after the Castro case. At the time, the state of Illinois charged Reggie Miles with rape after finding his DNA implanted on the bed linens at the crime scene. The linens were examined by Cellmark laboratories, which was an interesting choice seeing that past evidence examined by Cellmark had been thrown out in previous cases due to their inability to meet requirements set in place by TWGADM. However, this time around, Cellmark performed the procedures successfully and the statistics of a match were done accurately. A high probability

existed in Miles being the culprit, as there was a one in hundreds of thousands chance it could have been any other person (*People v. Miles,* 1991).

The ruling in this case provided much more trust and acceptability in the precision of the techniques and procedures of the results attained from the examination of DNA evidence. The new practices and guidelines provided by TWGADM, as well as the Two Bulls *Five-Prong Test* provided the assurance to the legal system that DNA could now be a heavily reliable means of physical evidence in the courtroom.

Paul Eugene Robinson, 1994, 2000, 2003

In the state of California, as required by law, a Statute of Limitations is set on sex crimes that have gone cold or unsolved for six years. As a sexual assault case approaches its six year Statute of Limitations, a general warrant is issued for the arrest of a "John Doe" suspect for whomever the individual is found to be that matches the evidence found at the crime scene. This is exactly what occurred in the Cal Expo area of California in 2000 for two sexual assault cases that occurred about six years prior in 1994. DNA evidence gathered at the scene of these two assaults did not match any previously convicted felons found in the FBI CODIS database, therefore investigators issued a warrant for the "John Doe" they would ultimately hope to find someday whose DNA profile would match the DNA profile from the crime scene.

As more DNA samples were gathered and stored in the database, in time it would eventually lead to match Paul Eugene Robinson. Since the warrant was issued prior to the Statute of Limitation expiring, the arrest of Robinson was possible (Associated Press, 2000). In 2003, this positive DNA match would lead to the conviction of Robinson on five counts of

sexual assault in the Cal Expo area. Robinson was sentenced to the maximum of 65 years in prison for the five counts of sexual assault dating back to August of 1994 (Scully, 2003).

The impact of this case was monumental for DNA forensics, as it was the first case ever to convict a felon entirely based on DNA evidence with no other supplemental evidence.

The landmark court cases mentioned in this chapter are great examples of the strides that DNA evidence and forensic technology have taken to becoming more widely accepted and utilized in the U.S. legal system. Along with the technology itself, the standards and procedures set in place to guide the technology have progressed to a great extent in forming a universal standard of interpreting DNA evidence and properly examining it so that it is consistent and accurate. As evidenced by this chapter, lots of revisions, updates, and add-ons have been made to previously existing evidence standards to increase the confidence of utilizing DNA evidence in both the scientific community and legal system. It is safe to say that DNA profiling is a type of physical evidence that is here to stay for years to come.

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CHAPTER-4: SENSATIONAL DNA COURT CASES

Archana Reddy

The impact of DNA fingerprinting technology on forensics has been astounding as a vital tool for identifying individuals based on their genetic make-up. By comparing a sample of DNA taken from a crime scene to a suspect's DNA, investigators can narrow down individuals with a high level of certainty. DNA fingerprinting has entered the courtroom in a big way. The previous chapter investigated landmark DNA court cases that affected the acceptance of DNA evidence in U.S. courts. In this chapter we will present several sensational cases, that although did not set any legal precedence, they likely are famous cases already known to the reader, which will remind us of the power of DNA fingerprinting technology even when performed years after the case was closed.

The Murder of Marilyn Sheppard, 1954

This case has been called the country's most enduring murder mystery, with all the elements of wealth, violence, sex, conflicting stories, and dramatic reversals. It stunned the nation in the 1950's, in a way no other case ever had.

Figure-1: Photo of Dr. Sam Sheppard and Wife Marilyn from Wedding Photo. (Cleveland Press, 1954)

On the evening of July 3 1954, Sam and Marilyn Sheppard had dinner with a neighborhood couple. Their suburban home was located on the shore of Lake Erie, and the atmosphere was quiet and peaceful, and everything seemed normal. After dinner, Marilyn who was four months pregnant went upstairs to sleep. Chip, their seven year old son too was asleep upstairs. Dr. Sam, as he was called, because he was an osteopath, dozed off on a downstairs couch. At about 5:40 AM, Spencer Houk, the mayor of the small community, and Dr. Sam's neighbor, received a call from Sam and he reportedly said "I think they have killed Marilyn". Houk hurried to the house and found Marilyn Sheppard dead, half naked, with wounds on her head, and blood sprayed all over the walls of the bedroom. Sam's face was bruised, his pants soaking wet, and he had no shirt on.

Figure-2: The Body of Marilyn Sheppard on Her Bed Picture Courtesy (AP)

Sam told the police that he had been awakened by loud cries for help. Realizing it was his wife crying for help, he ran upstairs to be confronted suddenly by a "bushy haired man", who knocked him unconscious. Soon he regained conscience, and hearing someone moving, he ran downstairs after the man and out of the house to the shore of the lake. He succeeded in catching him and grappled with the "bushy haired intruder" for a few minutes before being knocked down

once again. After regaining conscientiousness, he found himself lying partly in the water and pulled himself out and returned to the house. He then called for help (McClish, 2002).

The investigation was taken up by the county coroner, Dr. Samuel Gerber. Taking stalk of the situation, Gerber quickly came to the conclusion that Sheppard was guilty of murdering his wife. Cleveland newspapers which were initially of the view that the murder might have been committed by a thief or a drug addict, soon switched to believe Gerber's suspicion. The fact that Dr. Sheppard hired a defense lawyer was seen as evidence of guilt. The papers then began to press the authorities for action. Articles with headlines like "Someone is getting away with Murder" helped fuel public outrage against the doctor. The inquest held in a school gymnasium was filled to capacity by mostly housewives. They disturbed the proceedings by laughing and hooting, and cheered lustily when Gerber got Sheppard's lawyer removed for trying to have the outbursts noted on record. Dr. Sam was questioned for five hours by Gerber with no legal counsel present (McGunagle, 2004).

Dr. Sheppard's love life was a hot topic, and the people were fascinated by it. A female lab technician had confessed to an affair with the handsome doctor, while he foolishly denied it under oath. The prosecutors successfully nailed his lie by producing the woman in court. Coroner Gerber testified that he could make out the impression of a surgical instrument in a blood stain at the crime scene. While he could not say what instrument would make such a mark, he noted that Dr. Sheppard would have had access to something of that nature. The whole process was hardly forensic, and Gerber issued a "Coroner's Verdict", that asserted that "the injuries that caused this death were inflicted by her husband". How did he come to this conclusion? The evidence that he put forward was: the unlikelihood of Sheppard's story, his

failure to cooperate with the police, and the fact that he "called in two lawyers". The pressure from the press was high and Dr. Sam Sheppard was arrested.

The trial was covered by reporters, who came in from all over the country. Even before commencement of the proceedings, the trial judge blurted to Dorothy Kilgallen, a popular newspaper columnist, "He is guilty as hell. There is no question about it." But there were glaring loopholes and oversights in the investigation. The murder scene was trampled over, clues were overlooked, hardly any fingerprints were taken, and blood evidence was haphazardly examined. Prospective jurors' names, addresses and pictures were printed in newspapers much before they could be warned to avoid publicity. The whole situation snowballed into unmanageable proportions.

Dr. Sheppard's attorney, William Corrigan, argued that Sam had wounds that could have been inflicted by the intruder. There was evidence that the attacker was bitten by Marilyn, but Sam had no open wounds to explain that evidence. The crime scene was extremely bloody, but no blood was found on Sam except for a small spot. There was also a trail of blood drops found throughout the Sheppard home. Two witnesses testified to have seen a "bushy haired man", similar to Dr. Sam's description of the intruder.

Figure-3: Police Sketch of the "Bushy Haired Intruder" (Cleveland Press, 1954)

Another witness also testified that there were cigarette butts floating in the toilet at the crime scene, and neither of the Sheppards smoked. These facts, combined with the prosecution's

almost entirely circumstantial case, the defense called for acquittal. But, after a 43 day trial and deliberations lasting 5 days, the jury declared Dr. Sheppard guilty of second degree murder, and he was sentenced to life in prison. Kilgallen wrote "It was a verdict wrongly arrived at, and therefore frightening".

Appeals failed, and Sheppard remained in the Ohio penitentiary after refusing to confess in exchange for an early parole (McGunagle, 2004). In the early 1960's, the "Fugitive" became one of the most popular shows on television while Dr. Sam was behind bars. The series, which ran from 1963 to 1967, featured a mid-western doctor who was wrongfully convicted of killing his wife, escaped from custody and hunted the real killer. The parallels to Dr. Sam's case were obvious, though the writer denied that he was inspired by the story (Kelly, 2006).

F.Lee Bailey took on Sheppard's case in 1962, and filed a petition for appeal. He won his case in the federal court two years later. When the state appealed, the matter reached the US Supreme court. The high court in an 8-1 decision ruled for Sheppard and scathingly criticized the "Carnival Atmosphere" of the original trial. Ohio prosecutors indicted him again. The second trial lasted only two weeks. Sheppard was acquitted in November 16 1966 (Kelly, 2006).

Earlier in 1959 (five years after the original 1954 trial), a man named Richard Eberling was arrested, and was found in possession of Marilyn Sheppard's rings. He confessed that he had been a window washer at the Sheppard's home just before the murder, and that he had cut his finger and dripped blood down the stairs (McClish, 2002). However, the police would ignore Eberling's potential role in the murder, and he was subsequently released. In 1984, Eberling was again arrested for murdering an elderly woman. From prison he exchanged letters with Sam Sheppard's son, Chip, indicating that he knew the truth about Marilyn Sheppard's death. In the late 1990's Chip Sheppard appealed to the State of Ohio several times for his father's earlier

wrongful imprisonment. DNA tests conducted proved that Eberling's blood matched the blood from the crime scene, and his seminal fluid was found in Marilyn's vagina. The court however considered the samples inadmissible, due to being tainted by age. In 2002, the Supreme Court of Ohio ruled unanimously that only a person who had been imprisoned could make a wrongful imprisonment claim, but by then Dr. Sheppard was already dead, so after 48 years the Sheppard case was finally over (McGunagle, 2004).

The Case of Grand Duchess Anastasia

On the night of February 17 1920, a woman jumped off a bridge in Berlin, and was rescued and taken to a hospital. She had no I.D. and when questioned she refused to give her identity. She was then sent to a mental asylum, and while she was there someone recognized her as Grand Duchess Tatiana. She was given a list of the Tsar's daughters' names, and she crossed out all the names except Anastasia, indicating that she was Anastasia (Anastasia, 2003).

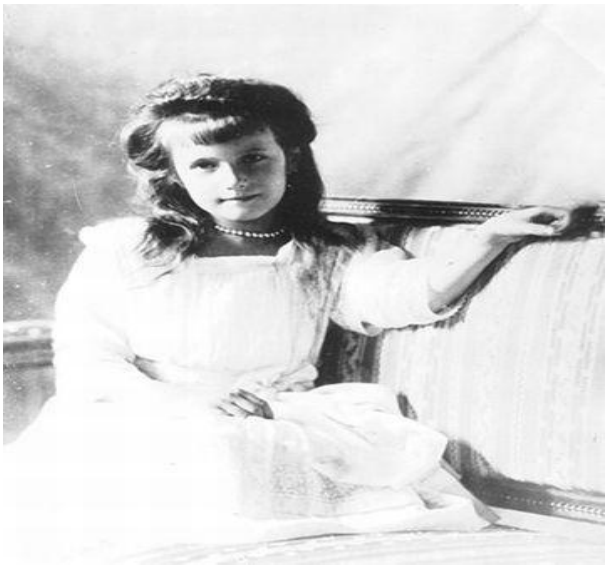


Figure-4: Picture of Grand Duchess Anastasia. (Logoi.com, 2007)

Grand Duchess Anastasia Nikolaevna was born on June 18, 1901. Her father was the last Tsar of Russia, Nicholas II, and her mother was Alexandria. She was the last among 4 sisters whose names were Olga, Tatiana, and Maria. Alexei was her only brother, who was younger by three years. Anastasia was the most intelligent and the most mischievous of the Tsar's daughters. She was an excellent mimic, and enjoyed playing pranks. Anastasia's childhood playmate Tatiana Botkin described her as "lively and rough". Her cousin Xenia described her as "frightfully temperamental, wild and rough". Years later, Tatiana Botkin and Princess Xenia met the girl who jumped off the bridge, who now called herself Anna Anderson and who claimed to be the Grand Duchess Anastasia. Both were convinced that Anna Anderson was Anastasia (Was Anastasia Real, 2003).

Anastasia, as a young girl was rather attractive, though she was short and somewhat fat. She had light brown hair and blue eyes. She could speak both English and Russian well (Was Anastasia Real, 2008). After twenty years of Nicholas II's reign, socialist groups started agitating for the overthrow of the Tsar, and for the creation of a classless society. World War I began in 1914, and by 1917 mutiny spread throughout the military. Disgusted by war losses and food shortages, workers rioted. On March 15 1917, Nicholas was forced to abdicate. The imperial family was moved to Siberia, and on July 16 1918 they were shot dead. The assassins did their best to destroy the family of the last imperial family. They were first thrown down a mine shaft and grenades were tossed in after them. The bodies were then again removed from the mine shaft, doused with acid or burned. The remains were thrown into a pit and buried. (Was Anastasia Real, 2008).

For decades, those who knew the location of the buried site kept quiet for the fear of the Soviet government. But there were several rumors about how one or more children survived.

Many people claiming to be Anastasia appeared over the years. The most famous one was Anna Anderson. Anna Anderson claimed that she escaped from the Imperial family's assassins. She said that she had been bayoneted, but survived because the weapon was blunt. A soldier whose name was Tschaikovsky saw that she had not succumbed and took pity on her. Taking advantage of the chaos that prevailed that night, he rescued her and took her to Romania. Anderson's story was a confusing narrative in which she is said to have been married to Tschaikovsky, and gave birth to a son whom she placed in an orphanage. Tschaikovsky later died in a street fight.

Anderson attracted many supporters for her position, and many deniers. Crown princess Cecille, the daughter-in-law of the former Kaiser, and a relative of Anastasia, believed that Anderson was the lost Grand Duchess. Cecille's son Prince Louis Ferdinand and his wife did not believe. Olga, Anastasia's aunt was at first not so sure, but she finally declared Anderson was not Anastasia. Anderson had strong supporters which included Anastasia's cousin Princess Xenia, Gleb, and Tatiana Botkin whose father was killed along with the imperial family. Gleb's childhood drawings of animals in court dress had delighted Anastasia. When he first met Anderson, she asked him about his family animals (Welch, 2007). Anastasia's uncle, Grand Duke Earnst of Hesse convinced that Anderson was an imposter, was determined to prove it. He backed an investigation that suggested that Anderson was a polish factory worker, Franziska Schanzkowska who disappeared before Anna Anderson made an appearance. Her refusal to speak Russian was another factor pointed out by her detractors. But she maintained that she would not speak Russian because the Russians had killed her family. She spoke good English and also some German and French, which seemed unusual for a polish factory worker. There were scars on her body which she said were from bullet and bayonet wounds. But her opponents

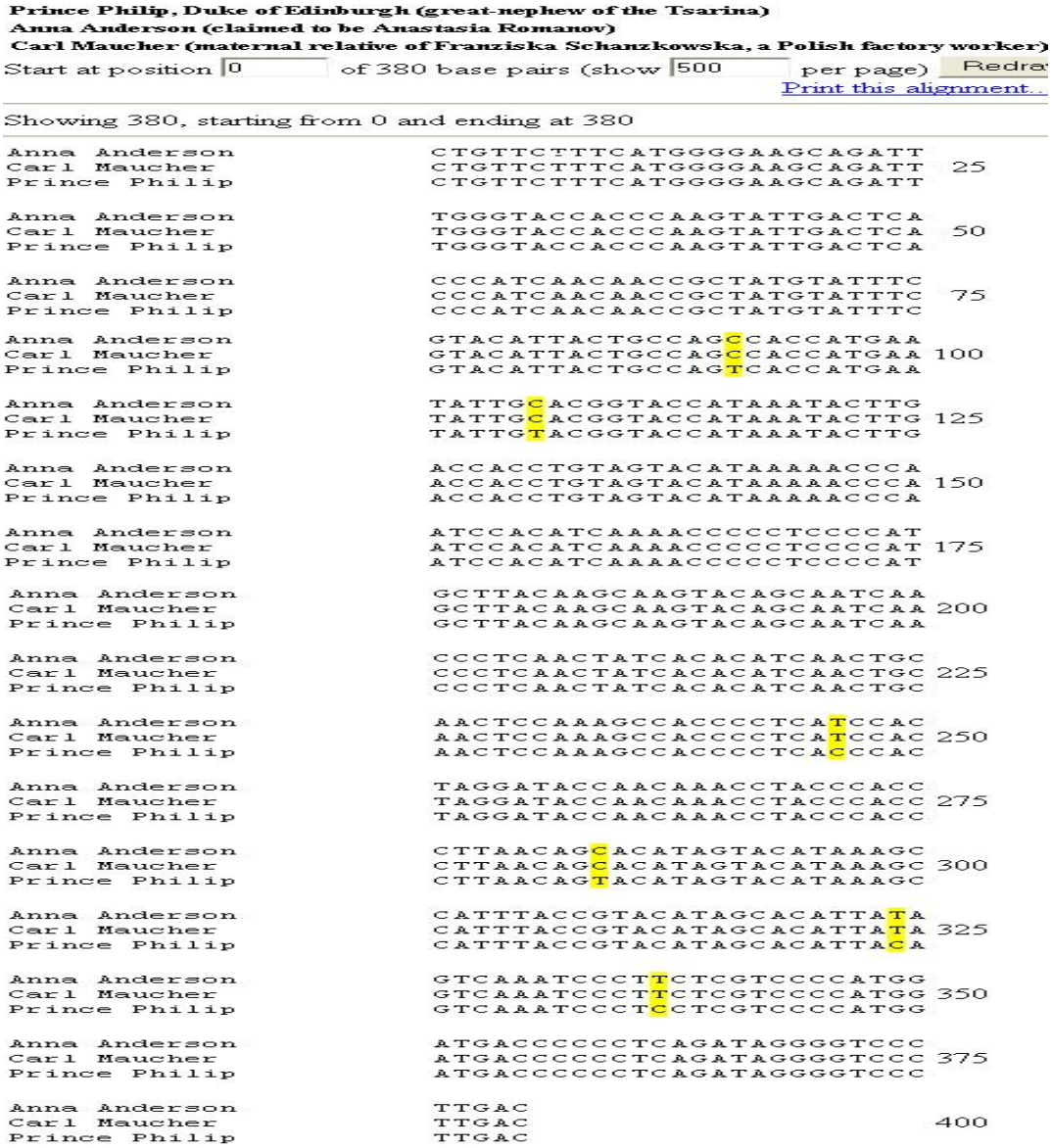
were of the firm opinion that she got them in a munitions factory when a grenade was dropped (Godl, 1998).

Figure-5: Picture of Anastasia (1913) (left), and Anna Anderson (1929) (right) (Kurth, 2003).

Anderson and Anastasia had other similarities. Both had a foot deformity, and faces which were very similar. An anthropologist, Dr.Otto Reche, testified in court that Anastasia and Anna Anderson had to the same person or identical twins. Anderson brought a suit in a German court in 1938 to prove her identity and claim her inheritance. A handwriting expert also swore that Anderson was Anastasia. Dr. Moritz Furtmayr, a forensic expert also believed that Anderson was Anastasia. The court finally ruled that she had not provided adequate proof to support her claim (Anastasia, 2003).

After the trial, Anna Anderson was married to American John Manachen for the last 15 years of her life. She died of pneumonia in 1984, and was cremated in accordance with her wishes by her husband. The controversy however was not laid to rest. DNA analysis of a tissue sample of a piece of intestine, preserved in a pathological laboratory of a hospital where Anderson had undergone surgery was performed in 1994. It was compared with the DNA analysis of a sample from Karl Maucher, nephew of Franziska, and also with that of Prince

Philip, Duke of Edinburgh who was a grand nephew of Tsarina Alexandria (Anastasia's mother). Anderson's DNA matched that of Karl Maucher but did not match Prince Philip's DNA.



Prince Philip, Duke of Edinburgh (great-nephew of the Tsarina)
Anna Anderson (claimed to be Anastasia Romanov)
Carl Maucher (maternal relative of Franziska Schanzkowska, a Polish factory worker)

Start at position 0 of 380 base pairs (show 500 per page) Redra

Print this alignment...

Showing 380, starting from 0 and ending at 380

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Anna Anderson      CTGTTCTTTCATGGGGAAGCAGATT
Carl Maucher       CTGTTCTTTCATGGGGAAGCAGATT  25
Prince Philip      CTGTTCTTTCATGGGGAAGCAGATT

Anna Anderson      TGGGTACCACCCAAGTATTGACTCA
Carl Maucher       TGGGTACCACCCAAGTATTGACTCA  50
Prince Philip      TGGGTACCACCCAAGTATTGACTCA

Anna Anderson      CCCATCAACAACCGCTATGTATTTC
Carl Maucher       CCCATCAACAACCGCTATGTATTTC  75
Prince Philip      CCCATCAACAACCGCTATGTATTTC

Anna Anderson      GTACATTACTGCCAGCCACCATGAA
Carl Maucher       GTACATTACTGCCAGCCACCATGAA 100
Prince Philip      GTACATTACTGCCAGTCACCATGAA

Anna Anderson      TATTGCACGGTACCATAAATACTTG
Carl Maucher       TATTGCACGGTACCATAAATACTTG 125
Prince Philip      TATTGTACGGTACCATAAATACTTG

Anna Anderson      ACCACCTGTAGTACATAAAAACCCA
Carl Maucher       ACCACCTGTAGTACATAAAAACCCA 150
Prince Philip      ACCACCTGTAGTACATAAAAACCCA

Anna Anderson      ATCCACATCAAAACCCCCTCCCCAT
Carl Maucher       ATCCACATCAAAACCCCCTCCCCAT 175
Prince Philip      ATCCACATCAAAACCCCCTCCCCAT

Anna Anderson      GCTTACAAGCAAGTACAGCAATCAA
Carl Maucher       GCTTACAAGCAAGTACAGCAATCAA 200
Prince Philip      GCTTACAAGCAAGTACAGCAATCAA

Anna Anderson      CCCTCAACTATCACACATCAACTGC
Carl Maucher       CCCTCAACTATCACACATCAACTGC 225
Prince Philip      CCCTCAACTATCACACATCAACTGC

Anna Anderson      AACTCCAAAGCCACCCCTCATCCAC
Carl Maucher       AACTCCAAAGCCACCCCTCATCCAC 250
Prince Philip      AACTCCAAAGCCACCCCTCACCCAC

Anna Anderson      TAGGATACCAACAAACCTACCCACC
Carl Maucher       TAGGATACCAACAAACCTACCCACC 275
Prince Philip      TAGGATACCAACAAACCTACCCACC

Anna Anderson      CTTAACAGCACATAGTACATAAAGC
Carl Maucher       CTTAACAGCACATAGTACATAAAGC 300
Prince Philip      CTTAACAGTACATAGTACATAAAGC

Anna Anderson      CATTTACCGTACATAGCACATTATA
Carl Maucher       CATTTACCGTACATAGCACATTATA 325
Prince Philip      CATTTACCGTACATAGCACATTACA

Anna Anderson      GTCAAATCCCTTCTCGTCCCCATGG
Carl Maucher       GTCAAATCCCTTCTCGTCCCCATGG 350
Prince Philip      GTCAAATCCCTCCTCGTCCCCATGG

Anna Anderson      ATGACCCCCCTCAGATAGGGGTCCC
Carl Maucher       ATGACCCCCCTCAGATAGGGGTCCC 375
Prince Philip      ATGACCCCCCTCAGATAGGGGTCCC

Anna Anderson      TTGAC
Carl Maucher       TTGAC                     400
Prince Philip      TTGAC
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Figure-6: DNA Tests that Proved that Anderson's DNA Matched Franziska's Nephew But Not the Royal Family. (Anna Anderson Exposed, 2007)

The amazing discovery of Imperial family's remains and subsequent DNA testing nailed Anderson's lie further. The Tsar family remains were exhumed in 1991 from a site where only

nine skeletons were found. DNA test confirmed they were of Nicholas, wife Alexandra, three daughters, and four others (one of whom was the Imperial family's physician and Gleb Botkin's brother). Two bodies were still missing, but were found later in a nearby grave, and DNA tests were conducted. The results proved that those remains belonged to the Tsar's son Alexei and one daughter. With this the total body count of the Imperial family was complete, and it proved that the entire family was murdered and that none had escaped.

There have been four different DNA tests involving the Anderson/Anastasia riddle: the 1991 bones tested versus the blood from the royals, the 1994 testing of Anderson's intestine versus the pattern sequence from blood of the royal family, the testing of Anderson's hair versus the DNA of the royal family, and the recent testing of the charred bone fragments found in 2007, with the 1991 bones. The results emphatically proved that Anderson was not Anastasia, and that Anastasia died along with her family in 1918. The DNA results further proved that Anderson was indeed Franziska Schanskowksa, the polish factory worker whose charade had at last come to an end. The grand myth is finally laid to rest (Kurth, 2003)

The Boston Strangler

Albert De Salvo, also known as the "Measuring Man", the "Green Man", and finally the "Boston Strangler" was a product of a violent and abusive home. He was born in Chelsea, Massachusetts in 1931. He was arrested and let off several times for breaking and entering while still a teenager. At 17 years of age he joined the army, and was stationed in Germany. He married a German girl, and returned to the US with her when he was transferred back. He was posted to Fort Dix in New Jersey, where he was charged with molesting a nine year old in January 1955, but was discharged in 1956 because the mother did not press charges. He had

sexual problems with his wife, calling her 'frigid' when she turned him down. Matters grew worse with the birth of their first child. Eventually, being short on cash, De Salvo went back to a life of petty crime. Arrested twice for breaking and entering, he received suspended sentences each time. At about the same time, Massachusetts women began falling prey to the 'Measuring Man', who posed as a talent scout for a modeling agency. After gaining entry into an apartment, the man would proceed to measure and record the women's measurements, in some cases fondling her intimately in the process. Some women complained to the police, but most did not, so the detectives did not treat the Measuring Man as a priority because there was no violent assault (Fisher and Fisher, 2000).

Figure-7: Picture of Albert De Salvo.
(Bardsley and Bell, 2003)

On March 17, 1960, when Cambridge police arrested De Salvo on suspicion of burglary, he confessed to being the 'Measuring Man'. He was charged with breaking and entering, and sentenced to two years in prison. After 11 months he was paroled, and being driven with sexual frustration adopted a more aggressive 'Green Man' rapist role. He was so called because he wore green work clothes while targeting victims. Police would later estimate he raped nearly 300 women, while De Salve himself claimed closer to 2000.

While police sought the 'Green Man' rapist throughout New England, Boston homicide detectives were searching for a killer, who raped and killed 13 women between June 1962 and July 1964. These women were strangled using a ligature (stocking, pillowcase, etc.) which was

always left around the victim's neck, tied in an ornament bow (Fisher and Fisher, 2000). The 13 known victims of the strangler are listed in Figure-8, and pictures of 8 of them are shown in Figure-9.

Name	Age	Died	Comments
Anna Slesers	55	14th June 1962	Discovered by her own son; Found to be strangled with her belt
Mary Mullen	85	28th June 1962	Killer left a New Year's greeting card wedged between the toes of her left foot
Nina Nichols	68	30th June 1962	
Helen Blake	65	30th June 1962	Forensic psychiatrists called in by Police to help profile killer.
Ida Irga	75	19th August 1962	
Jane Sullivan	67	20th August 1962	
Sophie Clark	20	5th December 1962	Suspicions of a 'Mother-Killer' on the rampage are quashed by the latest killing
Patricia Bissette	23	31st December 1962	
Mary Brown	69	9th March 1963	
Beverley Samans	23	6th May 1963	
Evelyn Corbin	58	8th September 1963	
Joann Graff	23	23rd November 1963	
Mary Sullivan	19	4th January 1964	De Salvo posed as a detective, and allowed his victim to live after apologising.

Figure-8: The 13 Known Victims of the Boston Strangler (Chitolie, 2008).

Figure-9: Photos of Eight of the Boston Strangler's Victims (Corbis, n.d.).

Ten months later on November 3rd 1964, De Salvo was taken for questioning on rape charges after one of the "Green Man's" victims gave the police a description strongly resembling the 'Measuring Man'. De Salvo's subsequent confession to a long series of rapes landed him in Bridgewater State Hospital, committed for observation. At Bridgewater State, he was befriended by George Nassar, a convicted murderer. De Salvo later confessed to the police of being the 'Boston Strangler' (Bardsley and Bell, 2003).

Based on De Salvo's confession, the Boston Strangler seemed like an open and shut case, but some critics maintain that Nassar may actually have been the strangler, briefing Albert on the details of his crimes in the hope of taking the authorities attention off himself. De Salvo, already facing life imprisonment for countless rapes, admitted that he struck a cash bargain with Nassar, whereby Nassar would pocket part of the reward for turning De Salvo in, and then afterward he would pass the cash on to De Salvo's wife. But the question remained as to which of the two was the real strangler.

With respect to direct evidence, the "Boston Strangler's" lone survivor Mary Sullivan chose Nassar as a suspect rather than De Salvo when shown several pictures. And although De Salvo confessed to all of the Boston Strangler murders (and two others), there was never any physical evidence connecting him to any of the crime scenes. And he did not match any witness descriptions of possible suspects. His name was not on a list of more than 300 suspects compiled by case investigators, nor was De Salvo ever tried in any of the killings.

De Salvo's lawyer F. Lee Bailey, who had already distinguished himself in the Dr. Sam Sheppard case, managed to negotiate a deal in 1967. In exchange for a term of life imprisonment for crimes committed as the 'Green Man', De Salvo would not be charged in the Boston Stranglings.

Figure-10: Photo of De Salvo Defense Attorney F. Lee Bailey Holding a Photo of His Client. (Corbis, 1967)

Six years after his 1967 plea bargain, in November 1973, De Salvo was stabbed to death by a fellow inmate at Walpole prison. It was almost as if Albert De Salvo was patting himself on the back when he wrote this poem in his prison cell a few years before his death:

Here is the story of the Strangler, yet untold,
The man who claims he murdered thirteen women,
young and old.
The elusive Strangler, there he goes,
Where his wanderlust sends him, no one knows
He struck within the light of day,
Leaving not one clue astray.
Young and old, their lips are sealed,
Their secret of death never revealed.
Even though he is sick in mind,
He's much too clever for the police to find.
To reveal his secret will bring him fame,
But burden his family with unwanted shame.
Today he sits in a prison cell,
Deep inside only a secret he can tell.
People everywhere are still in doubt,
Is the Strangler in prison or roaming about?

(Bardsley and Bell, 2003)

With respect to DNA analysis, in 2000, Elaine Whitfield Sharp, an attorney specializing in forensic cases, took up the cause of the De Salvo family and that of the family of Mary A. Sullivan (supposedly the final victim in 1964). Whitfield Sharp helped organize exhumations of

Sullivan and De Salvo bodies. She found various inconsistencies between De Salvo's confessions and the crime scene information. Contrary to De Salvo's confessions of rape, there was no semen in Mary's vagina, and she was not strangled manually but by ligature (BBC News, 2001). In his book 'A Rose for Mary: The Hunt for the Real Boston Strangler', Casey Sherman (Mary Sullivan's nephew), chronicled the evidence from the crime scenes, suspects, and police investigations. Sherman also elicited the aid of a forensic team led by George Washington University professor James Starrs for DNA testing. Starrs' team was able to find trace evidence of the killer on Sullivan's body, and that DNA evidence did *not* match Albert De Salvo. Sherman presents these findings of mismatched DNA in his book as he unrelentingly searches for justice and provides new revelations to unmask the real killer (Burns, 2006).

Even with old unsolved cases, DNA testing can still provide a vital tool in the hands of investigative agencies to get at the truth, long after the original trials have been completed. In the famous cases discussed above, though delayed, truth and justice prevailed, or will prevail.

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Chapter-5: DNA Database Ethics

Khushbu Patel

DNA databases are used for three different applications: genetics, criminal justice, and genealogy. DNA databases contain information derived from the unique loci on DNA molecules and allows for that information to be rapidly searched for matches. Within genetics, databases allow allele frequencies to be established for specific DNA loci, which allows for more accurate probabilities to be assigned to matches. Within criminal justice, databases allow the match of a crime scene DNA to other crime evidence, or to previously convicted felons whose DNA profiles are in the database. Within genealogy, databases allow studies on human relatedness and evolution. However, in spite of this amazing power, ethical problems arise concerning individual privacy rights, and whose DNA should be entered into databases. The purpose of this chapter is to discuss the topic of DNA database ethics.

The FBI's CODIS Database

The first DNA databases were not created until the 1990s. The FBI's Combined DNA Index System (CODIS) is now the world's largest, containing the DNA profiles of people convicted of a variety of crimes, and containing profiles from crime scene evidence. CODIS is a three tired system, containing linked local, state, and national databases. Local and state labs maintain their own databases according to their own laws, but they can also have access to the national database. The national level database is called the National DNA Index System (NDIS). It is maintained by the FBI, and includes more than 78,000 DNA samples collected from crime scenes, more than 100 from missing persons, 300 from relatives of missing persons, and 150

from unidentified human remains (FBI, 2004.) Most of the DNA profiles entered into CODIS come from convicted felons with DNA profiles assayed in a total of 175 crime labs in all 50 states and in Puerto Rico (FBI, 2004.)

In 1990, CODIS was created as a pilot for the FBI, but was nowhere near as large as it is today. In 1994, following a series of landmark DNA trials in which DNA technology was critiqued (discussed in Chapter-5) the DNA Identification Act was enacted, which mandated the establishment of standards in the industry. The outcome was a massive expansion of the technology into forensics, and an expansion of CODIS. Its main use is to help catch criminals, but scientists tap into CODIS regularly for genetic studies. According to Maryland's Governor's Office of Crime Control and Prevention, "this DNA database does exactly what they need it to, and has aided over 62,000 investigations since 2007".

Initially CODIS included only two *indices*: the forensic index (which contains DNA profiles for crime scene materials like blood or saliva), and the convicted offender index (which contains the DNA profiles of previously convicted offenders). As CODIS developed, additional indices were added including a missing person's index and an arrestee index.

Other Databases

Although CODIS is the world's largest DNA database, and the most used, it is not the only DNA database. In the UK, the NDNAD database (National Criminal Intelligence DNA Database) was actually the first of its kind invented. NDNAD was created in 1995, and was designed to capture criminals. Over four million records are held in this database (Maxine Myers, August 17th 2009).

France is an example of another government with its own national DNA database. Their

database was created in 1998, and is referred to as the Automated National File of Genetic Prints (FNAEG). This database was made for the sole purpose of stopping child sex offenders. Hit with an increasing number of unsolved sex offender cases, France acted quickly to begin entering convicted offender profiles into a database. In 1998, the French enacted the Guigou Law, which was mandated all sex offender profiles be entered in the database. Eventually the database uses expanded to other crimes.

Database Expansion?

One of the most ethically controversial topics with DNA databases is *whose* DNA profiles should be entered. In the US, the decision as to whose profiles are entered in a particular state database is dictated by laws in that particular state, and those laws vary tremendously from persons *convicted* of *violent* crimes, to entering all persons *arrested* for a crime. From a purely crime solving point of view, the more entries in a database the greater likelihood of solving a crime. And some ethicists are worried this idea will be taken to its extreme by mandating all babies at time of birth give cheek swab DNA. Most US states, including Massachusetts, currently take a compromise position of mandating persons convicted of violent crimes (both felonies and misdemeanors) to provide a sample.

Laura Neuman was a victim of sexual assault, and claims her attacker could have been stopped if the police had taken a DNA test. Instead it took twenty years to stop the man responsible for putting her through such trauma. "He could have been caught sooner if DNA had been taken, and he had been matched to the cases that were unsolved," Laura Neuman said. Alphonso Hill, the rapist, confessed to committing the crime twenty years later, and was also held responsible for six other related cases. If the DNA database had held his DNA profile after

the first crime, he likely could have been stopped from performing subsequent crimes. In addition, if everyone, including criminals, realized the police always run a DNA test upon arrest, it might force people to think twice before committing a crime (Arena and Bohn, 2008).

The FBI's website is loaded with CODIS success stories (Recent CODIS…2009). For example, Rita Baldo and her daughter Lisa were raped and murdered in Florida in the summer of 1992. The DNA profile from the crime scene evidence did not match any known suspect. So in 1998 the DNA profile was uploaded to CODIS in the forensic index. In May 2003, a hit occurred to James A. Frederick, who was serving time in Wisconsin, and whose DNA profile had just been entered into the database. Another story is that of Carol Shields, who in September 2000 was murdered in north Kansas City. Although no suspects were found, the crime scene DNA profile was scanned against NDIS, and matched rapist Wayne DuMond (Recent CODIS…2009). **Table I** shows the total number of DNA profiles in CODIS from 2000 to 2008, and the number of successful hits within that period. Note the drastic increase in total profiles and hits over this period, indicating the increasing use of DNA technology in forensics.

Offender/Forensic Profiles & Total Offender Hits

	2000	2001	2002	2003	2004	2005
Offender Profiles	460,365	750,929	1,247,163	1,493,536	2,038,514	2,826,505
Forensic Profiles	22,484	27,897	46,177	70,931	93,956	126,315
Investigations Aided	1,573	3,635	6,670	11,220	20,788	30,455
Forensic Hits	507	1,031	1,832	3,004	5,147	7,071
National	26	167	638	1,151	1,864	2,855
State	705	2,204	4,394	7,118	11,991	18,664
Total Offender Hits	731	2,371	5,032	8,269	13,855	21,519

Offender/Forensic Profiles & Total Offender Hits (cont'd.)

	2006	2007	2008
Offender Profiles	3,977,433	5,372,773	6,539,919
Forensic Profiles	160,582	203,401	248,943
Investigations Aided	43,156	62,059	80,948
Forensic Hits	9,529	11,750	14,122
National	4,276	6,508	8,479
State	28,163	43,305	58,304
Total Offender Hits	32,436	49,813	66,783

Table 1: CODIS Offender/Forensic Profiles & Total Offender Hits. (Federal Bureau of Investigation, 2009)

Databases and Ethnicity

Some individuals have complained that DNA database are misused, allowing racism to reach new heights, as the ethnic backround of the general population does not match that of database entries. Maxine Myers presented an alarming statistic in one of her articles, that "one in four black children from the ages of 10 have had their profiles placed in a police DNA database". Matilda MacAttram is well recognized as the founder and director of Black Mental Health, and is confident that DNA databases are damaging relations between races, arguing that black children are being discriminated against and innocent children are suffering for it. Although her argument may not acknowledge *why* the entries are being placed in the database in the first place, if it is because crimes are being committed, then most people would argue their privacy rights have been given up. But if the disproportionate entries result from police bias, her arguments stand. Myers noted that "according to new figures obtained by the campaign group Genewatch, almost 45,000 black children aged 10 to 17 in England and Wales have been added to the database in the past five years. In contrast, the DNA profiles of just fewer than 10 percent of white youth

have been added." The statistics show that more black children are being placed on the database than white. Is the DNA database promoting racism? If everyone was placed into the database, then the accusations of racism would be stopped, and cases like Laura Neuman's would have been solved sooner, but some argue this could be seen as an invasion of privacy.

Databases and Medical Predispositions

Some individuals also fear that DNA databases could be misused by insurance companies too. If insurance companies had access to the database, a person might be denied health coverage or life insurance based on medical predispositions. But most people do not realize that the type of information entered into CODIS does not include medical predispositions, you can not retrieve more information from a database than what is entered into it. As discussed in Chapter-1, the 13 core DNA loci currently entered into CODIS have never been proven to contain any medical predisposition data. But it might be possible to obtain such information from the original DNA sample stored in a freezer, so we agree that this original DNA sample should be destroyed after successfully obtaining CODIS information.

Perhaps one of the most striking arguments against having every person's DNA profile in a database is the cost associated with performing the tests, and of maintaining a very large database. And who should pay for this, government or private agencies?

The power of DNA databases is unquestionable, whether helping scientists learn more about human evolution and migrations, helping solve crimes, or identifying missing persons for the military. Although some individuals worry about privacy rights and medical predisposition data, no medical predisposition information resides in the 13 core loci used for forensic purposes. However, we do agree that the original DNA sample should be destroyed after obtaining the 13

core loci information as a more thorough analysis of DNA beyond what is entered into CODIS might reveal medical predispositions. With respect to whose DNA profiles should be entered into CODIS, the author of this chapter believes that DNA entries should be expanded to include every newborn's profile, and all people currently living in the US. Even though database misuses might arise with innocent people accidently being linked to crime scene evidence by mistake, those instances should remain rare and do not outweigh the benefits of a very large database to crime solving. Increased funding should be mandated to support the sample collection and to support increased database security.

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PROJECT CONCLUSIONS

Jerome Kirkland

This IQP attempts to reveal the great impact DNA fingerprinting technology has had on the scientific community, legal systems, and society as a whole. We began by examining the components that make up DNA, and how DNA is used to create profiles that are unique to every individual. We then described the two main methods for obtaining DNA profiles, the RFLP type and the PCR-type. RFLP is non-amplifying, while PCR is amplifying. A tradeoff exists between the two methods as the RFLP method takes more time to complete, requires a relatively large amount of DNA samples, but it can tolerate small amounts of DNA contamination. On the other hand, the PCR method is faster and can analyze smaller amounts of DNA, such as DNA from a single cell, but this method is more susceptible to contamination. A combination of these two main methods, known as AFLP-PCR, is a newer technique that is relatively cheap, fast, and reliable. This technique has broad applications for systematics, pathotyping, population genetics, DNA fingerprinting, and quantitative trait loci (QTL) mapping. This technique has the potential to be the method of first choice for forensic scientists when examining DNA evidence.

The second chapter continues with DNA evidence and the importance of handling it properly. Mishandling DNA can leads to contamination or degradation which lessens the chances of its admissibility in the courtroom. Some notable standards of proper DNA handling and collection include using gloves at a crime scene, proper chain of custody and documentation, and appropriate storage.

Chapter three explored multiple landmark court cases that set the groundwork for DNA evidence to make its way into the U.S. legal system. These cases that involved DNA evidence

were not the blockbuster type cases that may be familiar, but instead were cases that set legal precedence and formed standard procedures on how DNA is to be used in cases involving DNA evidence. These landmark cases highlight that gaining acceptance of highly technical evidence in US courts is an involved process, but when the evidence is gathered properly and analyzed precisely, DNA can be the dominant piece of evidence that can make a case. Due to the principles and guidelines created by these cases, admittance of DNA in the courtroom slowly garnered universal acceptance, paving the way for future trials.

The fourth segment of this project investigates three sensational court cases that involved DNA analysis, and are some of the most famous cases in US history. These cases were not cases that set legal precedence for technical evidence, however the power of DNA was applied long after the original crime. In cases such as the Boston Strangler where the case is still under investigation, it shows that DNA still has the ability to uncover the truth well after the original trials have taken place.

The last portion of this project revolves around DNA databases and the ethical dilemmas that arise with this topic. DNA databases are not only used to find matches to crime scene evidence, but they are used for genetics and genealogy to determine specific allele frequencies in the general population, or to analyze human relatedness and evolution. Databases are a controversial subject. Although one can make the case that the more entries a database contains the greater the likelihood of matching a crime to an individual giving society a better chance of keeping criminals off the streets, other people argue that having a universal database that would contain the DNA material of every individual in the world is a violation of individual privacy rights. Other concerns arise such as how long should DNA samples be stored before disposal, or the possibility of medical predisposition information being obtained. Most controversial is the

question of who should provide their DNA samples. Should it be all persons, anyone who has been *arrested*, or anyone *convicted* of a felony?

The authors of this project pondered these questions and have debated both sides of the argument. It is the view of one author that people are born with a clean slate and in good faith should be granted the right to privacy by not having to give out their DNA. Another author welcomes the idea of having every person in the US in a database to deter many people from committing a crime in the first place, making society a safer place. The third author believes that only *convicted* felons should be required to give their DNA because once an individual commits a crime that hinders the privacy of another then that criminal in turn should lose their right to privacy.

As is evident throughout this project, we can clearly see that DNA technology is a powerful tool when performed accurately. The universal acceptance we see today is in great part due to the steady development of the practice, and to the precedents set by the cases described in this paper. Many crimes would have gone unsolved and many criminals would not be behind bars if it were not for this remarkable technology, including cases in which no other evidence existed except for DNA. Although we have seen DNA evidence heavily influence the legal system, its expanded use should continue. As the procedures and practices improve, DNA technology will continue to strengthen decisions made in court rooms all over the world.