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DNA FINGERPRINTING

An Interactive Qualifying Project Report

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ABSTRACT

This IQP was designed to study the effects of DNA technology and examine its impact on society. The proper collection and storage methods for DNA evidence and the primary techniques for analyzing DNA were described. By documenting several landmark DNA court cases the authors were able to show the progression of legal precedence for admitting DNA evidence into US courts. Sensational DNA court cases were covered to demonstrate to the reader the power of DNA at solving crimes that are decades old, or where all conventional crime solving methods failed. The purpose of criminal and medical DNA databases, and the privacy rights issues surrounding them were discussed. Finally, the authors draw conclusions about this powerful technology.

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PROJECT OBJECTIVES

The purpose of this project was to examine the ethical and technical issues surrounding the use of DNA forensics and determine its effects on society. Chapter-1 introduces the reader to the processes used in DNA fingerprinting. The second chapter describes proper procedures and technology used when collecting and storing DNA samples. Chapter-3 examines landmark court cases that established the precedence for admitting and presenting DNA evidence in US courts. In Chapter-4 several sensational court cases are presented where DNA fingerprinting played a critical role in determining the guilt of the accused, and demonstrated the power DNA technology has to solve cold cases previously unsolvable by conventional means. The use and ethical concerns of criminal and medical DNA databases is discussed in Chapter-5. Finally, conclusions and recommendations are drawn by the authors of this IQP based on their research on this potent yet often controversial technology.

CHAPTER-1: DNA FINGERPRINTING, DESCRIPTION AND TYPES

Jessica McMasters

Introduction

At the tip of each finger there is a unique ridged pattern known to be mostly unique to each person, except for identical twins. For decades this traditional fingerprint has been used to help law enforcement identify individuals. More recently, DNA fingerprinting, or DNA profiling, has become a commonly used method in forensic sciences to establish identification based on distinct genetic differences between organisms (Krawczak and Schmidtke, 1998). Every individual has a unique DNA sequence within their genetic code, referred to as the individual's "DNA fingerprint". A person's genetic sequence is exclusive only to that person, so forensic scientists have applied this methodology to cases of paternity testing, crime scene identification, criminal investigations, and in the diagnosing of inherited disorders. The purpose of this chapter is to introduce the reader to the technology of DNA fingerprinting, discussing the two main methods for performing DNA analysis, and discussing some of its applications.

DNA Background

Nuclei, DNA, Genes

Compactly packed in almost every human cell, genetic information is stored away in the nucleus of the cell (**Figure-1**). The nucleus is a protective organelle in the cell that houses most of the cell's genetic information, and its main function is gene expression, articulated through chromosomes. Chromosomes are formed from a deoxyribonucleic acid (DNA) molecule and related attached proteins that contain inherited traits from both parents. The associated DNA

molecule in a chromosome includes thousands of genes, each gene coding for a certain characteristic or trait. Most DNA is diploid, with two copies for each gene, one from the mother and the other from the father. An allele of each gene is the variant for that particular characteristic. For example, everyone has genes dictating their eye color, but a person may have the particular alleles for blue eyes.

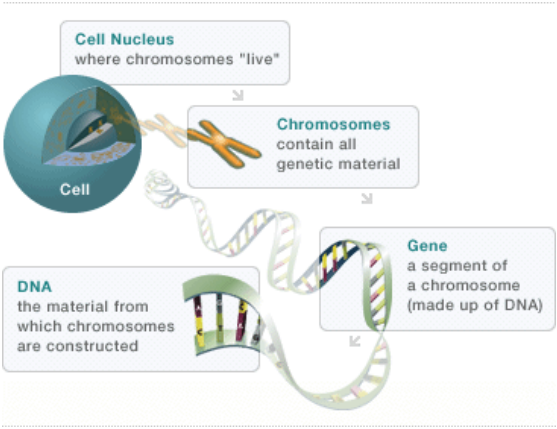

Figure-1: Diagram Showing the Relationship Between Chromosomes, Genes, and DNA (Cell Nucleus, 2011).

DNA Sequence

Arranged in two long strands forming a double helix, nucleotides form a DNA sequence. The *order* of nucleotides dictates the order of amino acids in the protein encoded by the gene. So in this way, the DNA sequence influences the specific traits expressed by genes. The strands of the DNA helix are composed of a sugar-phosphate backbone, and the strands are held together by weak hydrogen bonds between the nucleotide bases (Adenine, Thymine, Guanine, and Cytosine). Due to conformational restraints, Adenine and Thymine always pair, and Guanine and Cytosine always pair.

DNA Loci

The human genome is long, containing over 3 million nucleotides. Because of the immense length, scientists have only reviewed the genomic sequence a few times. Over the years, to make it easier and less-time consuming to analyze for identification purposes, geneticists carefully selected specific loci (locations) on the DNA molecule that vary between individuals. So DNA fingerprinting is performed by analyzing specific loci (locations) on the DNA molecule, not by completely sequencing the genome. These loci have been carefully selected by geneticists over the years to represent regions in the genome that vary between individuals. Human DNAs are approximately 99.8% identical, so fingerprinting loci must be carefully selected to reside in the unique areas most likely to differ between individuals.

The FBI's DNA database is termed CODIS (Combined DNA Index System), one of the world's largest. Since 1986, DNA profiles currently submitted to CODIS typically analyze 13 core loci, a standard set of loci carefully chosen for analysis (DNA.gov, 2011). The more loci analyzed, the more accurate the DNA analysis. For each location, the genotype is determined, and each genotype has a known frequency in the general population. When all 13 core loci are analyzed, the chance of a random match occurring is only one in several billion. Thus, if any two DNA samples have matching genotypes at all 13 CODIS loci, it is a virtual certainty that the two DNA samples came from the same individual.

Figure-2 shows an example DNA analysis of the 13 core loci created by forensic scientist Bob Blackett on his own DNA. Each locus is represented by a vertical column. For each locus (i.e. D3S1358 for example), the particular genotype at that location is determined (i.e. 15,18 refers to the number of repeats at that location). The frequency of that genotype is known in advance for the general population (i.e. 8.2%). The frequencies of each genotype are then

multiplied together to obtain the overall probability of a match. In his line of work, Bob "often compares the DNA profile of biological evidence from a crime scene with a known reference sample from a victim or suspect (The Biology Project, 2000).

Locus	D3S1358	vWA	FGA	D8S1179	D21S11	D18S51	D5S818
Genotype	15, 18	16, 16	19, 24	12, 13	29, 31	12, 13	11, 13
Frequency	8.2%	4.4%	1.7%	9.9%	2.3%	4.3%	13%

Locus	D13S317	D7S820	D16S539	THO1	TPOX	CSF1PO	AMEL
Genotype	11, 11	10, 10	11, 11	9, 9.3	8, 8	11, 11	X Y
Frequency	1.2%	6.3%	9.5%	9.6%	3.52%	7.2%	(Male)

Figure-2: Bob Blackett's DNA Profile Using 13 Core Loci. The core loci are represented by vertical columns. For each locus are shown the particular genotype at that location, and how often that genotype occurs in the general population. Also shown is the AMEL sex X/Y analysis. (The Biology Project, 2000).

Repeating DNA Sequences

The loci chosen for DNA analysis often have *repeating* DNA sequences that do not code for any proteins. DNA sequences that encode proteins are often conserved between individuals, and the sequence cannot vary or the protein will become non-functional. The DNA sequences at forensic loci vary between individuals by containing a different number of repeat sequences. There are three different types of repeating sequences: RFLPs, VNTRs, or STRs.

RFLPs (restriction fragment length polymorphisms) are DNA sequences that contain a target site flanked by two restriction sites. Restriction fragments might differ between individuals by their lengths. **Figure-3** shows how RFLPs are analyzed. First, DNA is purified, then it is cut with a restriction enzyme that cleaves DNA at specific sequences. This cutting process releases thousands of of restriction fragments flanked by that restriction site. The

restriction fragments are then separated by size using electrophoresis. Then the pattern of DNA fragments is blotted to a membrane to allow probe hybridization. The DNA on the membrane is denatured to single strands to allow it to hybridize with a probe. A radioactive DNA probe is then hybridized to the membrane. If a band is present with a complementary sequence, it hybridizes to the probe, allowing its identification. The final analysis looks like a bar code, making it easy to compare DNA samples. This method of DNA analysis does not amplify the DNA, so it takes a relatively large DNA sample for analysis. The procedure is also time consuming compared to other methods of analysis (Davidson College, 2006).

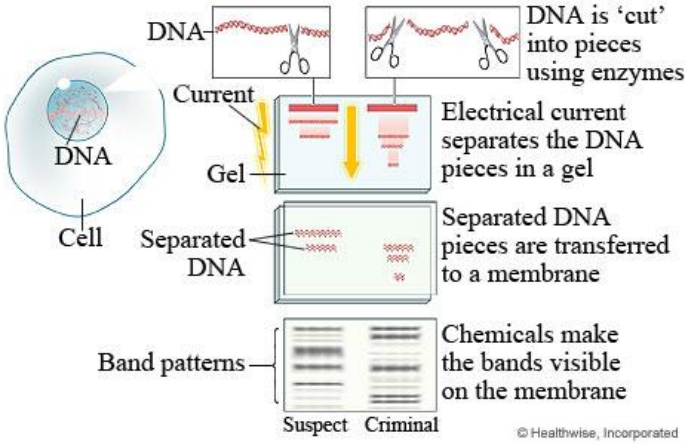

Figure-3: Diagram of RFLP Analysis. Shown in the diagram at the top, RFLP analysis cuts the DNA with restriction enzymes to create restriction fragments, electrophoresis separates the fragments by size (second row), the pattern of DNA is transferred to a membrane (third row), and the DNA on the membrane is hybridized to a probe to create band patterns (lower low). (Melnikow and Dolan, 2009).

VNTRs (variable number of tandem repeats) are repeating lengths of DNA sequences that vary in length from as little as two nucleotides to as many as hundreds of nucleotides (Chantler, 2004). The number of repeats in a VNTR varies from individual to individual, making their analysis useful in forensics. Their lengths also vary between the maternal and paternal loci.

Scientists can use RFLP-type analysis on VNTRs to help determine relationships between individuals (Chantler, 2004). However, due to relatively long lengths of VNTRs, scientists must use large samples of DNA, and the VNTRs cannot be amplified by polymerase chain reaction (PCR).

STRs (short tandem repeats) are similar to VNTRs, but contain shorter repeat sequences, usually a range of 2-5 base pairs repeated tens of times. Due to their short lengths, STRs can be amplified by PCR (discussed below). Considering STR analysis only needs a tiny amount of DNA sample, PCR is also much faster than RFLP or Southern blot-type analysis, leading it to be the most frequently used method of DNA fingerprinting (The Biology Project, 2000).

DNA Fingerprinting Types

DNA fingerprints can be formed using two main methods: non-amplification and amplification. Non-amplifying types are examined through RFLP analysis.

RFLP VNTR Analysis

The RFLP method is the most accurate, but requires a relatively large DNA sample and consumes about a week of time to be completed. RFLP analysis is used to detect genetic diseases, for paternity testing, and for genetic mapping. A DNA sample is usually extracted from a cheek swab, a sample of body fluids, skin, or a strand of hair. As discussed above for RFLP analysis, restriction enzymes like EcoRI or HaeIII, found in bacteria, are used to cut the DNA into fragmented lengths based on specific sequence recognition. These fragments are processed through gel electrophoresis. The gel used for fragment separation is made from seaweed agarose, and requires an electric charge distributed through the gel, with a positive charge on the

bottom and a negative charge at the top. Because the DNA is slightly negatively charged, the smaller pieces of DNA move towards the positive bottom of the gel. The fragment profile is blotted to a membrane, then baked to permanently fix the DNA onto the membrane. The membrane is then hybridized to a radioactive probe. If the probe is complementary to a particular DNA fragment it basepairs with it, allowing the fragment to become visible on x-ray film. Usually 5-10 different DNA probes are used simultaneously to form a complex image, similar to a bar code (Betsch, 2007). **Figure-4** shows an example RFLP/VNTR fingerprint analysis. Note in the figure that the pattern of DNA fragments from the victim (lower lane) matches one of the samples taken from the defendant's shirt (lanes 3 and 4).

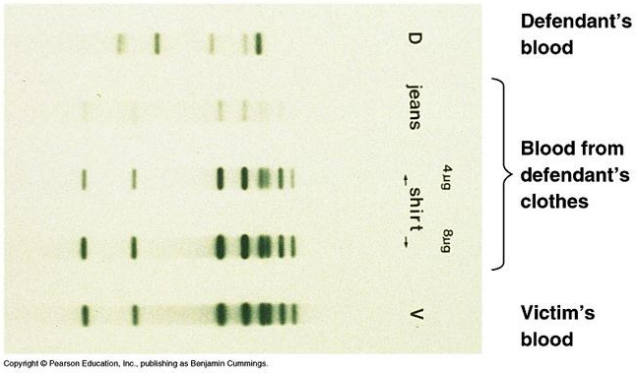

Figure-4: Example RFLP-VNTR Fingerprint. These RFLP profiles were taken from a crime scene comparing blood samples from a victim and a defendant's clothes. Note that the profile of the victim (lower lane) matches the profiles taken from the defendant's shirt. (University of Miami, 2006).

The advantages of the RFLP-VNTR method are it is the most reliable type of DNA analysis, and it is not easily affected by contamination. But it is a long process, which can take weeks, and requires relatively large amounts of DNA. Thus, it is highly important for the DNA sample to be substantial and of high quality (RFLP, 2011).

STR/PCR Analysis

The most common type of DNA analysis is STR/PCR. Polymerase chain reaction (PCR) is a DNA amplifying method that mimics the process of DNA synthesis when organisms copy their own DNA (**Figure-5**). During PCR, the temperature of a reaction tube is controlled by a thermocycler. The reaction contains DNA template, sense and antisense primers (that flank the STR of interest and serve as primers for synthesis), Taq polymerase to synthesize DNA, and deoxy-nucleotide DNA precursors. The reaction tube is heated to around 93°C to denature the two strands of template DNA. Then the temperature is cooled to around 55°C to allow the STR primers to anneal to the template, and the temperature is raised to 72°C the optimum for Taq polymerase to synthesize DNA from the primer sites. Through 35 cycles of DNA denaturation, primer annealing and DNA synthesis, the DNA is repeatedly amplified into millions of copies.

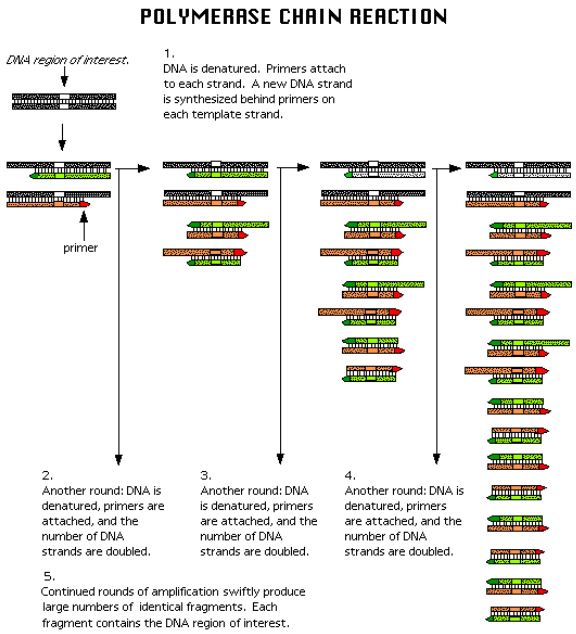

Figure-5: Diagram of PCR. The STR to be amplified is shown in black at the top of the diagram. Through each PCR cycle, the same STR segment is amplified into millions of copies (Access Excellence, 1992).

STR-PCR analysis can be run on only a few nanograms of DNA in a quick and inexpensive approach (The Biology Project, 2000). The process skips the drawn out hybridization steps of the RFLP/VNTR method, and is not as affected by degradation or low-quality DNA. But, with the severe sensitivity of this process scientists must take caution to avoid DNA contamination.

DNA Fingerprinting Applications

DNA fingerprinting is used worldwide in various applications including paternity testing, crime scene identification, identification of unknown human remains, and in molecular archaeology.

Paternity Testing

Blood group testing had been the traditional method for testing familial relationships, but DNA profiling has now become the standard way to prove paternity. Paternity testing is now one of the most common applications of DNA fingerprinting, and has been used around the world to determine a familial relationships. In fact, the world's first court application of DNA fingerprinting analyzed a relationship between a mother and child (Jeffreys et al., 1985). In the UK, scientist Alec Jeffreys was approached by a Ghanaian family whose son was not being allowed back into the country without proof of his relation to his mother. Through traditional blood group testing, the court was able to determine there was a general familial relationship between the mother and the disputed son, but it was not positive whether the relationship was mother-to-son, so their lawyer approached Jeffreys to perform a DNA analysis. The analysis is shown in **Figure-6**, and used two multi-locus probes. The panel on the left represents Jeffreys'

own blood sample as well as the blood samples from all four boys and the mother. The disputed boy is lane B. The bands absent from the mother's sample but found in the three undisputed boys were used to deduce the father's profile, considering Jeffreys could not obtain the father's sample. The results showed that the disputed boy shared 25 of the same bands as the mother, so Jeffreys identified the boy as her own son, and he was allowed to immigrate back to England (Jeffreys, 1985).

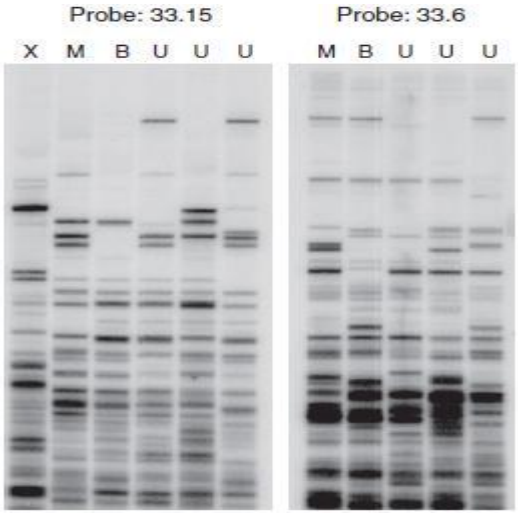

Figure-6: The RFLP Analysis Used by Jeffreys in his First Paternity Case. Lane B represents the disputed boy, lane M is the mother, and the three U lanes represent undisputed brothers. Jeffreys also included his own blood sample (lane X) as a negative control (Jeffreys et al., 1985).

Criminal Forensics

The second most used application of DNA testing is criminal forensics. DNA fingerprinting has provided a breakthrough for crime scene investigators to help solve numerous criminal cases. By scanning databases containing thousands of DNA profiles collected from previously convicted offenders or from crime scene evidence, investigators can compare DNA profiles. Investigators can also determine whether two crimes might be related.

The world's first conviction for murder by DNA testing was in England in 1988 in the case of Colin Pitchfork (The Black Pad Killer, 2004). The bodies of two young girls, both aged 15, were found in 1983 and 1986. When the first body was discovered, criminal investigators revealed she had been raped and murdered. From the semen collected, scientists were able to conclude the suspect was of blood type A, but the police had no suspects. It was not until three years later, when another girl went missing, and was found raped and murdered, that investigators found a suspect with the same blood type A. Richard Buckland had confessed to the second murder, but not the first. With the help of Sir Alec Jeffreys, using the new DNA fingerprinting technique, he proved that both girls had been murdered by the same suspect, and that person was not Richard Buckland. So this case became the first time a defendant was exonerated by DNA testing. Lacking a suspect for the murders, a year later, in 1987, investigators screened over 4,000 men in nearby villages between ages 17 and 34, by DNA testing. When scientists revealed that none of the samples matched, a woman overheard a discussion of a man bragging he had paid someone to provide another sample for his own. Police took that man, Colin Pitchfork, into custody, found a DNA match to crime scene evidence, and convicted him for a minimum of 30 years (Elvidge, 2011).

DNA testing is also increasingly being used in rape cases. **Figure-7** shows an example of a rape investigation. In this case, the DNA profile obtained from the victim's vagina (lane 7) matches the DNA profile of defendant-1 (lane 4).

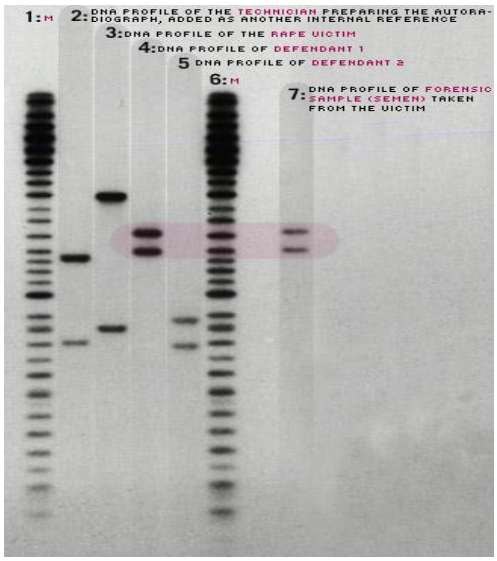

Figure-7: Example of DNA Fingerprinting Solving a Rape Case.
Note that the profile in lane-7 (forensic evidence from victim) matches that in lane-4 (suspect-2). (University of Michigan, 2002).

Identification of Unknown Remains

Another use for DNA testing is to identify unknown remains. One of the best known applications of this use was following the World Trade Center disaster. Rummaging among the wreckage and rubble, scientists continue to use any remains they can to collect tissue samples. In some cases, DNA could only be obtained from the marrow of charred bones. Mitochondrial (mtDNA) has also been used for analysis, as its higher copy number provides a stronger signal (World Trade Center, 2001).

Molecular Archaeology

DNA analysis can also be applied to determine what has happened in the past, many years before our time. Molecular archaeology has recently become a new method for identifying

blood relations for humans and animals. Some of the most admired molecular archaeology research has been done on the "Tyrolean Ice Man" or "Ötzi", dating back to 5350-5100 years before today (**Figure-8**). Remarkably his DNA was in good shape due to preservation in the cold temperatures in the ice he was buried in. After careful analysis of the DNA tissue and bone samples, scientists concluded he was about 46 years of age. He died from an arrow to the shoulder. They even know what food he had just ingested. Analysis of his mitochondrial DNA indicated he came from the Italian Alps region. This archaeology example, which immensely impacted forensic science, proves the amazing power of DNA analysis to link the unknown past and present (Ermini et al., 2008).

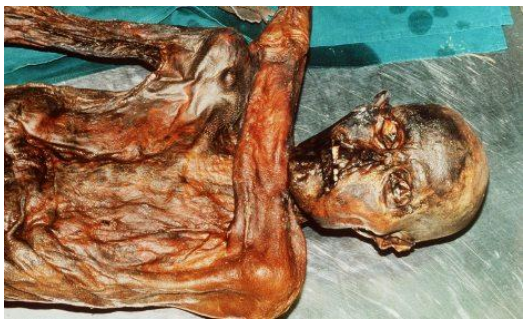

Figure-8: Photograph of Iceman. Discovered in 1991, and approximately 5000 years old, his DNA analysis indicates he came from the Italian Alps region of Italy. (Ermini et al., 2008).

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Chapter-2: DNA Forensics

Mikhail Tan

For hundreds of years, throughout thousands of different cultures and regions, mankind has attempted to form the perfect utopia. Part of this utopian society would include creating a set of rules or laws to govern people by. With these laws comes a process in which those who are accused of violating the laws set forth by each society have the chance to defend themselves from the punishments that lay ahead. For centuries, people have been trying to determine, with some degree of accuracy, the truth behind criminal accusations. Before modern technology and advances in forensic science, those who were accused of violating laws were brought before a figure of high authority who, knowing that their decision would ultimately change one person's life forever, would use mostly subjective techniques and occasionally some objective techniques to decipher the truth. For example, during the Massachusetts Salem Witch trials, the few doctored and misrepresented testimonies of those who wanted to save themselves from punishment lead to the wrongful accusation and death of fellow townsmen.

In the same way, it is of upmost importance that in today's society, when we bring individuals to justice, we use the best techniques at our disposal to determine the legitimacy of the claim. One of the most convincing pieces of evidence in today's forensic arsenal is DNA evidence. This is because each molecule's sequence is unique to each individual, so it can serve to help identify individuals present at a crime scene. However, just like with fabricated testimony, improper DNA collection or testing can alter the results, changing the life of an innocent person. Thus, when utilizing DNA evidence, proper techniques such as avoiding DNA degradation or contamination, and maintaining evidence chain of custody are used to ensure an

error free reading. The purpose of this chapter is to discuss some of the techniques used to ensure proper DNA evidence collection.

Avoiding DNA Contamination

Arguably one of the biggest trials involving alleged DNA contamination was the OJ Simpson trial in the summer of 1994. During the course of the criminal trial, mistakes by the Los Angeles Police Department (LAPD) were uncovered, providing a shadow of doubt to some of the evidence collected, and ultimately leading to a verdict of not guilty (Wang, 2001; Thompson, 2011). During the cross examination of the prosecution's experts, all of them stipulated that when DNA samples are exposed to moist, warm conditions DNA will degrade quickly, and as a result the DNA can become useless leaving a chance for a small contamination to generate a false positive. In addition to the critical errors by the LAPD evidence response team, crucial mistakes were made during lab testing that in the eyes of the defense team proved the innocence of their client. The defense team argued that "…after accidently contaminating his lab gloves with Simpson's blood, the LAPD DNA analyst contaminated the blood drops found at the crime scene with OJ's blood on June 14th"(Wang, 2001). The contamination in the LAPD's forensic laboratory became so rampant that "…it appeared that the reference vials containing the blood of Nicole Brown Simpson and Ronald Goldman were contaminated with OJ's DNA! DNA alleles consistent with OJ's appeared when the victims' blood was typed both at the LAPD laboratory and at two other laboratories to which the same vials were later sent"(Thompson, 2011). From cases like this, many police agencies revamped their forensic procedures, stressing the importance of following proper procedures so another case like this does not happen.

Disposable Gloves

One of the most important ways of reducing DNA contamination while collecting or testing evidence is also the simplest, and is therefore commonly overlooked: frequently changing gloves. According to the National Forensic Science Technology Center (NFSTC), "gloves should be worn throughout sample processing. At a minimum, gloves should be changed at the completion of each step of the process. If gloves become contaminated, discard them and replace with new ones" (Tilstone, 2009). Although when processing large caseloads this quality assurance method may prove a little costly, it could make a key difference between contamination and acceptable evidence. Had the LAPD forensic laboratory technician followed this protocol, the outcome of the trail may have been different, as later samples would not have been exposed to the contaminated gloves.

Gloves are an example of what is termed Personal Protective Equipment (PPE), which is used by individuals to protect them from toxic chemicals or to keep their own DNA from contaminating a sample. Another layer of PPE that helps ensure that DNA evidence is not contaminated is the clothing being worn by the forensic technician. It should become a common practice to wear a clean lab coat/overall when handling or processing evidence (Tilstone, 2009). Wearing lab coats and other PPE can help avoid creating false positives with the collector's DNA, avoiding "…contamination of pre-amplification areas [original crime scene and storage areas] with amplified product [someone else's DNA)]" (Tilstone, 2009). A small sample of a collectors' DNA leaked onto evidence before the DNA amplification process by PCR (discussed in Chapter-1) only requires the minutest amount of contamination to lead test results in the wrong direction.

Kimwipes

Another technique for keeping the accidental transfer of DNA to evidence is the use of Kimwipes, butcher paper, or other types of paper placed under the evidence. This technique will help prevent the remnants of one sample from being left on the work surface and will prevent the new sample from picking up anything that may be on the surface of the work station and adding it to the new sample. In addition, since these products are relatively cheap and disposable, it makes for a very cost effective way to prevent cross contamination between samples.

There are also proactive ways in which to prevent DNA contamination using common sense. When collecting evidence, "avoid touching the area where you believe DNA may exist" (National Institute of Justice, 1999), so that when you collect other evidence the DNA will not be transferred from object to object. In addition, "avoid talking, sneezing, or coughing over evidence" (National Institute of Justice, 1999) as your DNA can easily be passed on. Finally, collectors must "avoid touching your face, nose, and mouth when collecting and packaging evidence" (National Institute of Justice, 1999) to prevent spreading their DNA to the evidence.

Bleach Solutions

Another important step that will greatly reduce the chance of contamination is the constant maintenance and cleaning of surfaces and equipment. The traditional way most forensic laboratories use to clean their surfaces is a 10% mixture of bleach and water. The 10% of bleach is just concentrated enough to kill "…almost all bacteria, fungi, viruses, and protozoa" (Center for Disease Control and Prevention, 2003). With this technique, all equipment and work

surfaces should be cleaned periodically, followed by a rinse of water to prevent the buildup of sodium hypochlorite crystals or any corrosion.

UV Light

A less damaging, but arguably equally as effective, method of surface decontamination is by ultraviolet light (UV irradiation). With this technique, the areas believed to contain high levels of contamination, or those scheduled for regular cleaning, are exposed to UV light of "…254 nm for a minimum of 5 minutes, which is sufficient for disinfection and will inactivate nucleases and extraneous DNA on surfaces" (Tilstone, 2009). The UV treatment, can be used for longer periods of time. This technique has been so beneficial at preventing contamination that UV lights are often used in fume or chemical hoods even while they are not in use, so the area is continuously purged of all foreign bodies.

While using UV light may seem like the wave of the future, this technique has its limitations. One of the biggest limitations is the UV light must be used correctly. To achieve optimal irradiation the "…surface must be perpendicular to the light source to achieve optimal light intensity" (Cone and Fairfax, 1993). In addition to the angle of incident, any glass or transparent surfaces tend to refract light and therefore distort the intensity and wavelength. Thus, some curved surfaces are hard to decontaminate. Because of this, it is highly advisable that both PPE and surface decontamination techniques be used together to build layers of protection into the forensic system.

Evidence Chain of Custody

Equally important to preventing evidence contamination is keeping intact the evidence chain of custody. The chain of custody is defined as "the documentation of movement and location of physical evidence from the time it is obtained until the time it is presented in court" (Chain of Custody, 2011). The documentation associated with the chain of custody for every piece of evidence should include a list of all the people who handled the evidence, and anyone who may have come into contact with the evidence. In addition, the chain of custody also helps document the time and date in which each individual would have come in contact with the evidence. Additional documentation records the reasons a person would be handling the evidence, and what changes or tests, if any, may have been done on the evidence. Also added are the date and time of the evidence collection.

Although the name suggests a continued monitoring of evidence, the documentation actually starts before any evidence is collected. When a crime scene is first approached by law enforcement officers, the first thing that has to happen is for the location to be quarantined to ensure that from the time the crime was committed to the time that the evidence response team arrives, nothing has changed or that there was no opportunity for a third party to introduce contradicting or misleading evidence.

Once the evidence has been collected, it enters thorough system of constant verification and documentation. When the evidence is first collected, important information is included on the packaging or the tag attached to each piece of evidence, and a tamper-evidence seal or packaging is added. Probably the most important information placed on the tag is the item description. Since not all evidence can be placed in clear plastic bags or containers, it is important to provide an accurate description of the contents, so that later laboratory technicians

do not have to open and possibly contaminate every bag to find the evidence they are seeking. The description of the evidence should also include any specific identifiers on that particular item such as a serial number or a specific product brand. In addition, the police case number should also be added. This way, after evidence is analyzed in the lab, it can be returned to the proper storage location.

Documenting the location the piece of evidence was collected is important. At all crime scenes, either a responding police officer or an evidence response technician should draw some sort of schematic of the crime scene, showing the location and orientation of the evidence in relation to both each other and to different landmarks such as walls or a body. This is important because photographs cannot always provide an accurate representation on the special orientation of the evidence collected. Finally, the last piece of information that should be present on all evidence tags and bags should be the name or the identification number of the person who had initially collected the evidence.

With the evidence tag now complete, the next step in the chain of custody can begin. At every stage from transportation of the evidence from the initial crime scene to the storage facility to the forensic lab to the courtroom, the trail the evidence takes needs to be documented. Just as DNA contamination can cause the evidence to be thrown out of court, if the chain of evidence is broken, the piece of evidence might be ruled inadmissible. If the responsible agency cannot maintain a constant and consistent database in which to log the location and access to the evidence, the defense team might be able to petition the judge to have that piece of evidence ruled inadmissible in court, because during the hole in which the evidence cannot be accounted for, there is some possibility that the evidence could have been swapped or contaminated. Therefore, the chain of custody "…establishes the proof that the times of evidence collected at

the crime scene is the same evidence that is being presented in a court of law" (Byrd, 2011). It is important to document the location of the evidence, and to record who had access to it at what time, where the evidence came from, where it is going, and what has been done to the evidence.

Avoiding DNA Degradation

After collecting DNA evidence it should be stored only in a controlled room or facility with locked access, and controlled temperature and humidity to prevent DNA degradation. Unlike other evidence collected from a crime scene, great care must be taken with DNA evidence to ensure that between the crime scene and the forensic laboratory, the sample does not degrade. For the OJ Simpson murder trial, the evidence response teams learned in trial the importance of following proper procedures for collecting DNA evidence. One of the most important things to remember when collecting DNA evidence is to let it fully dry before sealing it in a container. Even when swabbing a wet or damp sample, the evidence response technician needs to wait for the DNA to fully dry on the swab. When the sample is completely dry, it is then important to place the swab inside a paper container and not plastic. If the plastic bags are sealed, it locks in any residual moisture that may damage DNA evidence. Paper bags allow any residual moisture to evaporate, so are better to use. In addition to not using plastic bags, when available, tape should be used to secure the package containing the evidence, not staples, because staples "…are easily removed and can bring up unnecessary question concerning the integrity of seized evidence. Don't forget the defense attorney only has to raise 'reasonable doubt', to get an item to lose its value during a trial" (Multnomah County Sheriff's Office, 2008). Furthermore, "staples do not properly seal items containing fine particles of material" (Multnomah County Sheriff's Office, 2008), and "staples can, and do, cause injury to evidence officers handling

items" (Multnomah County Sheriff's Office, 2008) which can introduce them to dangerous blood borne pathogens or cause their own DNA to contaminate the evidence.

Furthermore, when waiting for the evidence to be sent to a storage facility, it should be stored out of direct sunlight and out of hot environments such as the back seats or trunk of police vehicles. If there is no other alternative option, the air conditioning should be turned on to maintain a cool environment. For longer storage, DNA evidence should be kept in cold and dry location. If stored properly, even DNA that has been stored in a frozen state for 20 years has provided successful DNA testing results.

Even though a room may be lockable, it may be not appropriate to store evidence. When picking a location to store the evidence either permanent or temporary, it is very important that a minimal amount of people actually have direct access to the evidence. When the evidence leaves the secure facility for analysis, it should be accompanied by an evidence request that should contain the name of who released the evidence at what time, who received the evidence at what time, the sample being tested, the test to be performed on the evidence and which machine was used.

Types of Evidence Containing DNA

Deciding which evidence to collect at a crime scene is very important. Because DNA is microscopic, law enforcement personnel must know in advance which types of physical evidence likely contain DNA within it. It would be easy to glance over particular items that may hold crucial pieces of DNA evidence. Some tests can be performed at the crime scene to determine whether an item likely contains bodily fluids that may contain DNA, including Luminol testing. Luminol testing can determine whether blood has been washed away with water or has faded

into the surroundings, but there is no definitive test to check for saliva. **Table-I** shows the common types of evidence in which DNA is found.

Table-I: List of Common Types of Evidence Containing DNA.

Evidence/Item	Possible Location of DNA	Source of DNA
Baseball bat or similar blunt force weapon	Handle, end	Sweat, skin, blood, bodily tissue
Hat, bandanna, or mask	Inside	Sweat, hair, dandruff
Eyeglasses	Nose or ear pieces, lens	Sweat, skin
Facial tissue, cotton swab	Surface area	Mucus, blood, sweat, semen, ear wax
Dirty laundry	Surface area	Blood, sweat, semen
Toothpick	Tips	Saliva
Used cigarette	Cigarette butt	Saliva
Stamp or envelope	Locked area	Saliva
Tape or ligature	Inside/outside surface	Skin, sweat
Bottle, can, or glass	Sides, mouthpiece	Saliva, sweat
Used condom	Inside or outside surface	Semen, vaginal or rectal cells
Blanket, pillow, sheet	Surface area	Sweat, hair, semen, urine, saliva
"Through and through" bullet	Outside surface	Blood, bodily tissue
Bite mark	Person's skin or clothing	Saliva
Fingernail or partial fingernail	Scrapings	Blood, sweat, bodily tissue

(Source: National Institute of Justice, 1999)

Even though this chart provides a potential checklist of evidence that may contain DNA, it is important to remember that this chart should not be solely used while searching for evidence, as other types of evidence might also contain bodily fluids. If possible, investigators

should ask victims or someone familiar with the scene if anything has been moved, or looks out of place, to determine whether those items should be analyzed. This can be a more effective use of time than testing all evidence sporadically.

When deciding which item to collect, is it important to note quality. For example, when hair samples are found, the part of the hair that actually contains DNA is the root not the shaft. Therefore a piece of hair that has been cut is useless for DNA testing, although it could be used in other comparison tests. Secondly, even though blood is a common source of DNA, without the presence of white blood cells, the blood sample will not contain any DNA, because red blood cells contain no nuclei and no nuclear DNA. They do however contain mitochondrial DNA. Furthermore, any bodily tissue to be tested for DNA must be tested before the sample starts to degrade.

Bones and teeth are sometimes used to help solve old cases. Even though all bones in the body contain some amount of DNA, when attempting to recover DNA for old cases, the long bones of the body contain the best chance to extract DNA. Finally, while urine is listed as a possible source of DNA, "urine itself does not contain DNA but it may contain epithelial cells, which contain DNA. Most healthy individuals, however, do not excrete epithelial cells into their urine" (University of Arizona, 1996).

Evidence Collection

With vast differences in the type of physical evidence potentially containing DNA, different techniques can be used to collect the evidence to ensure the DNA can be suitably extracted. The first method is cutting a section of the evidence containing the stain from the rest of the material. This method may be used if the portion containing the stain is small. If not, the

second method might be used: wet absorption. This method uses a moistened sterile cotton swab wiped over the stain, which is then allowed to dry before placing it in storage. Some protocols call for a second dry swab of the same evidence to act as a negative control, and others may require a control sample of the solution used to swab the evidence. When using the wet absorption technique, collectors must ensure that the stain is concentrated on the swab enough to allow testing. In addition, a scrapping method can be used if the cutting technique cannot be used. In the scrapping method, a sterile knife or blade is used to scrape the dried evidence on to a sterile piece of paper, and then the paper is stored. Finally DNA evidence can be lifted like a fingerprint for non-absorbent materials. Just like lifting a fingerprint off a surface, this method uses clear tape pressed on to the surface to adhere to the stain, and then it is pealed off the stain. The backside of the tape can then be sealed with another piece of tape.

When collecting or looking for DNA evidence from hair samples, different techniques are used. The first and simplest method is a visual inspection and collection of hair evidence found on any surface. A second method similar to that of the lifting stains with tape is placing strips of tape over a section of material, and lifting off any fibers or hairs that may be on that surface, then placing an additional piece of tape on the back to secure the evidence. A final way for collecting hair evidence uses a vacuum to collect residual evidence. The vacuum method, however, is not highly recommended as cross-contamination from different scenes or different investigations can occur if a thorough cleaning is not done.

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Chapter-3: Landmark DNA Court Cases

Mikhail Tan

Even though the use of DNA evidence is quite common in courtrooms worldwide currently, that was not always so. The admission of DNA evidence in courts actually made a long journey from the discovery of the technology in 1985 to it being widely accepted and admissible in court today. As history shows us, for any new technology to be accepted into the court room, a precedent must be set by landmark cases. These select few landmark cases truly challenge what was the standard at that time. The early court cases that ultimately affected the ruling of DNA evidence in today's justice system had nothing to do with DNA itself, but rather the process in which new scientific discoveries may enter the court. The purpose of this chapter is to discuss several of these landmark court cases.

Frye v United States, 1923

One of the earliest court cases that set a standard for admitting a new scientific technique into the court room was *Frye v. United States* (1923). James Alonso Frye was originally charged with murder in the second degree. A lower court found him guilty of the charges, yet Frye still maintained his innocence. He and his defense attorney attempted to submit an early form of a "lie detector test" that would have shown that Frye was not lying when he said that he did not commit the murder. This early form of a lie detector "…asserted that:

> blood pressure is influenced by changes in the emotions of the witness, and that systolic blood pressure rises are brought about by nervous impulses sent to the sympathetic branch of the autonomic nervous system. Scientific experiments, it is claimed, have demonstrated that fear, rage, and pain always produce a rise of systolic blood pressure, and that conscious deception or falsehood, concealment of facts, or guilt of crime, accompanied by fear of detection when the person is under examination, raises the systolic blood pressure in a curve, which

> corresponds 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"("The Frye Opinion, 2006).

Frye and his attorney eventually appealed to the Supreme Court of the United States to get the systolic blood pressure test to be part of the evidence to help prove Frye's innocence. From this case the court developed multiple precedence to help future courts rule the admission of new evidence. "Three different approaches emerged. One treats the validity of the underlying principle and the validity of the technique as aspects of relevancy. A second approach, ultimately adopted by the U.S. Supreme Court, is known as the reliability test. A third approach, which requires the proponent of a novel technique to establish its *general acceptance* in the scientific community…" (Scientific Evidence, 2006). Using these three principles, it was ultimately decided that the systolic blood pressure test would not be admissible in court. This was especially the result of the third premise as stated above, the court determined that there was not enough "…general acceptance in the scientific community…" to validate the findings of this test. To add additional clarification, the court stated:

> "Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the 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" (Goothuis, 2008).

Federal Rules of Evidence (401, 402, 403, and 702)

As the US courts continued to process different criminal and procedural cases, by 1975, an advisory committee commissioned by Chief Justice Earl Warren presented "…rules designed to secure fairness in Judicial Administration to eliminate justifiable expense and delay, and to

promote the growth and development of the law of evidence so that truth may be ascertained and proceeding justly resolved" (Federal Rules of Evidence, 1975). The rules were called the Federal Rules of Evidence (FRE). Just as the justices decided in *Frye v. United States*, the FRE helped to determine which evidence should be admitted in court. When admitting evidence, the prosecuting attorney needs to decide whether a specific piece of evidence is *relevant* to the case. In section four of the FRE, rule 401 deals with the "Problems of relevancy…to the question where an item of evidence, when tested by the process of legal reasoning, possesses sufficient probative value to justify receiving it in evidence" (Federal Rules of Evidence – Notes on Rule 401). When evidence is collected at any crime scene, not every piece may be relevant to the person being charged. Therefore, to ensure a speedy and just trial, only pertinent evidence is admitted to the court.

To help further ensure that the defendant is guaranteed a speedy trial, rule 402 of the FRE continues the thought of FRE 401 by stating that "The provisions that all relevant evidence is admissible, with certain exceptions, and that evidence which is not relevant is not admissible are 'a presupposition involved in the very conception of a rational system of evidence'"(Federal Rules of Evidence – Notes on Rule 402). Because of this rule, the foundation of which "…the structure of admission and exclusion rests" (Federal Rules of Evidence – Notes on Rule 402). Thus, as stated in rule 402, not all evidence may be admissible in the court of law.

Rule 403 of the FRE then lays out the circumstances in which relevant evidence may not be entered into the court. Rule 403 states that evidence may be excluded because of the "…risk of unfair prejudice, confusion issues, misleading the jury, or waste of time… 'Unfair prejudice' within its context means an undue tendency to suggest decision on an improper basis, commonly, though not necessarily, an emotional one" (Federal Rules of Evidence – Notes on Rule 403).

One rule in the FRE that arguably has the biggest impact on evidence and witness presentations to the court system is Rule 702. Rule 702 limits and presents the criteria in which expert testimony or new evidence through recent advancements in forensic technology must pass for the courts to recognize it as a legitimate form of evidence. According to rule 702, "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" (Federal rules of Evidence, 1975). In addition, several factors that the Daubert Court determined to be useful for determining the "…reliability of scientific expert testimony" include:

> "…(1) whether the expert's technique or theory can be or has been tested – that is, whether the expert's theory can be challenged in some objective sense, or whether it is instead simply a subjective approach that cannot reasonably be assessed for reliability; (2) whether the technique or theory has been subject to *peer review* and publication; (3) the *known or potential rate of error* of the technique or theory when applied; (4) the existence and maintenance of standards and controls; and (5) whether the technique or theory has been generally accepted in the scientific community" (Federal Rules of Evidence – Notes on Rule 401 and 702).

With the adoption of these Federal Rules of Evidence, older standards set forth by the courts, such as the Frye Standard, were now updated and more universal in their application. This governing document now allowed courts to systematically judge new changes in the legal system using a broader range of criteria. Instead of waiting for a general acceptance of a new scientific discovery, the new FRE standards rely on various criteria including *reliability* to decipher whether the evidence should be admitted.

US v Downing, 1985

In United States v. Downing (1985), John Downing was accused of mail fraud, wire fraud, interstate transportation of stolen property, and aiding and abetting. Mr. Downing and his fellow conspirators were accused of defrauding several manufacturing vendors when they presented themselves as members of the Universal League of Clergy (ULC) at different trade shows where they indicated an interest in purchasing different vendor's products. They would have these vendors ship them products on credit with no intention of paying them back. The prosecution produced twelve different witnesses that identified John Downing as the man they knew as Reverend Claymore. During the trial, the defense team attempted to bring forth a psychologist that would testify as to the unreliability of eyewitness testimonies. The judge declined to admit the expert testimony "…because he felt it was the jury's function to judge the credibility of the witnesses" (United States v. Downing, 1985).

When Downing appealed, the Third Circuit Court decided that the district court was incorrect in its decision to withhold the expert testimony, and ordered the district court to conduct an evidentiary hearing to determine whether the expert testimony should be added to a new trial. In this evidentiary hearing, both the prosecution and the defense team called upon different psychologists to determine whether eyewitness testimonies are reliable. Although the evidence presented by the defense team's psychologist was convincing, there were drastic differences between the tests as to what the eyewitnesses experienced. For example, when the defense performed their tests, the subject was only exposed to the perpetrator for less than one minute, while the witnesses in the Downing case were exposed to the defendant for lengths of time ranging from five minutes to forty-five minutes. As a result, the evidentiary hearing

concluded that the expert testimony would prejudice the jury, so the expert testimony was not allowed, and the guilty verdict stood. From this case came a Downing Standard that when there is a question regarding the *relevancy* of evidence, it is important to conduct an evidentiary hearing into the evidence in question.

People v Castro, 1989

One of the earliest court cases to deeply challenge the theory of DNA fingerprinting was the case of the *People of New York v. Joseph Castro* (1989). Joseph Castro was charged with the murders of his neighbor, Vilma Ponce, and her two-year-old daughter on February 5, 1987. After stabbing the two of them to death, some of the victim's blood dried on Castro's watch. While the police were questioning Castro, investigators noticed the blood stain on his watch, collected the stain, and sent it to Lifecodes for DNA analysis. The DNA testing showed that the sample taken from the watch matched the victim, stating the chance of a random DNA match occurring in the Hispanic community was one in one hundred million. But the defense argued that Lifecodes "…had not applied approved procedures…" when analyzing the sample, so moved to exclude the DNA evidence from trial (Patton, 1990). This began the greatest challenge to the new DNA testing technology at that time.

The New York Superior Court held a twelve-week inquiry into the admissibility of DNA evidence. From this, Judge Scheindlin developed a three-prong test to measure the admissibility of DNA evidence:

> "Prong 1. Is there a theory which is generally accepted in the scientific community, which supports the conclusion that DNA forensic testing can produce reliable results? Prong II. Are there techniques or experiments that currently exist that are capable of producing reliable results in DNA identification and which are generally accepted in the scientific community? Prong III. Did the

> testing laboratory perform the accepted scientific techniques in analyzing the forensic samples in this particular case?" (Patton, 1990).

Over the following weeks, testimonies from both the defense and the prosecution presented expert testimony and scientific data to back their sides. In respect to the first prong, the court decided that DNA testing "… to be generally accepted as reliable and hence admissible under the Frye rule" (Patton, 1990) thus it satisfied prong-1. As for the second prong, the court ruled that "'DNA forensic identification test to determine inclusions are reliable and meet the Frye standard of admissibility,' and that 'DNA forensic identification tests to determine exclusions are reliable and meet the Frye standard of admissibility'" (Patton, 1990), thus the second prong was satisfied. For the final prong, the court's investigation concluded, "…Lifecodes did not follow accepted scientific procedures because it failed to perform certain experiments, technique and controls necessary to produce reliable results" (Patton, 1990), thus prong-3 failed. So the DNA evidence was not allowed at trial. This turned out to be moot as Castro admitted his guilt, and the case never went to trial.

The outcome of the Castro case was a thorough critique of the new DNA science and the establishment of the three prongs for determining whether to admit evidence at each trial. Another outcome was the recommendation to standardize DNA testing protocols, so a Technical Working Group on DNA Methodology (TWGDAM) was formed that helped standardize the procedures. The result of this case produced recommendations of "…extensive discovery requirements for future proceedings, including copies of all laboratory results and reports; explanations of statistical probability calculations; admissions of any observed defects or laboratory errors, including observed contaminants; and the requirement for chain of custody documents" (National Institute of Justice, 1996).

United States v Two Bulls, 1990

Another case that seriously challenged DNA testing and ultimately strengthened the case for DNA fingerprinting was *United States v Matthew Sylvester Two Bulls* (1990). Matthew Two Bulls was charged with aggravated sexual abuse and sexual abuse of a minor when he raped a fourteen-year-old girl. Police seized the underwear that the girl was wearing and sent it to the Federal Bureau of Investigation for further analysis. The FBI then discovered a semen stain that likely belonged to the perpetrator. After comparing the DNA sample found on the underwear with a sample from Matthew Two Bulls, the FBI concluded the samples matched. During the pre-trial hearing to determine admissibility of the DNA evidence, the district judge heard expert testimony from the prosecution stating "…that it has sufficiently established that DNA evidence is reliable, so the evidence could be presented to the jury" (918 F.2d 56, 1990). The DNA evidence was allowed and Two Bulls was found guilty.

But the defense appealed, saying "…the trial court erred because it applied Federal Rules of Evidence 702 [reliability] in determining the admissibility of the DNA evidence instead of using the [general acceptance] test in Frye v. United States … a more rigid standard. He argued that the district court violated his due process because the pre-trial suppression hearing was incomplete" (918 F.2d 56, 1990). So, as in *People v Castro*, the court went into a hearing to determine the criteria to use when deciding whether to accept DNA evidence in trial. The court eventually developed a rigorous five-prong test that assimilated several previous standards:

> "(1) Whether DNA evidence is *generally accepted* by the scientific community [Frye standard], (2) whether the testing procedures used in this care are generally accepted as *reliable* if performed properly [Rule 702], (3) whether the test was performed properly in this case [Castro standard, and Federal Rules of Evidence], (4) whether the evidence is more prejudicial than probative in this case ([Downing standard, and Rule 403], and (5) whether the statistics used to determine the

> probability of someone else having the same genetic characteristics is more probative than prejudicial under Rule 403 [Rule 403]" (918 F.2d 56, 1990).

A new pre-trial hearing was scheduled to determine whether the Two Bulls evidence satisfied all five prongs, and it was concluded that the evidence would be allowed. The original Two Bulls guilty verdict was upheld and he was sent back to prison. Like the Castro case, this case reminded both prosecutors and defense attorneys to be cautious of DNA testing unless it is done properly and under the correct circumstances.

People of the State of Illinois v Miles, 1991

On November 3, 1987, Reggie Miles allegedly broke into a house, sexually assaulted the female resident and forced her to withdraw money from her account before running away. Reggie Miles was then charged with two counts of home invasion, five counts of aggravated criminal sexual assault, one count of criminal sexual assault, one count of aggravated unlawful restraint, one count of armed robbery, and two counts of residential burglary. When police investigated her house, they found fingerprints belonging to Reggie Miles located on several locations including various windows and doors and a bottle of soda. In addition to the fingerprints, they found semen on the bed sheets of the female occupant when he raped her, whose DNA profile matched Miles. In court, the prosecutor presented both the DNA evidence and the traditional fingerprint analyses proving that Reggie Miles was the one who broke into the house, sexually assaulted the occupant, and ransacked the house. Miles was found guilty.

However, Miles appealed the verdict stating that "…[M]y objection at this stage of the proceedings is that the scientific principles on DNA testing are not sufficiently well established to meet the test of *Frye v. United States* as adopted by the Illinois Courts" (*People v. Miles*,

1991). The defense attorney argued that in the past, Cellmark Diagnostics, the company performing the DNA testing in this case, had not followed established procedures. However, when a research scientist and the forensic technician responsible for the actual testing of the DNA sample were brought to the stand, it was revealed that Cellmark had learned from its previous mistakes and had made adjustments to their procedures to be in accordance with the guidelines recommended by the Technical Working Group on DNA Methodology (TWGDAM). The appellate court denied Reggie Miles' appeal and upheld the previous conviction. With the successful prosecution in this case, the public's confidence in DNA fingerprinting became bolstered, and the TWGDAM guidelines validated.

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Chapter-4: Sensational DNA Cases

Jessica McMasters

Introduction

Before modern DNA technology, many investigators left cases unsolved or suspects were wrongly accused. Today, DNA profiling has modified the legal system and is the number one forensic procedure used in some of the world's most popular litigations. DNA is unique to each individual, sometimes helping convict high profile criminals. After previously discussing the process of how DNA profiling works, its applications, and the landmark cases that set precedence for entering the technology in the court room, the purpose of this chapter is to discuss some sensational cases the public is already familiar with to remind them of the role played by DNA. These cases have either involved popular faces, or have contained unique DNA analyses. We will examine three specific sensational court cases, and discuss how DNA played a role in each.

Murder Trial of OJ Simpson

One of the most notorious murder trials of all time, The OJ Simpson Trial made headlines from day one. On the morning of "Bloody Sunday in L.A", June 13, 1994, Nicole Brown Simpson and Ronald Goldman were found dead in the front walkway of Nicole's condo in Brentwood, CA. In 1985, Nicole Brown had married Orenthal James Simpson, a professional running back for the Buffalo Bills' football team, and divorced him in 1992, two years prior to her death. The couple had gotten into fights and physical altercations, but had remained friends for those couple years after their divorce. The previous 9-1-1 calls made by Nicole for physical

abuse throughout their marriage lead investigators to keep OJ as a number one suspect in her murder.

The Night of The Crime

The night of Brown and Goldman's deaths, Simpson attended his daughter's recital sitting separately from Nicole and the rest of her family. He was jealously complaining of how revealing her dress was and how upset he was over their split. After being asked to go to dinner with them, Simpson declined and claimed he went home to prepare for an 11:45 PM flight to Chicago. After dinner, when Nicole arrived back home, she called The Mezzaluna Restaurant at 9:35 PM asking about a pair of sunglasses her mother had left there. The police insinuated she had a relationship with Goldman due to a special request for him to deliver her the sunglasses that night, along with finding her body dressed in a mini black dress with candles lit and music playing inside the house (USA TODAY, 1996).

Living only six blocks from the restaurant, Goldman headed home to change and possibly shower before arriving at Nicole's house around 10:30 PM, as did a limousine several blocks away at OJ's estate to take him to the airport as previously arranged. After waiting 15 minutes outside of OJ's estate, the limousine driver went up to the intercom hoping to reach Simpson inside, but receiving no answer returned to the car. Sitting outside of the estate, the driver noticed a dark, tall figure sneaking into the estate at 10:55 PM. Prior to this, OJ's house guest, Brian "Kato" Kaelin, was disturbed by a large thumping noise outside next to his air conditioner at approximately 10:40-10:45 PM. It was not until 10:56 PM that Kaelin had allowed the limousine into the estate. OJ loaded the limo leaving for the airport between 11:10- 11:15 PM (USA TODAY, 1996).

Meanwhile, back at Brown's condo, neighbors found her dog barking and wandering along the street at 10:56 PM. When returning the dog back home, Sukru Boztepe, Brown's neighbor, found both bodies lying dead outside the front area of her condo, a little after midnight. Nicole Brown's neck was slashed almost severing the head from the neck, and Goldman's body was found with 34 stab wounds to the left side of his head and neck, four of them fatally deep wounds.

The day after OJ arrived in Chicago he caught a flight back home to LA after the police told him the news of his ex-wife's death. Investigators swarmed Simpson's home while he was away in Chicago, noticing blood spots on the ground outside the estate and on the door of Simpson's white Bronco door. After Simpson arrived back in LA, police took him in for questioning. No arrest was made that day, but after confirming a match of the blood stains collected at Simpson's estate and Brown's condo, police issued a warrant for Simpson's arrest on Friday, June 17. After an infamous well televised low-speed chase on the highway, police made the arrest ("OJ Main Page", 1995).

The Trial

The trial lasted 133 days, from January 25 to October 3, 1995. It included 150 witnesses and cost $15 million. With a large amount of blood evidence, witnesses, and convincing arguments, the prosecution thought they had a slam dunk case. But with each step, the defense planted doubts in the jury's mind, especially about the possibility of evidence tampering and DNA contamination. Police Detective Mark Furhman was shown to lie on the stand about using a derogatory word. The defense argued that the white detective had made racial slurs in previous interviews, leading him to lash out against Simpson by planting the bloody glove he found

outside of Simpson's estate and other evidence (Thompson, 2008), which could have angered the jury containing 9 blacks (Linder, 2000).

LAPD criminalist, Collin Yamauchi, admitted that while working in the evidence process room, he had spilled a reference vial of Simpson's blood which could have contaminated blood samples from the crime scene. Also, the defense pointed out that blood collected on wet cotton swatches were left in a plastic bag, baking in the hot backseat of a truck, which could have partially degraded the samples.

Deliberating for only three hours, the jury found OJ "not guilty" for two accounts of first degree murder. Simpson was acquitted, but was not yet free. Soon after the murder trial ended, several people spotted Simpson sporting the size 12 Bruno Magli shoes, which were identified as the killer's shoes, having made claims that he had never owned them. A civil dispute arose accusing him of causing the wrongful deaths of Nicole Brown Simpson and Ronald Goldman. In the civil trial based on the "preponderance of evidence" he was found liable for their deaths, and ordered to pay compensatory damages of $8.5 million and punitive damages of $25 million (Linder, 2000).

Role of DNA

DNA blood stain analysis was the most crucial evidence in the trial. Using genetic fingerprinting, Simpson's DNA was found in the blood at both the crime scene and his estate (**Figure-1**). A large quantity of blood was found belonging to both victims, Nicole Brown Simpson and Ronald Goldman, and OJ. From the killer's escape, a trail of blood was found from the walkway out front of the condo leading to the driveway. Examined by three crime labs, the LAPD lab, a private lab in Maryland, and the California Department of Justice Lab,

this trail of blood, possibly from the killer's own wound, contained Simpson's blood determined by DNA profiling.

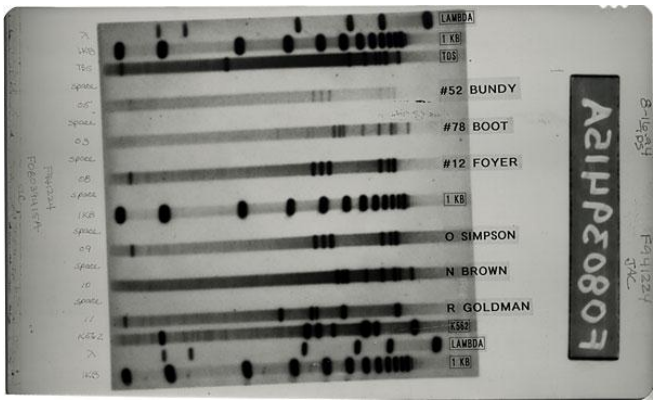

Figure-1: DNA Profiles from the OJ Case. Shown is a radiograph with DNA profiles from the crime scene, Simpson's estate, the victims, and suspect. Notice that the sample found at Nicole's Bundy condo is an exact match to Simpson's DNA. The sample found on the boot is also an exact match to Brown's DNA (National Anthropological Archives, 2002).

Analysts used the RFLP, Restriction Fragment Length Polymorphism, process on the largest blood drop found in the driveway, concluding that the sample was 1 in 170 million match to Simpson's DNA, meaning there is only a 1 in 170 million chance of a similar match occurring randomly. The other four blood drops from the killer's trail on the walkway were tested using PCR, finding a 1 in 5,200 match to Simpson's DNA. With such convincing statistical evidence, the defense did not protest the matches, but instead protested the way the evidence was collected, as discussed above. The jury was persuaded by the defense's tactics, but if the blood samples were accidently contaminated with a small amount of Simpson's blood, it would have shown both OJ's and the real killer's profile, but only OJ's was present.

Putting aside the defense's claims of *potential* evidence tampering, the blood evidence placed OJ squarely at the crime scene. And scattered across Simpson's white Bronco door and

instrument panel were blood spots containing DNA from Brown, Goldman, and Simpson. A shoe print of Goldman's shoe had Brown's blood on it, matching the sample of blood found in the foyer and driveway of Simpson's estate. Socks found in Simpsons' bedroom also contained Nicole's blood. The glove found at OJ's estate had blood from all three individuals (**Figure-2**). But, in the end the defense swayed the jury's' opinion that the evidence could have been tampered.

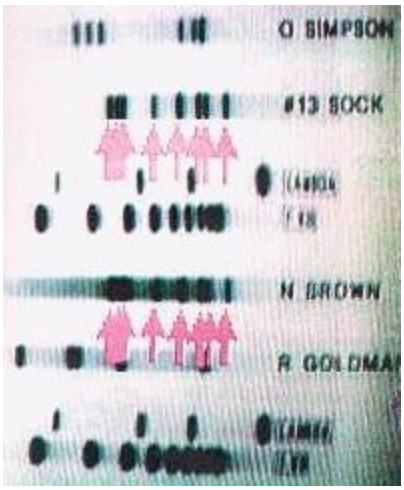

Figure-2: Additional DNA Profiles from the OJ Case. Notice the blood sample collected from Nicole Brown Simpson matches the blood found on Simpson's sock found in his estate. (Linder, 2000)

The Green River Killer (Gary Ridgway)

DNA profiling was used to capture one of the most notorious serial killers in US history. For over a decade, Washington State was terrorized by the "Green River Killer". Most of the victims were prostitutes, the others runaways, ranging in the ages of 15-38. Police investigated the first five victims whose bodies were found in the Green River, strangled to death, and suspected Gary Ridgway (**Figure-3**) a person known by them to hate prostitutes, but they could not find evidence linking him to the crimes. Detailed by his ex-wives, friends, and

family, Ridgway had a love/hate relationship with prostitutes. He became very religious throughout his second marriage and would look at prostitutes with disgust, but at the same time had a lust for them. In previous claims, his second ex-wife, Marcia Winslow, confessed to having once been physically abused by Ridgway when he placed her in a chokehold. According to a background check, he was also known for physical violence in his teen years when he was caught trying to kill a 6-year old boy in the woods. The boy, who survived, said Ridgway walked away saying he always wondered what it would be like to kill someone (Green River Killer, 2010). In 1987, investigators took hair and saliva samples from Ridgway, but with the existing DNA technology they could not obtain DNA profiles to match Ridgway to the victims.

Figure-3: Gary Ridgway. Photo shows the Green River Killer in a recent 2011 hearing for the murder of Rebecca Marrero, the 49th victim. (CNN, 2011)

For over 20 years, the killer went unidentified, and Ridgway still could not be linked to any of the crimes. Then in 2001, Detective Tom Jensen sent biological evidence to the Washington State Patrol Crime Laboratory (WSPCL) for DNA typing. Using the up-to-date technology, DNA analysts finally matched the crime scene evidence to Ridgway (Maleng, 2003). Following his arrest on November 30, 2001, Ridgway faced seven counts of Aggravated First Degree Murder, only a fraction of the Green River killings. His expected

sentence would have been the death penalty, but to spare his life he entered a plea bargain declaring he was willing to confess to 47 counts of murder (Green River Killer, 2010). With a life sentence without parole, Gary Ridgway remains incarcerated at the Washington State Penitentiary in Walla Walla, WA. In a recent update, Ridgway also confessed to his 49th murder on February 18, 2011 regarding the murder of Rebecca Marrero (CNN, 2011). In his confession, Ridgway stated that prostitutes were "easy to pick up and that he hated most of them" (Green River Killer, 2010).

Role of DNA

The reason the Green River case went unsolved for so long was the lack of pervasive DNA technology in the mid-1980's. Although the technology was first discovered in 1985, it was not commonly used in crime solving. In 1987, blood stain analysis was the main tool to identify murder suspects linking them to the victims. The crime lab had obtained a saliva sample from Ridgway, but could not profile the DNA until 2001. With the more widespread use of DNA analysis, the scientists analyzed the 14 year-old evidence using STR-PCR analysis, comparing the semen samples in the victims to Ridgway. It was not until Detective Jensen submitted biological evidence to the WSPCL that Forensic Scientist Beverly Himick found the match. Examining vaginal swabs taken from victim, Marcia Chapman, and pubic hairs from victim Opal Mills, Himick discovered a male DNA profile consistent with Ridgway's DNA profile. Forensic Scientist Jean C. Johnston also analyzed vaginal swabs of victim Carol Christensen and discovered a sperm sample identical to Ridgway's DNA (Maleng, 2003).

Anastasia and Anna Anderson

DNA profiling has also been used to solve old cases. Almost a hundred years ago, the royal Romanov family of Russia was trying to escape the Bolshevik revolution. They were captured and executed in July 1918, and buried in secret site. Rumors indicated that the youngest daughter Anastasia, and her brother Alexis may have been spared from the assassination.

Almost two years after the assassination, in 1920, a woman was found in a Berlin canal with a head injury claiming to be Anastasia. She later changed her name to Anna Anderson (**Figure-4**). German investigators believed she was one of many imposters. Anastasia and the woman had similar physical characteristics: hair color, eye color, and a deformed foot. And a relative who knew Anastasia claimed the woman could be her. But the evidence was inconclusive. Anderson had her believers, but suspected of being a traitor, she moved to the US and started her life over in 1968 out in Charlottesville, Virginia (Welch, 2007). Anna Anderson spent her whole life convincing people that she belonged to The Romanov Family until her death.

Figure-4: Photo of Anna Anderson. She was the most memorable imposter in the missing case of Grand Duchess Anastasia Romanov. It was not until she died that investigators could prove she was in fact a Polish factory worker (Welch, 2007).

Role of DNA

After the bodies had been disposed of and buried, only a few people knew the location of the burial site. They kept quiet for fear of the Soviet Government, until 1991, when the gravesite was discovered nearby the site of execution (Anastasia and Anna Anderson, 2003). It was determined that the site contained 9 bodies. Five out of seven of the Romanov family members were found. Considering the extent the murderers went to destroy evidence, the remains were too degraded to contain intact nuclear DNA, but did contain intact mitochondrial DNA. Mt-DNA, mitochondrial DNA, is found in mitochondria in the cell, unlike nuclear DNA found inside the nucleus of the cell. Nuclear DNA is inherited from both parents and is most commonly used in forensic sciences (National Institute of Justice, 2002). Mt-DNA is maternally inherited, providing clues as to the maternal linkage, and is a higher copy number than nuclear DNA, so it is more likely to be intact at old crime scenes. According to witnesses of the shooting, 11 people had been shot that day (Tsar Nicholas II, his wife and five children, a doctor, nurse, and 2 servants). Only 9 bodies were located, leaving two missing, the youngest daughter, Anastasia, and her younger brother, Alexis. Using DNA information collected from Prince Philip of England, a relative of Empress Alexandra and Queen Victoria, mt-DNA collected from the skeletons proved a maternal lineage from Queen Victoria, proving the discovery of Empress Alexandra, mother of Anastasia and wife of Czar Nicholas II. Three other skeletons were recognized as her three oldest daughters by mt-DNA analyses and determining the ages of the bones. Nicholas' skeleton was determined from the comparison of DNA profiles found in bone fragments to a bloodstained shirt kept in the State Hermitage Museum in St. Petersburg, Russia; he had previously been attacked in 1981 in an attempted assassination. Scientists had also used

the Y-chromosome markers found in bone fragments showing a linkage from his ancestor, Duke Fife (Science Daily, 2009).

In 2007, DNA analysis was finally performed to determine who Anna Anderson was. Anna's body had been cremated, so no tissue could be obtained from her grave, which some people believe was part of Anna's plan. But what was not part of her plan was a piece of her body residing in a hospital storage area from an earlier surgery. They also obtained hair samples from a hairbrush. The DNA profile was compared to blood and hair samples from Prince Phillip, great nephew of Anastasia's mother and husband to Queen Elizabeth II. There were no matches to the royal family, but Anderson's DNA matched Carl Maucher, great nephew of Franziska Schanzkowska. Franziska was a Polish peasant who went missing around the same time Anastasia disappeared. Anna's DNA profile had five mismatches to the royal bloodline, but no mismatches with Karl Maucher's mtDNA (Anna Anderson Exposed, 2007).

Many of Anderson's believers had their doubts about the testing and tissue samples. Errors occur in labs, and the samples could have been swapped to frame Anderson as an imposter. But the tests were performed in four different labs, all receiving identical matches. Dr. Thomas Dudley performed a tissue comparison later in 1993 just to assure the tissue taken back out of storage after 14 years had not been swapped. Both the slides from 1979 and 1993 were an identical match (Anna Anderson Exposed, 2007).

With respect to the real Anastasia's remains, in late 2007, two additional bodies were discovered near the site of the original 9 bodies. The length of their bones matched that of Anastasia and Alexis, and their mt-DNA analysis matched Prince Philip, who shared a maternal grandmother with Anastasia. So the bodies were confirmed as Alexi and Anastasia (Science Daily, 2009).

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Chapter-5: DNA Databases

Markus Ito

Analyzing DNA profiles is a powerful identification tool in the law enforcement arsenal, and a valuable source of information for the medical profession. However, the DNA profiles by themselves are not particularly useful. To search for correlations or similarities between individuals, large DNA databases are necessary. These databases, whether used for identification or research, contain thousands of individual profiles. Depending on the type of database, different kinds of information are stored, and each has its own ethical considerations. As with any large collection of data, there are risks and potential dangers that must be taken into account. Information must be kept private, and the data must only be accessible by authorized individuals. This chapter will discuss the various forms of DNA databases and the benefits and problems associated with them.

Types of DNA Databases

There are two main types of DNA databases, law enforcement databases and medical genetics databases.

National DNA Index System

In the US, the FBI and other law enforcement agencies use several levels of forensic DNA databases: local, state, or national. Although most people think of the Combined DNA Index System (CODIS) whenever DNA databases are mentioned, this is erroneous. The CODIS database they are actually referring to is NDIS, the National DNA Index System. NDIS is comprised of a network of all the local and state DNA databases. CODIS is "the automated

DNA information processing and telecommunication system that supports NDIS" (DNA Initiative, 2011). Essentially, CODIS is like a sophisticated search engine. It can operate within a single state database or can scan all state databases.

CODIS uses two primary indices for evaluating possible matches of the DNA profiles from separate sources. The *Convicted Offender Index* has profiles of individuals that, as the name implies, have been convicted of specific types of crimes (discussed below). Each state dictates which type of crimes mandate DNA contribution, and some states even require *arrestees* to provide DNA (although only that state can access that information). The second index, the *Forensic Index,* contains DNA profiles gathered from samples obtained at a crime scene (Niezgoda and Brown, 1995). The main difference between the two indexes is that the DNA profiles in the Forensic Index have not been associated with an individual. When a DNA sample is run through CODIS, the database compares the unknown sample to both the Convicted Offender Index and the Forensic Index. This allows investigators to determine if there is a link between crime scenes, and also if the sample matches any previously convicted criminals. Obviously, getting a "hit" in the offender index is more desirable as it gives investigators a suspect, but finding links between crime scenes and joining different cases can prove to be equally valuable. Both indices only contain information pertinent to making a match, including "a specimen identifier, the names of laboratory personnel responsible for the DNA profile, and the actual DNA characteristics" (Niezgoda and Brown, 1995). This point is not well understood by the public and prevents the CODIS DNA profile from being used for any purposes other than identification. There may also be Arrestee Profiles and Suspect Profiles present in the states that allow it, but these are not eligible to be uploaded into NDIS, and as such are only available to CODIS labs in that particular state (DNA Initiative, 2011).

In addition to allowing searches for various law enforcement agencies, the CODIS database system allows weekly searches of all the DNA profiles in NDIS to look for matches. These are called "cold hit" searches and have been successful in closing several cases. Since October of 2000, CODIS has discovered 391 case-to-case matches and 846 "hits" in its offender database (Cold Hit Statistics, 2009).

Medical Genetics Databases

In addition to DNA databases used by the justice system, there are also databases used by medical geneticists created for the purpose of research. One such database, the Íslendingabók, or "Book of Icelanders", has been established for over ten years in Iceland (Hlodan, 2000). Unlike CODIS and other DNA databases used solely for the purpose of identification, this database contains significantly more information about an individual, and was established as part of a national health database by the Icelandic government in 1998 (Hlodan, 2000). To that end, citizens were first asked to voluntarily donate tissue samples for DNA analysis, which would then be entered into the database and screened for genes associated with specific diseases. The Icelandic database includes medical records from individuals, as well as their DNA, enabling companies with access to the data to look for correlations between diseases and potential genetic mutations that could have led to those illnesses.

DNA databases used to determine the probability of genetic mutations being associated with diseases in a population employ an entirely different method of analysis than STR analysis in CODIS. Since scientists are looking for a particular gene mutation that has been purported to cause disease, there must be considerably more information contained in the database. The Icelandic database compiled by *deCODE genetics* is being used to search for genes that have

been associated with 30 different diseases, including heart attacks and various types of cancer (Hlodan, 2000). Part of the rationale behind the database is that it could help scientists track inherited diseases, so drugs could be created that would focus on treating or preventing the disease by manipulating that particular gene or gene products (proteins) responsible for it. These DNA databases are also usually tied to medical records, as is the case with the Icelandic database. Thus, researchers can attempt to link medical symptoms with particular gene mutations. So researchers can look for correlations between individuals with the same disease and possible matches in their DNA.

CODIS STR Loci

The primary difference between DNA databases created for law enforcement versus medical research is the type of information that is stored and how it is used. CODIS uses its data for identification only, and relies on Short Tandem Repeats (STRs). As discussed in Chapter-1, STRs are "short sequences of DNA, normally of length 2-5 base pairs, that are repeated numerous times in a head-tail manner" (Hallick and Ryan, 2000). For example, the sequence "tagctagctagc" would represent 3 copies of the STR segment "tagc". Everyone possesses these STR segments, but the arrangement, or "genotype" of the STR (for example, the number of repeats at that location) varies between individuals.

Even so, many members of the population have the same STR genotype at one location, so analyzing only one STR segment would result in several thousand matches. To counteract this, CODIS uses 13 different STR segments, known as the 13 core loci (Foundation for Blood Research, 2009). While the probability of another individual in the population sharing one STR

genotype could be relatively high, the probability that two completely different individuals share *all thirteen* STR segments is virtually nonexistent (**Table-I**).

Table-I: Example DNA Profile for 13 Core Loci.

Locus	D3S1358	vWA	FGA	D8S1179	D21S11	D18S51	D5S818
Genotype	15, 18	16, 16	19, 24	12, 13	29, 31	12, 13	11, 13
Frequency	8.2%	4.4%	1.7%	9.9%	2.3%	4.3%	13%

Locus	D13S317	D7S820	D16S539	THO1	TPOX	CSF1PO	AMEL
Genotype	11, 11	10, 10	11, 11	9, 9.3	8, 8	11, 11	X Y
Frequency	1.2%	6.3%	9.5%	9.6%	3.52%	7.2%	(Male)

(Hallick and Ryan, 2000)

The table shows the STR genotypes for 13 core loci (various table columns) plus the AMEL sex locus (lower right) for an FBI agent that has been subjected to STR analysis. For each genotype is shown its corresponding frequency in the population. For example, for STR locus D3S1358, the genotype 15, 18 is found in approximately 8.2% of the population. By combining all of the probabilities of the 13 STR segments, we find that the frequency of this profile is 1 in 7.7 quadrillion, so by analyzing all 13 loci (if possible), the end result becomes extremely precise. Thus, if a match is found between an individual in CODIS and DNA evidence recovered at the scene of a crime, so long as the DNA was collected without contamination, law enforcement can be almost certain that individual was present at the crime scene.

CODIS also relies on the total number of profiles it contains to help establish accurate frequency percentages (Brenner, 2004). As the total population contained in the database increases, the accuracy of the frequency determination also increases. Moreover, the larger the

database, the more likely it will contain a significant number of profiles of various ethnic groups, which makes matches to minority suspects far more accurate.

DNA Database Ethics

Whose DNA is Collected?

In the US, which individuals are required to submit a DNA sample to CODIS is determined at the state level. In recent years, as the collection of DNA evidence has become more routine for law enforcement, and has been increasingly accepted by the judicial system, many states have begun to broaden the laws requiring certain individuals to submit DNA sample. However, defining the limits regarding the collection of DNA profiles is a difficult and often controversial subject. In order for a particular group, such as sex offenders, to be included, there needs to be a clear rationale and justification that supports gathering of DNA from those individuals. Furthermore, there should also be regulations that address the disposal of DNA in the event of an overturned conviction or acquittal.

Currently, all 50 states require the collection of DNA from convicted sex offenders, as these individuals are deemed highly likely to become repeat offenders, and their profiles are thus likely to help solve crimes. All but six states also mandate that persons convicted of felonies also provide a DNA sample (National Conference on State Legislatures, 2010).

In Massachusetts, all persons that commit (are convicted) of offenses "punishable by imprisonment in the state prison" are required to submit a DNA sample within one year of conviction (Mass. General Law, Ch 22E Sec 3). These laws also apply to minors who commit certain crimes that if committed by an adult, would result in prison time. This definition offers the Massachusetts justice system considerable leeway when determining who should provide

DNA. However, this only applies to people *convicted* of the aforementioned crimes. While this limits the collection of DNA in Massachusetts to convicted individuals and not arrestees, it safeguards the privacy of individuals who are accused and then acquitted. This is an important distinction that differs from other states such as California, which holds that those *accused* of felony crimes must provide DNA (NCSL, 2010).

With respect to removing DNA profiles from the database, despite the Massachusetts ruling that DNA samples are to be collected only from convicted individuals, it is possible during a case that an individual may be called to provide a DNA sample prior to a criminal trial. However, in the event they are acquitted, there is a provision of Chapter 22E that allows an individual to request that their DNA profile be expunged from the state database (CODIS Expungement Policy, 2011). Unfortunately, this is a lengthy process where one must appeal to the Superior Court and is not always successful. Provisions are also in place for individuals to expunge their DNA from NDIS if their profile has been uploaded to the national system, but again, this is a complex procedure that requires a written and certified court order establishing that the conviction or arrest has been overturned (CODIS – Expungement Policy, 2011). This places the burden on the individual to have his DNA removed, instead of the burden being on the courts.

California's laws are far more inclusive than for Massachusetts. In California, Proposition 69, which deals with collection and processing of DNA, has much harsher regulations concerning mandatory DNA collection. Here the law states that "any adult *arrested* or charged with any felony offense" is required to provide a DNA sample (Prop 69, Sec 3 2C). This may be permissible if the intent is to ascertain if the arrestee was present at the crime scene or committed an offense, but under no circumstances should his DNA be stored in a state

database unless it is already on file for a previous conviction. As stated in the 4th Amendment, when an individual is arrested, the arresting officer must have probable cause to make the arrest (Fourth Amendment, 2011). For the same reason, to hold an arrestee's DNA, there should also be probable cause that justifies the retention and processing of the sample (American Civil Liberties Union, 2004). The probable cause for a profile entered into the Forensic Index could be as simple as the fact that an unknown DNA profile was recovered at the crime scene. However, when an individual is found to be innocent, the probable cause that supported the collection and banking of his DNA no longer exists, thus the DNA should no longer be kept on file.

Even more disturbing is the fact that some states are also collecting DNA samples from *misdemeanor* offenders (NCSL, 2010). While DNA has its powerful uses, the continual increase of crimes requiring DNA submission seem to indicate that DNA is becoming a "magic bullet" that law enforcement keeps turning to. There needs to be some kind of minimal requirements that must be met for an individual to be required to submit DNA for inclusion in the Offender Index. This is precisely where the difficulty lies. While the inclusion of sex offenders may seem obvious, the reasons behind that can also be applied to other crimes. In many violent crimes, biological evidence from the perpetrator is left at the crime scene. If we extend the database to include all felons, we can cover more of those crimes. A key justification given for offender databases is known as the predictivist theory, which states that an individual convicted of one crime is more likely to commit more crime than those with no criminal history, including DNA samples from these people in the database would thus help in solving future crimes (Kaye and Smith, 2003). This seems logical, but there are other factors which can also help predict who will be a repeat offender.

DNA Privacy Rights

It is human nature to want to keep our lives private. It is even explicitly stated in the 4th Amendment of the Constitution that all people have the right "to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures"(Fourth Amendment). However, the word "unreasonable" is open to interpretation, and we give up this right on occasion when search warrants are approved and executed by law enforcement.

Yet the collection of DNA evidence does not seem to fall under any clear category. In view of the technology advances that made DNA fingerprinting possible, the definition of unreasonable searches and seizures has been blurred. Although the Supreme Court and lower courts have ruled that the collection of DNA is considered a type of "search" under the 4th Amendment, they have defended these searches on the grounds that offenders who are having their DNA collected are, by virtue of being an offender, subject to lowered privacy rights (Hayes and Katsanis, 2008).

Let us examine this hypothetical scenario: Law enforcement is monitoring a potential suspect, when they observe him throw out an empty drink cup while leaving a restaurant. They recover the cup and test it for DNA. They are able to pull a DNA profile from the saliva on the rim of the cup, which gives them sufficient evidence to arrest the individual. Does this fall under the "unreasonable search and seizure" area? Since the cup was discarded, is it now considered trash, and does the individual forfeit the right of privacy of his DNA simply because it was on the cup he disposed of? These questions are often put forward as arguments addressing laws that deal with DNA collection. Our DNA has a wealth of information that we are only beginning to uncover, and yet when it comes to ownership and protection, we have no specific guidelines.

We might draw a parallel between DNA and a firearm. Both could be accidentally left at a crime scene. The firearm, if it belongs to the perpetrator, can be traced back to him and lead to his arrest. Likewise, the DNA could also place the individual at the crime scene. Thus, even if we "own" our DNA, that does not prevent it from being used to identify us.

DNA used for purposes other than identification, such as research, cannot be regulated in the same way. Since genetics databases contain information far more revealing than forensic databases, they could have implications directly affecting the donors, thus steps must be taken to ensure that those who submit their DNA for research are aware of this. Despite this, in some cases the basic requirement of asking for a person's consent to use their DNA has been altered. For the Icelandic DNA database, asking for the consent of everyone in the population was impractical, so researchers "flipped the presumption, by including individuals in the database unless they objected" (Kahn 1999). Stated this way, individuals would need to opt-out to not be included in the DNA collection. Conceivably, any individual who was unaware of the study could have their DNA collected while on a routine doctor's visit and entered into this database without their knowledge. This would completely circumvent informed consent, one of the cornerstones of any research project that requires subjects to provide information. Any individual who has their DNA entered in a research database should be told of the consequences of doing so, informed of their legal rights regarding the use of the DNA, and *always* have the option of withdrawing from the database, and having all information pertaining to that individuals DNA including the actual sample destroyed.

In this particular case, what is particularly troubling are the agreements between the Icelandic government and the companies it contracted with to create the database. The primary contractor, deCODE genetics, was granted the exclusive rights to the health records of all those

entered into the database. They then partnered with a Swiss pharmaceutical company, Hoffman-LaRoche, to begin testing the DNA for diseases (Hlodan, 2000). The agreement was that free medical drugs would be provided for certain conditions to Icelanders, but only if deCODE and its partners acknowledged that the drug was developed through the use of the database. This is an obvious conflict of interest. Even if such drugs were developed, those involved in the development would have a financial incentive to deny that the database aided the process. Offering medical drugs for free would mean that the companies would make little or no profit after having spent millions in R&D. The creation of this database was flawed from the very beginning, and future genetic studies and databases would do well to learn from these mistakes.

A controversial point against CODIS and other Criminal DNA databases lies in the vast amount of information that people fear could possibly be misused. One common concern is that medical insurance companies might have access to this information, and use it to discriminate against individuals genetically predisposed to specific diseases. The same applies for employers who might not hire a new employee if a serious medical predisposition was known in advance. This fear, while valid for medical databases, is completely baseless for CODIS. As stated before, criminal databases only contain specific information pertinent to the 13 core loci and the identification of the individual (Niezgoda and Brown, 1995). This makes it impossible for any medically relevant data to be extracted from CODIS, even if insurance companies had access to CODIS.

The only potential weakness in the CODIS system is the storage of the original DNA sample which could in theory be further analyzed to obtain medical information. Often, once DNA has been collected and processed, it is retained and frozen for future use in case the CODIS analysis has to be repeated. Since the DNA sample still contains a person's complete genetic

makeup, it is in theory possible to extract information that could be of interest to medical insurance companies or employers. Thus, one could recommend the destruction of this evidence once the DNA identification information has been obtained. However, given the value of DNA in solving cold cases, I would recommend that only the DNA samples obtained directly from individuals be destroyed, as this DNA could easily be reacquired if retesting was necessary. Any physical evidence that might contain DNA is normally retained, as it could have other implications beyond just the DNA itself. The physical evidence should remain as "classified" and be kept in a secure location inaccessible to anyone not involved with law enforcement. In addition, crime scene DNA is often the last hope for individuals who are wrongly convicted. One such individual, Kenneth Ireland, was convicted of rape and murder and spent 21 years in prison before new DNA testing proved he was innocent (Pierce, 2009). If it hadn't been for DNA testing, he would still be in prison.

However, research databases, like the one being employed in Iceland, are completely different. Given the vast amount of personal information being stored in the database, the fear of it being misused seems very real. The fear is magnified when DNA samples are linked to the medical records of individuals, as is the case in Iceland. Despite deCODE's assurances that the data is encrypted (Hlodan, 2000), it is possible for codes to be broken thus compromising the privacy of the entire population. A better system would be to remove identifying information from the database, leaving only the raw DNA for analysis. This would limit the ability for researchers to follow up on individuals since names and other personally identifiable information would not be included, but it would protect the privacy of the individuals in the database in the event the data is compromised.

Chapter-5 Conclusions

DNA databases are critical to law enforcement, and without them it would be much more difficult to match suspects to crime scenes. Advancements in DNA technology have allowed law enforcement to gather the minimum data necessary to identify an individual (13 core STR loci) while keeping the subjects medical data safe. DNA identification has taken a similar route to traditional fingerprints, and may eventually replace fingerprints altogether. By accepting only specific types of information, CODIS and other identification databases adhere to standards that protect the privacy of the DNA donor. Even so, I still believe that there is room for improvement; specifically the DNA should be destroyed once testing has been completed, especially if the analysis was properly performed with controls so it is less likely to need a repeat analysis. DNA contained in any of the levels of CODIS (city, state, national) should continue to be restricted for use by law enforcement only for the purpose of identification.

However, the use of DNA databases for research purposes is still in its infancy, and as such poses a much greater threat to personal privacy. The Íslendingabók "Book of Icelanders" is a clear example of the amount of information that such a database can contain, and should that information be compromised or fall into the wrong hands, it could have disastrous consequences for the included individuals. In addition, the construction of the Íslendingabók contained several flaws that not only misled the individuals donating their DNA (such as not requiring specific donor consent, excluding only those who complained about privacy rights), but the database also contained very little restrictions on the use and access of the data.

Fortunately, more recent DNA databases have learned from the mistakes made with the Icelandic database, and have implemented more stringent guidelines and better safeguards (Nicholson, 2000). In Germany, the Deutsche Forschungsgemeinschaft, an independent German

scientific agency, gave its support for a DNA database, but placed several ethical conditions that stipulated the collection and storage of DNA (Pincock, 2003). Judging by the steps being taken to protect the privacy of individuals in the creation of new medical DNA databases and the ethicality being demanded by those individuals whose DNA the database will contain, we can be assured that any future developments in DNA database technology will be carefully scrutinized.

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PROJECT CONCLUSIONS

DNA profiling has arguably been termed the most powerful tool in the history of forensic science. The technique has many applications beyond forensics, including paternity testing, molecular archeology, identification of unknown remains, and documenting human historical migrations. Chapter-1 discussed the two main ways of performing DNA analysis: RFLP and PCR-STR. RLFP analysis requires a larger DNA sample than amplifying PCR techniques, and take about a week to perform, but is more accurate and less prone to contamination. PCR type analysis is more rapid and sensitive, but is prone to contamination.

Chapter-2 discussed DNA forensics. DNA can be an incredibly powerful tool for forensic investigators, but precautions must be taken to ensure the viability of the collected sample and to prevent cross-contamination. By using personal protective equipment and cleaning surfaces as discussed in Chapter 2, we can prevent foreign DNA from compromising the evidence. Keeping DNA samples in the correct environment to prevent degradation is also vital when storing DNA. Only by adhering to these regulations can we ensure the collected DNA samples will be admitted in court.

Chapter-3 discussed several landmark DNA court cases that set legal precedence for accepting technical information in US courts. The 1923 *Frye Standard* determined that only scientific techniques that are generally accepted in the scientific community will be admitted in court. In 1976, this standard was complemented with Rule 702 of the Federal Rules of Evidence, allowing expert testimony to address the reliability of the new technology and how relevant the tests are. The 1989 *People v Castro* case established a three-prong test to be performed in a pre-

trial hearing to determine acceptability of evidence, and in 1990 *Two Bulls v US* expanded the test into 5-prongs: (1) is the technique generally accepted (Frye Standard), (2) is the technique reliable (Rule 702), (3) was the technique used appropriately in this specific case, (4) is the evidence more probative than prejudicial, and (5) would the testimony be unduly prejudicial to the jury. The five prong Two Bulls standard is still in use today.

Chapter-5 discussed DNA databases which are invaluable to today's law enforcement. Without them it would be considerably harder to identify suspects. However, we need to address several shortcomings of both criminal and research DNA databases. The authors of this project strongly believe a Genetic Privacy Law should be implemented that will set regulations that all law enforcement agencies must adhere to when collecting DNA samples. This law should also cover research DNA databases.

Forensic and criminal DNA databases are relatively secure, and have shown that they are able to provide vital information to law enforcement with a minimal amount of data collected from DNA. One of the main misconceptions addressed in this chapter centered on the 13 core loci analyzed for the CODIS database, which contain no medical information. Thus, individuals concerned with the hacking of medical information from CODIS need not worry. There are however, a few areas where the CODIS system could be improved. Foremost should be the required destruction of all original DNA samples (to prevent additional information from being obtained) and removal of DNA profiles from arrestees who are eventually found innocent. There should also be more stringent regulations dictating whose information can be entered into these criminal databases. The authors believe that arrestee profiles may be entered into CODIS on a limited time basis only, and are subject to the same limitations mentioned above. Convicted individuals should have their DNA on file with CODIS, but this should be limited to serious

crimes to prevent the inclusion of DNA from minor crimes and to prevent labs from being flooded with too many profiles, allowing them to focus on the backlog of profiles for serious crimes.

Medical DNA databases are still very much in their infancy, and it is here where the majority of regulation should take place. Although it is unlikely the US will establish a nationwide medical database in the near future, we should nevertheless create legislation to protect our DNA from those who would exploit the information in the event the US deems a database beneficial. In the author's opinion, if the genetic privacy of individuals is safeguarded, they would be more open to the idea of a medical DNA database. Informed consent, along with the right to opt out at any time, should be mandatory for any research being done that requires DNA from donors. In addition, as a further safety feature in the event the database is hacked, DNA profiles in medical databases should not be linked to any personally identifiable information. In the event general medical records from individuals are necessary, only the pertinent medical information should be released, and only on a case-by-case basis. While a law that covers these issues would limit what the information could be used for, given the potential for abuse, we don't believe we should do anything less.