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DNA FINGERPRINTING AND SOCIETY

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ABSTRACT

Many argue that DNA fingerprinting is the greatest tool in forensic science today, but this has not always been the case. This project investigates the process of DNA typing, describes how it is executed, and investigates its route to become a powerful technology in forensics and in the US legal system. Finally, the authors of this report provide their own conclusions about this powerful new technology.

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PROJECT OBJECTIVES

The purpose of this IQP was to investigate the impact that DNA fingerprinting has in our society today, both in forensic work and in U.S. court cases. Since many argue that DNA typing has revolutionized the world of forensics, the goal of this project will be to investigate the various procedures that have made this technology more efficient, to describe landmark court cases that set legal precedent for admitting complex technical evidence in court rooms, and to discuss the ethics of DNA databases.

CHAPTER 1: DNA FINGERPRINTING AND APPLICATIONS

DNA fingerprinting, also known as DNA typing or genetic fingerprinting, is an identification system that depends on genetic differences in organisms, including human beings. The DNA profile from one sample is compared to that of a different sample. Due to its sensitivity and accuracy, this technique is rapidly becoming the primary method for identifying human beings. The purpose of this chapter is to describe the way DNA profiles are obtained, and to discuss some of its main applications.

WHAT IS DNA?

DNA (deoxyribonucleic acid) is the genetic component of most living organisms. The sequence of its chemical components dictates the properties of the cell containing it. Most cells, tissues, and organs in a human body contain the same DNA. Most of the DNA lies in the cell nucleus, although DNA is also located in mitochondrial organelles. DNA molecules exist as two DNA strands containing a sequence of nucleotides (**Figure-1**) (Moody, 1994). The nucleotides (A, C, T, G; shown as colored rungs of the ladder in the figure) bind to each other in a specific way: A with T, and C with G (Moody, 1994). Information in the sequences of nucleotides determines the features of a person. As seen in Figure-1, each base pair is attached to a sugar/phosphate backbone (blue in the figure) which are joined by ester bonds. The strands run in opposite direction. The base, sugar and phosphate together constitute a nucleotide. DNA forms chromosomes, which are rod like structures of tightly coiled DNA. Humans have 23 pairs of chromosomes in every cell (except the gametes). The part of DNA that controls traits is known as a gene.

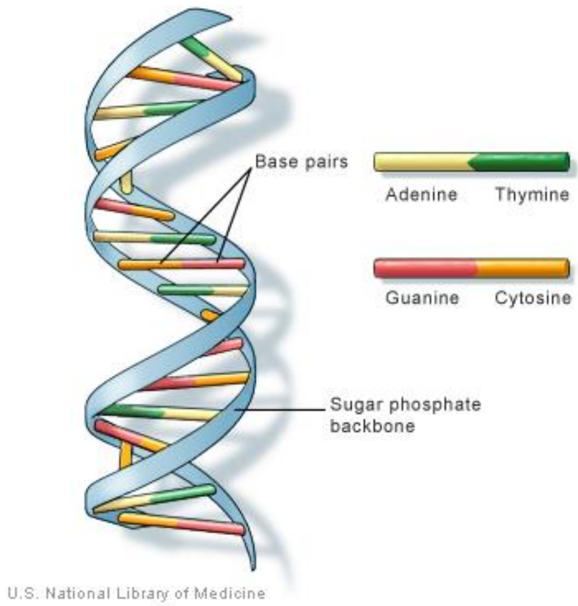

Figure 1: Diagram of DNA Structure.
http://ghr.nlm.nih.gov/handbook/basics/dna

DNA VNTRs and STRs

The DNA sequence is approximately 99.9% identical between all individuals, which establish us as human beings. Much of this *conserved* sequence is required for cell function, so its sequence cannot vary much or the genes will become non-functional. However, the regions on DNA analyzed in fingerprint analyses are not the conserved areas, but instead are locations or loci that are *different* between individuals. Much research has gone into carefully identifying these varying loci, and determining how frequent each pattern is in human populations.

The loci that vary between individuals often contain repeating DNA sequences, and individuals differ in the number of repeats at a given locus. One type of repeat is termed variable number of tandem repeats (VNTR). VNTR loci are usually too long to be analyzed by PCR (see below), so are usually analyzed by the RFLP type technique (see below). Short tandem repeats (STRs) also contain repeating sequences, but their overall lengths are short enough to be analyzed by PCR.

THE PROCESS OF DNA FINGERPRINTING

There are two main techniques for creating DNA profiles: RFLP and PCR. The RFLP technique was the original technique developed in 1985, and is less prone to contamination, but it is not as sensitive as PCR. The PCR process is rapid and sensitive, so it is usually performed first on DNA samples while using the best practices to avoid DNA contamination.

RFLP Technique

The RFLP (restriction fragment length polymorphism) technique was adapted from an earlier Southern blot test by Sir Alec Jeffreys (Jeffreys et al., 1985). DNA is isolated from an individual's blood, hair fiber, cheek swab, etc. using organic solutions such as phenol. The purified DNA is then digested with restriction enzymes that cut DNA at specific sequences. The cutting forms DNA fragments of different sizes. The fragments are separated by electrophoresis, a process in which DNA is loaded onto a gel and an electric current is applied. DNA is negatively charged due to its phosphate residues, so it migrates towards the positive anode. The smaller fragments move faster than the larger fragments as they sieve through the gel. The pattern of separated DNA fragments is then blotted from the gel onto a membrane, which allows the DNA to be hybridized to a complementary labeled DNA probe. The probe sequence is chosen very carefully to hybridize only to specific locations (loci) in the DNA known to vary between individuals. The presence of the probe is then visualized by exposure to x-ray film, which shows a dark band (Gill, 1994). The length of the specific fragment (locus) analyzed represents the number of repeat sequences present for that individual.

The text below describes the detailed protocol for preparing an RFLP-type fingerprint (Betsch, 1994):

- ***Isolation of DNA.***
  A small amount of tissue is isolated to recover DNA from cells or tissues (**Figure-2**, **left side**). This is done chemically by using a detergent that washes the extra material off the DNA. Isolation can also be done mechanically by pressing out the DNA while applying pressure on the sample.

- ***Cutting, sizing, and sorting.***
  Restriction enzymes are used to cut the DNA at specific sites. The DNA pieces are then sorted according to size by a technique called electrophoresis (**Figure-2, middle panel**). The fragments are passed through a gel containing agarose that sorts the DNA pieces by size. An electrical charge is applied to the gel: The positive charge is at the bottom and the negative charge at the top. The pieces of DNA are attracted towards the bottom of the gel because DNA has a slightly negative charge; smaller fragments quickly move to the bottom.

- ***Transfer of DNA to nylon.***
  The separated DNA is next heated or chemically treated in the gel to denature it to single strands that are capable of hybridizing to a probe. The denatured pieces of DNA are then transferred to a sheet of nitrocellulose membrane which will allow the DNA to be hybridized to a probe (**Figure-2, right panel**). The membrane is then heated until baked to permanently attach the DNA to the sheet.

- ***Probing.***
  Adding one or several radioactive probes to the membrane sheet (Figure-2, red) allows the probes to hybridize to their complementary DNA fragments on the membrane to produce a pattern called the DNA fingerprint. Each probe typically sticks to only one or two specific places on the sheet.

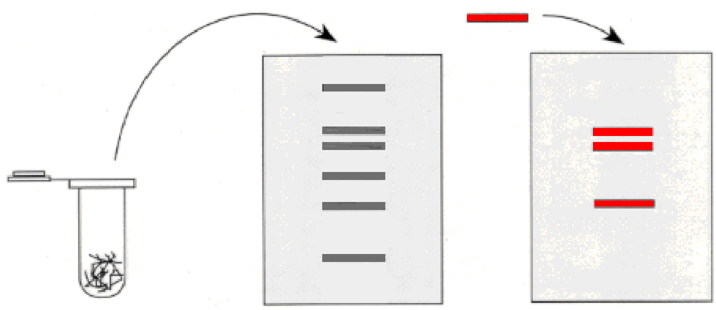

Figure 2: Diagram of the DNA Blotting Technique.
http://protist.biology.washington.edu/fingerprint/blot.html

PCR DNA Fingerprint Technique

The second main method of preparing DNA profiles uses polymerase chain reaction (PCR). PCR is a process for amplifying DNA, so it is well suited for analyzing limited quantities of DNA, especially limited DNA from a crime scene or archeological site. This process involves a repeated cycling of a DNA sample at different temperatures, so is performed in a thermocycler machine (Biotechnology, 2009). The DNA sample is first denatured to separate the strands. This denaturation is usually performed at 94ºC (just underneath boiling temperature). Next, the temperature is lowered to about 55ºC, and two DNA primers (sense and antisense) are hybridized to the DNA template at sites that flank the STR region of interest. Then the temperature is raised to about 72ºC, the optimum temperature of Taq polymerase, a DNA polymerase that synthesizes two new DNA strands using the primers as starting points. The Taq polymerase is heat-stable and remains active throughout the procedure. The amplification cycle is usually repeated about 35 times to prepare millions of copies in just a few hours (Biotechnology, 2009).

The PCR technique is rapid and sensitive, so it is usually the first technique tested on a sample. But it is restricted to analyzing STRs not the longer VNTRs, and it is very prone to contamination. Great care must be used to avoid DNA contamination when collecting DNA samples for PCR analysis.

APPLICATIONS OF DNA FINGERPRINTING

PATERNITY AND MATERNITY

VNTR and STR patterns are inherited genetically (one allele from the mother, and one from the father), so these loci are often analyzed for paternity testing (DNA Paternity Testing, 2005). In fact, the world's first application of DNA testing was for a paternity case in England (Jeffreys et al., 1985) that proved a son of two immigrant parents was really who they said he was. Paternity testing currently is the most frequent of all the applications of DNA testing technology.

CRIMINAL FORENSICS

The second most common application for DNA testing is in criminal forensics. This application is also the most famous. In this application, DNA isolated from crime scene evidence is profiled and compared to the DNA profiles of suspect's DNA, or the DNA profiles present in DNA databases to try to find a match. This technique can be applied to all kinds of criminal cases, from rape to murder.

DIAGNOSIS OF INHERITED DISORDERS

DNA typing also allows genetic counselors to assay for the presence of certain gene types that predispose to inherited disorders. This technology is being used to identify disorders in adults, young children, newborns, and even prenatal fetuses. Some of the disorders that can be detected include: cystic fibrosis, hemophilia, Huntington's disease, familial Alzheimer's, sickle cell anemia, thalassemia, and many others (Betsch, 1994) Early detection of these disorders can allow early treatments to be applied, or can allow parents and medical staff to prepare for a troubled unborn child.   But the technique also has some ethical considerations for diseases like Alzheimer’s where no known cures exist, so the value of early knowledge may only needlessly worry the individual with no clinical recourses.

IDENTIFICATION OF MILITARY PERSONNEL REMAINS

DNA testing can also be used to identify soldier remains when the body is severely damaged. DNA samples are taken from a soldier prior to combat, so the DNA profiles can be compared to unidentified remains if needed. Samples of DNA are also sometimes taken from fire protection personnel to aid their identification in severe fires.

CHAPTER 2: DNA FORENSICS

Forensic science is used to solve criminal cases, but this science can also help determine whether regulations have been violated in manufacturing processes for food, medicines, and even beverages. Therefore forensics has revolutionized the way that criminal cases are being solved and has had a great impact in the justice department.

DNA forensics unfolded about 24 years ago with the invention of RFLP type DNA analysis by Sir Alec Jeffreys (Jeffreys et al., 1985). In the US, its use the courtoom began 18 years ago with the Andrews case in 1991 (discussed in Chapter-3) which set strong legal precedence for DNA evidence in US courts. Detectives had to wait for the process to be generally acceptable and reliable so as to be able to crack old criminal cases from the "unpreserved and microscopic bits of substances that could yield an accurate DNA reading" (Human Genome Project, 2009). The acceptance of this technology rapidly expanded its use in the judiciary system and completely changed the nature of cases.

"We've been using PCR for identification since 1986," said Dr. Mary Claire King, molecular biologist, University of Washington with international expertise in DNA identification of decomposed or damaged remains (Levitt, 2008). So why did it take such a long time before DNA forensics was acceptable. A notable reason is there was not a legal precedence for accepting DNA evidence in courts, and this topic is discussed in detail in Chapter-3. Another is due to the complex nature of murder investigations, as evidenced by the Gary Leon Ridgeway case:

Gary Leon Ridgway, 52, of Auburn, WA was arrested on 11-30-01for the murder of 4 females, believed slain by the Green River Killer. He is 5' 10" tall, 155 pounds. He wore a baseball cap. He read the Bible at work, drank beer and solicited prostitutes for over 20 years. Ridgway was set in his ways, meticulous, overbearing and friendly. He could talk about anything for any length of time. He never said much about himself. He was good-natured when others poked fun. In 1980 he was accused of choking a prostitute but the police let him go.

1986 he took a lie detector test and passed. 1987 his home was searched and he was told to chew a piece of gauze, so they would have a sample of saliva. Eventually he was arrested because DNA linked him to three murders and circumstantial evidence in another. *http://www.karisable.com/greenrivergr.htm*

As for the Ridgway case described, eventually good crime scene DNA evidence was found which linked to the suspect, but it still took a long time to process this case. The case still continued to be investigated until February of 2000. Additional reasons given for this technology to take such a long time to be accepted in the mainstream includes understaffed labs where the workers are either overworked or underpaid.

13 CORE LOCI

To classify individuals by DNA testing, forensic scientists currently analyze 13 core loci. These regions vary from person to person, and it is hard to find someone with another person's DNA sequence at all 13 locations. This in turn forms the DNA profile entered into CODIS to link samples of evidence to DNA from suspects (Human Genome Project, 2009). Some examples of DNA uses in forensics are:

- Link DNA evidence from a crime scene to potential suspects.
- Absolve innocent persons wrongly accused of crimes.
- Identify calamity victims.
- Establish paternity, and help in custody and child support litigations.

- Identify endangered and confined species as an aid to wildlife officials to prosecute poachers.

PROBLEMS WITH DNA FORENSICS

Although this technique may be the most powerful forensic technique in history, it also comes with some cautions and disadvantages.

Contamination

This problem sometimes obscures the ability of samples to be compared, and is known as the “Achilles heel of the process” (Kujtan, 2004) The occasional corruption of the DNA samples allows for the DNA analysis to be thrown away and not taken into account. For this reason, scientists have devised protocols for minimizing contamination during evidence collection, (discussed below). And sometimes it is advisable for investigators to get a clean sample of tissue from a victim and then compare it to the sample gotten earlier right after the crime. The difference between these two samples will represent the suspect’s DNA.

POPULATION GENETECIS IN DETERMINING PROBABILITY

The VNTR’s and STRs analyzed are not evenly distributed in the human population, therefore it is necessary to estimate the allele frequency for each of the 13 core loci in the human population. So for example if a suspect’s DNA has 4 repeat sequences at locus-1, how many other people have that same 4 repeat sequences at that location in their DNA. The probabilities at each locus are then multiplied together to get the overall chance of a random match (Moody, 1994). The frequencies vary with people’s genetic background. VNTRs that occur in African Americans are not the same as those that occur in Caucasians. This may result in new questions and challenges that scientists feel could lead to an era of racial discrimination once again.

Error calculations in the probabilities should be carefully considered, and swayed towards the conservative side when possible. If the allele frequency of locus-3 is only known in the general population, yet the suspect is Caucasian, then use of a conservative probability at this locus is advised until its frequency only in the Caucasian population can be determined.

DNA FORENSIC TECHNOLOGIES

DNA AND EVIDENCE COLLETION PRINCIPLES

In law enforcement, the collection of DNA evidence is critical in connecting the suspect to the crime scene, but as noted above contamination or degradation can cause this evidence to be omitted from court. To avoid this, procedures have been enacted to minimize the chance for contamination or degradation.

Swab Method

This method of obtaining DNA from crime scene evidence uses cotton swabs to absorb wet stains from evidence. The swab is slightly moistened at the tip with clean water, and then the stain is swabbed to absorb it. Protective gear should be worn at all times to decrease pollution of the scene from aerosols and hair from the collector. Forceps should be used to handle each swab. The swab is dried and packaged into paper bags to avoid moisture. This sample should be kept away from any direct sun to decrease DNA degradation (Kramer, 2009).

Tape Lift

This method of sample collection uses tape to trap fibers etc from crime scene evidence. This is especially useful for dried blood samples, and it preserves the size and shape of the stain. The tape is then stuck onto a piece of white paper with sticky side facing down on the paper. The paper allows for the collected specimen to remain dry (Kramer, 2009).

Blood Samples

Blood is the most common way to obtain DNA from a crime scene. Different techniques are used in the collection of blood samples from a crime scene, depending on whether the blood sample is dried or wet. For dried blood stains that are small and transportable, they are packaged in an envelope. This allows for minimal interaction with stain and thus less contamination takes place. Liquid blood samples can be collected in both living and deceased persons easily. The blood is preserved in one of the following tubes:

- Grey NaF (blood alcohol)
- Purple (EDTA)
- Yellow (ACD) sexual assault kit
- Red top (plain) or green top (heparin) tubes SHOULD NOT BE USED.

When working with a wet blood stain that is small and transportable, the sample is then packaged in an envelope and air dried. The envelope allows for minimal interaction between the stain and investigator, while allowing the blood to remain dry to prevent DNA degradation. If the stain is large, the stain is this absorbed in a swab (as discussed above) and packaged in a plastic bag. This is then air dried and repackaged to another container. The new package is also air dried.

CHAPTER-3: LANDMARK DNA COURT CASES

Although DNA technology has been deemed by some people as the greatest forensic tool in the history of forensic science, the acceptance of this complex technology in US courts has not been straightforward. This chapter describes some landmark cases that helped establish legal precedence for accepting DNA fingerprinting evidence in US courts, including some early cases that pertained to technical evidence but did not involve DNA.

Frye v. United States (1923)

James Alphonzo Frye was originally convicted of second degree murder in 1923, but the case was appealed to the Supreme Court of the District of Columbia based on the premise that Frye had previously passed a "lie detector test" proving his innocence. In the second trial, the Supreme Court questioned the viability of this new lie detector technology, wondering whether published scientific studies could back it up, and whether it had general acceptance in the scientific community. The court ended up ruling the lie detector technology did not have general acceptance in the scientific community, so the lie detector evidence was not allowed, and the original guilty verdict stood (Frye v. United States, 1923).

After serving 3 years in prison, Frye was released because another person confessed to the crime. So although the lie detector test may have been correct in this case, it still did not have general acceptance in the scientific community, and lie detector tests are still not allowed in US courts today. Eventually the *Frye Standard* of general acceptance was used for several decades as the gold standard for allowing technical evidence in courts (Bernstein, 2001). Unfortunately, the DNA evidence did not achieve the rigorous Frye Standard until the case of U.S. v Two Bulls, 1990.

U.S. v. Downing (1985)

In 1985, John W. Downing was charged with mail fraud, wire fraud, and the interstate transportation of stolen property (U.S. v. Downing, 1985). Downing lead a group called the "Universal League of Clergy" who defrauded vendors by collecting money and not delivering the goods. Twelve eyewitnesses claimed Downing was the man they knew as Reverend Claymore who had defrauded them. The defense argued that eyewitness testimony is generally unreliable, and wanted to use a psychologist as an expert to prove that point, but the Court denied the defense request. Downing appealed the District Court guilty decision on the basis that eyewitness testimony is inaccurate. In the appeal, the U.S. Court of Appeals agreed that the District court was wrong for not including the psychologist's expert testimony on eyewitness testimony, as including the expert's comments would be *relevant* to the case. The case was sent back to the district court for a new ruling. But the district hearing failed to reinstate the expert witness, so the original guilty verdict stood (U.S. v Downing, 1985). This case helped establish the *relevancy* and *usefulness* rules of expert technical witnesses, which outweighs the Frye Standard (Harvard Law Publications, 1999).

Andrews v. State of Florida, 1988

Tommie Lee Andrews was a suspect in more than twenty assaults in the Orlando area in 1986. He was finally linked to a rape in 1987 when Life codes (Valhalla, NY) matched his DNA to semen left at a crime scene (Andrews v. State, 1988). A relevancy hearing was conducted which concluded that DNA testing is “scientifically reliable “. This hearing took place because DNA evidence had never been used before in US court cases. The court ruled that the technology was “positively reviewed by peers” and thus was acceptable in the court system (Andrews v. State, 1988).

Although the first trial ended in a hung jury, the retrial included the DNA evidence. This included DNA statistical data (allowed by applying the Downing relevancy test), and Andrew’s traditional fingerprints left on a windowsill, and his identification from a photo lineup. Tommie Lee Andrews became the first person in the U.S. to be convicted of a crime based on DNA evidence. Andrews appealed the verdict, but on November 22, 1988, the original convictions and sentences were affirmed (Andrews v. State, 1988). Soon after that trial, Andrews DNA was found to match that of several other victims in the Orlando area. His prison sentence went from twenty-two years for one rape, to over one hundred years for serial rape. “Following Andrews v. State, DNA testing could now be more easily applied to future cases, especially involving sexual assault and other crimes of violence (Coleman and Swenson, 2003).

People v. Castro (1989)

Joseph Castro, a thirty-eight year old Hispanic maintenance man in New York, was accused of murdering his pregnant neighbor, twenty-year old Vilma Ponce, and her two year old daughter (People v. Castro, 1989). Life codes Corp. analyzed a bloodstain on Castro’s watch, and it matched the victims. Statistically, the chance of a match in the Hispanic population was one in one hundred million. In August 1989, Judge Gerald Sheindlin developed a three-pronged test to determine whether DNA evidence should be accepted. This was done by following thousands of pages of expert testimony over a twelve week period. The Judge wanted to know whether there was a general acceptance of DNA technology in the scientific society (prong-1), whether viable and reliable results could be obtained from this procedure (prong-2), and whether the DNA testing was correctly performed in this case (prong-3).

On August 14, 1989, the New York Supreme Court held that Castro prong-1 and prong-2 met the Frye Standard, but not prong-3 in this particular case (People v. Castro, 1989) since Life codes did not use generally accepted scientific techniques for obtaining their results. Thus, the DNA evidence was ruled out. The case never went to trial, Castro confessed to the murders in late 1989. But the Castro three prong test served as a strong standard for which other DNA evidence cases were subsequently judged. This in turn increased the need for more experimental standards for DNA fingerprinting. Following the rigorous Castro hearing, the FBI created its "Technical Working Group on DNA Analysis Methods" or TWGDAM, whose universal recommendations remain in effect to this date (Federal Bureau …1998).

People v. Miles (1991)

In 1991, the State of Illinois convicted Reggie Miles of 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 (People v. Miles, 1991). The evidence against Miles included traditional fingerprints and crime scene DNA profiles that matched the defendant, performed by Cell mark Diagnostics (Maryland) following the then newly established FBI TWIGDAM guidelines. Miles appealed the convictions to the Appellate Court of Illinois, Fourth District, arguing that Cellmark did not use procedures that give reliable results. The appeal court denied his appeal, upholding the earlier conviction. This case provided overall strong support for DNA evidence, and verified the then new TWGDAM guidelines.

CHAPTER 4: SENSATIONAL DNA COURT CASES

Sensational DNA court cases are different than landmark cases. These cases do not necessarily establish new legal precedence, but they remind the reader of the key role that DNA has played in cases that captured the attention of the nation. This chapter will discuss a few of these sensational cases.

The first man to be arrested and convicted of a crime using DNA evidence was Colin Pitchfork in 1988. This famous case involved two rape-murders in England. Initially, the police had no suspects, so DNA samples were collected from men in the local area to compare their profiles to the evidence left on the two murder victims. The DNA profiles from both murder victims was the same, so both women were raped (and likely murdered) by the same man. But the crime scene evidence did not match any samples provided by the local men. And worse, the profiles eliminated one man who had claimed to commit the murders. The problem was eventually solved when a woman in a bar overheard an individual brag that he had provided a blood sample for Colin Pitchfork. When the police tested Pitchfork's DNA, the profile matched that from the crime scene evidence, and Pitchfork admitted to committing both murders (HBO Forensic…2004; Colin Pitchfork, 2007).

Another sensational DNA case that stands out is JonBonet Ramsey. In this famous case in Denver, young JonBonet was found strangled in the basement area of her parent's home. No suspects were found, so the police turned their attention to the parents. For eight long years, the Ramsey parents suffered from people thinking they had murdered their daughter. It wasn't until forensics scientists found DNA on the victim's clothing and underneath her fingernails that the parents of JonBonet Ramsey could be cleared of the murder. In 2005, the DNA found on

JonBenet did not match the parents, so they were exonerated (JonBonet...2005). Although this famous case has not been solved, the investigation continues, and police hope a match to the crime scene evidence will eventually be found. Some people argue this case highlights the need for a national DNA database containing everyone's profile so likely this case would be solved, but this idea is ethically controversial (see Chapter-5).

Another sensational DNA court case which captured the public's attention was the Boston Strangler. The Boston Strangler sexually assaulted and killed 13 women in the 1960s. During this time DNA forensics did not exist. The investigators never found a suspect, until 1965 when Albert DeSalvo confessed to the murders while serving time in a Massachusetts prison for another crime. Some argue that DeSalvo was innocent of the strangler crimes, as no eyewitnesses or evidence could place him near the crime scene. Moreover, in police lineups, surviving victims (not murdered, but with similar MO's) thought DeSalvo's cellmate Nassar looked familiar to them, but not DeSalvo. Some argue that DeSalvo learned the details of the crimes from his cellmate, and passed them to the police in his confession, as he wanted to be famous and make money off the book rights for his family (Bardsley and Bell, 2003). DeSalvo was stabbed to death in jail in 1973. It wasn't until 2001 that DNA forensic analysis was applied to this famous case, and it showed that the DNA profile from the DNA on the underwear of Mary Sullivan did *not* match that of DeSalvo (Guardian News…2001). Thus, almost 50 years later it was proven that DeSalvo did not rape Mary Sullivan, and may have lied about being the strangler. Many wonder if he lied about all the murders, and the Boston Strangler is still at large. This sensational case provides the public with an example of just how powerful DNA evidence can be even decades after the crime. James Starr the head of the strangler DNA forensic team had this to say: "The evidence that was found is quite clearly indicative of the fact that Albert

DeSalvo was not the rape-murderer of Mary Sullivan"(Guardian News.. 2001). Starr also wishes the authorities in Massachusetts and Boston would release more information on the other strangler victims to see if they were all raped by the same man. This case should be an example to all criminals who believe they got away with their crime, because with increasing knowledge about DNA testing, the more difficult it will become for criminals to get away.

Handling of DNA evidence must be done very carefully and by a strict protocol to avoid contamination or DNA degradation. This protocol if not done properly could jeopardize all of the DNA evidence in a case, and this is exactly what happened in the *trial of the century*, the O.J. Simpson trial. In this case, famous former football player OJ was on trial for the murder of his ex-wife Nicole Simpson and her friend Ronald Goldman. Blood DNA profiles were key forensic evidence at this trial. With respect to DNA sample degradation, blood found at Nicole Simpson's house was accidently left by a new forensic technician in a hot truck for several hours, which degraded the samples. Because of this, experts agreed that it could not be used for DNA testing. With respect to contamination, a vial of OJ's blood was spilled in the laboratory by a Los Angeles Police Department criminalist who may or may not have contaminated other blood samples. And in one of the most famous portions of the trial, Detective Mark Fuhrman was found to have used racist comments in an interview, raising the possibility that he could have contaminated blood samples on purpose. Although the DNA evidence in this trial was abundant, and could have been very useful in solving this criminal case, the mishandling of the evidence rendered the DNA evidence useless. This highlights how easy it to get DNA samples mixed up or contaminated, so strict protocols need to be followed. This case also may raise concerns for anyone convicted of a crime using DNA evidence, how do they know their DNA samples were not mishandled? (Wang, 2001; Thompson, 2008)

Thousands of new DNA profiles are being entered into databases each year, so the hope is that more past crimes can be solved. Unfortunately, there is just not enough money or people working on this technology to prevent a sample backlog in most states. If the real Boston Strangler is eventually found, it will be a huge step for DNA forensics because the public will be amazed that more than 40 years later there still is a chance of justice. Although sex crimes have a six year statute of limitations, no such limitation exists on murder crimes. Many convicted criminals are now asking for post-conviction DNA testing, and this demand has further increased the sample backlog.

These sensational court cases provide excellent examples to the public of the power of DNA testing, even years after a crime has been committed. There can be a lot said about convicting the correct individual, but it is even more imperative that innocents are not punished for crimes they did not commit. Hopefully as DNA technology advances, it will help provide a deterrent to criminals who realize its power for solving crimes.

CHAPTER 5: DNA DATABASE ETHICS

DNA databases are computer depositories of DNA profiles that other crime scene profiles can be compared against for hopefully finding a match. Such databases are routinely used today for helping to solve crimes. But key ethical questions arise as to *whose* DNA profiles should be entered into a database. From purely a crime solving point of view, some people argue that every individual's profile should be on file in a database, and this would greatly increase our chances of solving crimes. But should innocent people be required to donate their DNA? Should people *arrested* of a crime provide DNA? Should people *convicted* of a crime provide DNA? This chapter discusses this important ethical topic.

Genetic Privacy and Forensic Databases

Sir Alec Jeffreys, the scientist who invented genetic fingerprinting (Jeffreys et al., 1985) has expressed concerns of innocent people's DNA being present in national DNA databases. In England, their National DNA Database (NDNAD) holds more than 5 million DNA profiles of individuals, and it is intended for criminals that have been *arrested* of crimes. The problem is there are thousands of innocent people's profiles on the database who were arrested but later exonerated. Approximately 573,639 people on the database have no conviction (Merry, 2008), which can violate their privacy rights. Why are these individuals still on the database? Why is it so hard for them to be removed from the database? What information on the database, if any, could threaten someone's civil liberties?

In the U.S., the world's largest DNA database is CODIS (combined DNA index system). This database is currently managed by the FBI. Since 1988, all fifty states have made laws authorizing the taking of DNA from *convicted* offenders. Initially, the database was to only include sex offenders, but now most states have expanded the required coverage to include those convicted of murder, manslaughter, kidnapping, arson, and robbery. Federal law allows the storage of DNA of persons convicted of a crime, crime scene specimens, unidentified human remains, and relatives of missing persons. Having a database could help solve unsolved cases. For those crimes with a statute of limitation, a "John Doe warrant" can be issued for the individual belonging to the DNA profile, which keeps the case open until a match can be obtained.

Some people argue that taking DNA samples threatens major civil liberties such as genetic discrimination and genetic privacy. Although the DNA samples themselves contain personal information about ethnicity, paternity, race, and disease susceptibility, this type of genetic information is not contained in any of the 13 core loci currently entered into the CODIS database. And one *can not* extract more information from a database than is entered into it, but some are still concerned. Genetic discrimination can be seen when people have been denied medical or life insurance based on their genetic predictions from DNA samples and the human genome project. Thus, if a DNA sample is taken, it should be destroyed after the 13 core loci have been analyzed for forensic purposes, to prevent any subsequent testing to obtain medical information. Some people have concerns of criminals breaking into a database and possibly taking innocent's peoples DNA and making it public. But again, even a world class hacker cannot obtain medical information from a *forensic* database if the database only contains the 13 core loci.

If a DNA database can solve crimes and increase public safety then it should be used, but it should not be abused. The director of Virginia's DNA database program said "it is revolutionizing the way police do their work" (Manuel Roig-Franzia). DNA fingerprinting is responsible for many individuals who were wrongly convicted of crimes to be freed, even freeing some individuals from death row. The forensic database has also helped solve crimes that are decades old, and others that had convicted the wrong person. Some individuals voluntarily give their DNA so they can clear their name from an investigation which saves law enforcement a significant amount of time to find the guilty individual. The database not only helps solves crimes but it also helps to prevent crimes, because the criminal knows that one hair or drop of sweat can prove his guilt in the crime. For these reasons it is understandable why so many are in favor of having a forensic DNA database worldwide. The database would make the world a safer place, and that is where the public's interest is…a safer community. The question is not the database's capabilities but rather who is to remain on the database and is it safe to have your DNA on the database?

If a crime occurs where DNA is found, some argue is makes sense to first eliminate all suspects that do *not* match the DNA to save the police time questioning suspects, and to avoid embarrassment to other questioned individuals? DNA could easily clear someone's name that would normally be a suspect had it not been for the DNA. For instance in the JonBonet Ramsey case, if the DNA under her fingernails was found and tested right away the parents of JonBonet would not be seen as they are today in the public opinion as murderers. When a person becomes a suspect of a crime their rights are diminished. Their homes and personal belongings are searched. Even their traditional fingerprints are taken to see if there is a match, and those fingerprints are kept in the police computer to potentially identify the person later for a different crime. If traditional fingerprints are kept this way, then why if there is DNA at a crime scene should the DNA not be profiled and placed in a database to later prove the person innocence or guilt in a much quicker fashion?

A problem that could arise from this kind of investigating in which all *arrested* suspect's DNA profiles are stored is there would have to be strict rules that the suspects must be legit. Once considered a suspect, they would have to allow their DNA to be taken. If someone is a suspect of a crime they did not commit, most people would want to voluntarily submit their DNA to be cleared of the crime. Not wanting to give your DNA only raises more suspicion towards you as a suspect.

In the U.S. all 50 states require all sex offenders to give DNA samples, and 46 states require convicted felons to give DNA samples to the state's database (National Conference, 2009). DNA databases in all states are also connected to the National DNA Index System which is used in for federal and state information sharing. The problem with this system is that not all states have the same laws for whose DNA can be taken and for what crimes. For instance, only eleven states take DNA samples for certain misdemeanors, and 15 states have laws stating it can take DNA samples from any arrestee. More than half the states in the U.S. allow for DNA sampling for misdemeanors which means there are twenty four states that only take sampling from serious felonies. When someone's DNA sample is taken it is put on a national database, so it seems unfair that if a person in Texas commits a crime and is arrested his DNA is on the database, but the same crime in Massachusetts does not allow for the taking of that person's DNA. The controversy is that each state must have the same guidelines for who and for what crimes DNA should be taken, because it is not just a state database it a national database that can be shared all over the country.

Genetic Privacy and Individualized Medicine

Genetic privacy could become a major concern in the future if databases begin to include people's entire genomes that would include medical information. Such entire genome sequencing may be the wave of the future for individualized medicine, as physicians learn which gene sequences help patients respond to specific drug treatments, and which sequences make the patients resistant to treatments. Other people may not want to know what diseases they will have, because it may change the way they live their life. It is their right whether to know this information or not, but how is that individual sure that someone else is not be looking at his or her genome sequence from a DNA sample they had given at an *earlier* date for a different reason. Many states do not have protection against the abuses that could occur with having a medical DNA database hacked into. Although prior knowledge of one's genetic sequence can result in treatments or cures for some conditions, it also could lead to discrimination from insurers, where the insurer will higher rates or denies coverage all together. It could also discriminate against race, as blacks and minorities are disproportionately represented on the database. For instance, in the UK, forty percent of black men have their information stored on the database, which could lead to abuse from law enforcement (Haddow, Ian).

England's Database and Innocent Persons

In 1995, the British database only contained the DNA of convicted criminals, but in 2001 the law changed stating that all DNA collected by forensics will be stored in the database. Since 2004, British police have had the power to take DNA swabs from anyone brought to a police station. If the person was later found to be innocent, the police still have the person's DNA in the database, and they do not have to delete the DNA sample. This raises concerns about individual's privacy rights. The National Policy Improvement Agency (NPIA) claims that the NDNAD database is not a criminal records database as it once was back in 1995 because it holds such little information about the subjects. The NPIA believes that there is "no personal cost or disadvantage of being on it" (Merry, 2008). The National DNA Database Ethics Group considers the NDNAD to be a crime related intelligence database. The National DNA Database Ethics Group has come up with 11 recommendations for the NDNAD. Some of these recommendations are to clarify to the public the actual role of the NDNAD, and to reinforce that its sole purpose is for criminal intelligence. Another recommendation the National DNA Database Ethics Group has proposed is that it be made easier for innocent individuals to be removed from the database, and that the retention of individual's data is aligned with human rights legislation and data protection legislation.

The British Human Genetics Commission also made up 29 recommendations, most of them the same as the National DNA Database Ethics Group. But recommendation #18 is as follows: "If a person who's DNA has been loaded on to the database is found to be innocent or is released, the DNA sample must be destroyed and the profile removed from the database by law. Innocent people on the database should now be removed" (Human Genetics Commission). This seems to be an obvious recommendation, because if the NDNAD is used for criminal intelligence, then innocent people should be removed, unless the intent is to eventually have every human being present on the database. The government must clarify what the DNA database is used for, is it just for criminal intelligence, or is there another purpose for the database so innocent individuals can understand why they are on the database.

In Britain there are 40,000 innocent children on the NDAD database (Drury, 2008) and there are convicted criminals that are not. Chris Huhne a liberal Democrat and home affairs spokesman believes that the British government is building a database by "stealth." This is causing a lot of controversy because many believe that innocent adults should not be on it, and especially not innocent children. If every convicted criminal is not on the database, then how can there be innocent people on the database? It is believe by many that the innocent people should be removed immediately from the database.

Civil Libertarians and DNA Samples

Civil libertarians frequently criticize the use of DNA testing. They believe that the rights of individuals should be more important than the common good of people. DNA usage has major benefits for law enforcement, military personnel, etc. and to not use DNA for these benefits because one thinks that the government is going to abuse the DNA database is not weighing the common good and realizing how much positive can come out of the database. When something new is being tested or something new is developed there is always going to be people that criticize and find the negative aspects of the technology. It is the responsibility of the government to figure out if the new device is better for the people, and in the case of forensics it seems that having the database would greatly benefit people. If DNA tests can provide a better society and help sustain law then it should be used. Isn't that one of the government's jobs, to always improve living, and maintain law and order?

In the US, the government run, national CODIS database contains approximately 1.2 million DNA samples. This forensic database is regulated by the FBI, and seems to be a lesser concern of abuse than the databases that are beginning to form within private sectors. Local police departments store DNA taken from suspects in their computers, thousands of blood samples taken from newborns are sitting in hospital freezers and in their computers, blood drive banks have thousands more, all which could be used to create a private database. Many people who have given a blood sample do not even know that they are at risk of having their sample sold by these private for research or profit, although no US law currently allows this act. Arthur Caplan, director of the University of Pennsylvania's Center of Bioethics, agrees and says "protections are absolutely inadequate" (Hawkins, 2002). He believes there should be an independent source safe guarding for all these blood samples. Some companies can even buy blood samples online to research and fight disease, although the blood donors for such samples are anonymous. Although the intentions of these companies may seem to be for the good of the people and medical research, great caution must be used to negate the identity of the individuals donating the blood for research purposes. In fact, in many cases the blood provided for medical research and sold commercially represents *pools* of blood donated from dozens of patients, making it impossible to trace any DNA medical information back to one individual. The majority of times the individual is unaware his DNA sample was sold. The samples may come from previously given blood or saliva sample for different reasons. Other companies create DNA banks for families of firefighters and policemen for the sole purpose of using their DNA so the family can identify them if they are killed in the line of duty. So long as the original DNA sample itself is destroyed following forensic testing on the 13 core loci, it would be impossible to obtain any medical information from the fireman's database, even if hacked. In rare cases, companies may take DNA from the deceased to research their DNA and sell back to the families what may have caused the death and how other family members can avoid it. But this rare case uses family consent, and is not applied to the general public. Many experts agree that there should only be a national repository for storing genetic information from everyone, and that the repository be run by one agency with strict laws and safe keeping so as not to have discrimination or breech of individual rights.

PROJECT CONCLUSIONS

Genetic fingerprinting has had both positive and negative impacts in our society. Without doubt it has been an extremely useful tool in the world of forensics. This technology has enabled investigators to pursue and solve homicides and other criminal cases by using DNA obtained from collected crime scene samples and matching them to individuals of interest. This technology has also helped solve numerous rape and child molestation cases, identify the remains of unknown soldiers, helped in the identification of people in fire, mauling, and chemical accidents by comparing the unknown samples to family members, has allowed parents to be reunited with their children in child support litigation cases, and has allowed for adopted kids to find their biological parents and get reconnected.

Our research into the types of DNA fingerprints indicates that the PCR type is more rapid than the VNTR type, and is more sensitive, but is also more prone to contamination. Thus, a solid approach would be to use the PCR technology first on a sample to save time, and then if time allows and sufficient DNA sample is available the VNTR approach could follow.

With respect to landmark DNA court cases, our research indicates that the acceptance of complex technical information in US courts has not been a straightforward process. Numerous different landmark cases have been required to finally establish the currently accepted 5 prong test in pretrial hearings to determine the validity of DNA testing for each case.

Unfortunately, DNA fingerprinting was developed for the good of society, it also has its negative side to it. The institutions involved in DNA databases may start taking advantage and invade people's privacy. Privacy issues especially here in America are very much protected through amendments to the constitution, and many civil rights groups serve as watchdogs to help protect these rights. But when considering databases and privacy rights, it is extremely important to distinguish *forensic* databases like CODIS (that only contain information on the 13 core loci, and do not contain any medical information) versus *medical* DNA databases (that will eventually contain complete human genomes, including medical predisposition information). The best hackers in the world cannot obtain more information from CODIS than is already entered in that database, so it is impossible to obtain medical information from CODIS. With CODIS, the main concern based on the research performed in this IQP is passing legislation that mandates destruction of the original DNA sample itself after the 13 core loci are analyzed. This will prevent any further testing of the sample by anyone to possibly obtain medical information. And the authors of this IQP believe this destruction should apply to all DNA samples, whether provided for forensics, or military or fire protection personnel.

The second ethical question with forensic databases is *whose* DNA profiles should be entered. Based on the research performed for this IQP, the authors believe that individuals that have been convicted of violent crimes and/or any type of sex crime should have their DNA entered into the database. Most importantly, we believe that a federal law should be enacted to equalize the various state laws to make them all in agreement with whose DNA should be provided.

With respect to medical databases, the research performed in this project indicates such databases demand strong oversight protection, as medical predisposition data indeed lies within. This information can be used by medical or life insurance companies to deny coverage to individuals predisposed to certain illnesses. It also allows for companies or even criminal investigators to discriminate against a certain race, especially if database entries are unequal. Thus strong protection of this medical database system will be needed to keep humans who prey on this information away to protect the public. For this type of database, the individual should determine if they are willing to give their DNA for genetic diagnostics. Humans have rights, and to take ones DNA sample without their knowledge is going against the rights that they possess.

In general, DNA typing has brought more good than bad. As seen with most every type of technology, although the original design is meant meant to enhance and improve humans life, unfortunately the technology can also be used for evil, especially if sensitive information falls into the wrong hands. Thus, caution has to be taken when dealing with DNA information maintenance and care, especially keeping in mind the ethical issues that are at hand.

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