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DNA FINGERPRINTING

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ABSTRACT

This IQP studies the process of DNA fingerprinting and its impact on society. The background and methodology behind DNA profiling is explained. The procedures for proper collection and usage of DNA in the field of forensics, the introduction of DNA evidence into courts, and the assembly of DNA databases are explored. This exploration allowed for discussion of the societal effects of this controversial issue.

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PROJECT OBJECTIVE

The purpose of this IQP was to investigate the technology of DNA fingerprinting and its impact on society. The project described the methodologies used to obtain DNA profiles, how such profiles are currently used, and the proper procedures for DNA evidence collection and handling. The impact of this technology on society was investigated through a description of landmark court cases that set legal precedences, and a discussion of the ethical issues of DNA databases.

CHAPTER-1: DNA FINGERPRINTING TECHNIQUES

DNA fingerprinting has arguably been called the greatest tool in the history of forensic science. This chapter investigates why this technology is so powerful, and describes the various ways of performing these fingerprints. Unlike the case with normal digital fingerprints where it has been estimated that 3-4 individuals may have the same fingerprint, every person has a distinctive DNA fingerprint, except for identical twins. An individual's normal fingerprint can be erased by filing down, however an individual's DNA fingerprint cannot be changed through any known method. Also a DNA fingerprint (DNAF) can be produced from a rather small amount of DNA from tissue, skin, semen, blood or hair. When accompanied by current polymerase chain technology (PCR) for amplifying DNA, there is enough DNA in one hair root to create a DNAF (Betsch, 2006).

Examples of Applications of DNA Fingerprinting

There are many applications of DNAF such as identification, forensics, paternity testing, and diagnosis for inherited disorders. The armed forces have started to collect DNA from all of its members. In the event of a fatality the DNAF will help to identify the remains with more precision than the current methods, such as dental records and normal fingerprints. Forensics allows biological criminal evidence to be coupled to the DNAF of the perpetrator of the crime. Many difficult crimes have been solved and cases decided using DNAF. There is also the FBI's Combined DNA Index System (CODIS) a national criminal DNA data bank, which is created by linking county, state and federal DNA databanks (Adams, 2002; CODIS, 2004). Paternity testing tells who the legitimate parents of a child are. Which is helpful in reuniting separated families, and settling custody and child support issues. Inherited disorders in newborns and pre-newborns can be detected using DNAF. If such disorders can be identified early, there can be a "head start" to identify risks and prepare for special treatment. If the disorder can be identified, perhaps in the future a genetic treatment can be created (Betsch, 2006).

DNA Background

DNA; deoxyribonucleic acid, is known as the molecule of inheritance. DNA directs the growth, function, organization and operation of every cell. DNA is found in almost every cell of every living organism. DNA consists of bases whose names are abbreviated A, C, G, and T. The sequence of these bases differs between any two individuals. The DNA is contained in the Chromosome (wikipedia, 2006). The chromosome is located in the nucleus of the cell and is visible with a normal microscope, the DNA is not visible (Betsch, 2006). A genotype is the inheritable instructions carried by living organisms. These instructions control all aspects of life (Blamire, 2000). Various locations in the DNA are called loci. The current DNA test used by the FBI begins with an analysis of 13 core loci, which have been determined over the years to have a high probability of differing between individuals.

Types of DNA Fingerprints

There are three main ways to run a DNAF: RFLP, VNTR and STR. Restriction Fragment Length Polymorphism (RFLP) describes the difference in lengths between specific DNA fragments cleaved with restriction enzymes. Restriction enzymes cut DNA at specific sequences of bases, for example the enzyme EcoRI cuts DNA at the sequence GAATTC. If the DNAs from two different people are cut with EcoRI, and the specific fragments at a core forensic locus are compared, their lengths are different. Such differences in DNA fragment lengths can be caused by DNA insertions and deletions in bases (Davidson College, 2001). Variable Number of Tandem Repeats (VNTR) describes one way restriction fragments can vary their lengths. In this instance specific restriction fragments from two people may differ in length due to different numbers of tandemly repeated bases, i.e. one individual may have GATC-GATC-GATC-GATC, while another individual may have GATC-GATC (Melcher, 2000). To identify specific restriction fragments in a RFLP or VNTR type fingerprint, the DNA is cut with restriction enzymes that cut at specific locations (Figure-1, 3rd panel), then the fragments are separated by size using electrophoresis (Figure-1, 4th panel). Because DNA is negatively charged, it moves towards the positive anode with the smaller fragments moving through the sieving material faster. Then the DNA fragments are blotted to membrane to allow hybridization to a probe (Figure-1, 5th panel). The probe hybridizes or sticks only to a specific fragment (whose sequence is complementary to it), allowing only specific fragments to be visualized (Figure-1, 8th panel).

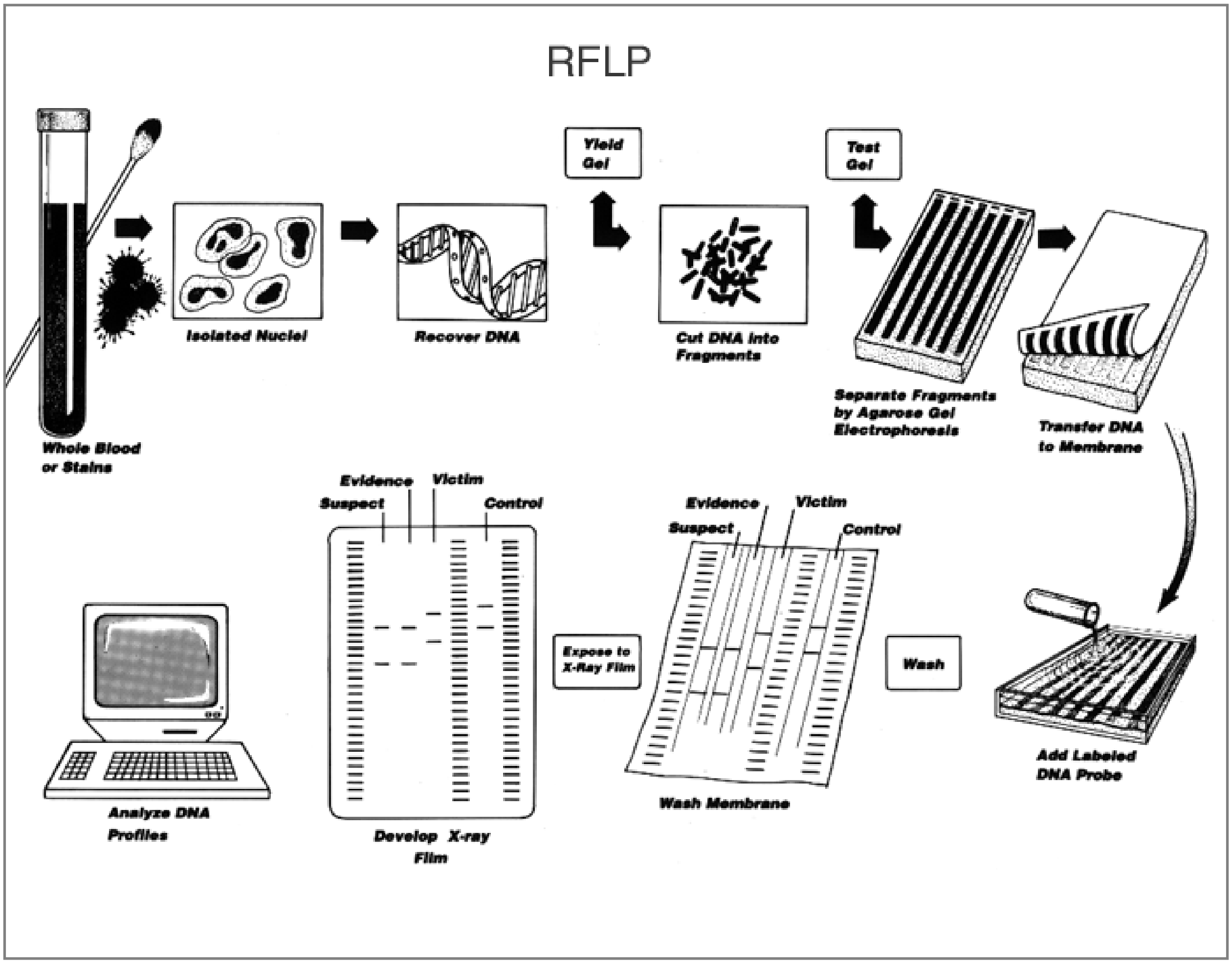

Figure-1: Diagram of an RFLP-Type DNA Fingerprint (Student Web Projects, 2006).

Figure 2 shows an RFLP from an actual investigation. The blood found on the defendant's clothing (center of the diagram) is clearly not the defendant's blood (lane D). However there is a match with the blood taken from the victim (lane V). This indicates the victim's blood is found on the defendant's clothing.

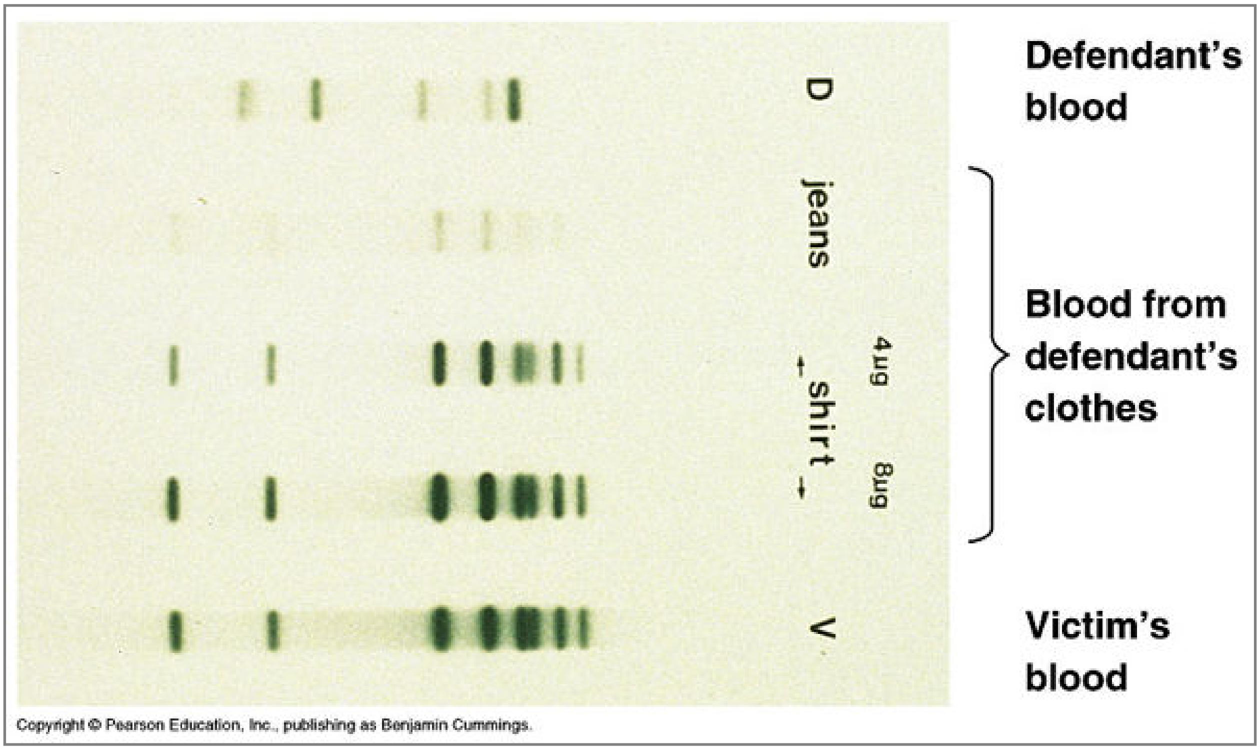

Figure-2: Example of a VNTR Fingerprint for a Crime scene Analysis (University of Miami, 2006).

Short Tandem Repeats (STR) are short sequences of DNA (from two to five base pairs) repeated in a head tail manner (The Biology Project, 2000a). STRs are so short they can be amplified millions of times in a process called Polymerase Chain Reaction (PCR) (Dolan DNA Learning Center, 2006). Thus the combined use of PCR/STR for DNA analysis is highly sensitive. Currently the FBI analyzes 13 core loci in the DNA. PCR amplification (Figure 3) is exponential, theoretically twenty PCR cycles would yield over two million copies of the original sequence. Scientists were even able to extract enough DNA from an eighty million year old insect trapped in pine pitch to use for PCR amplification.

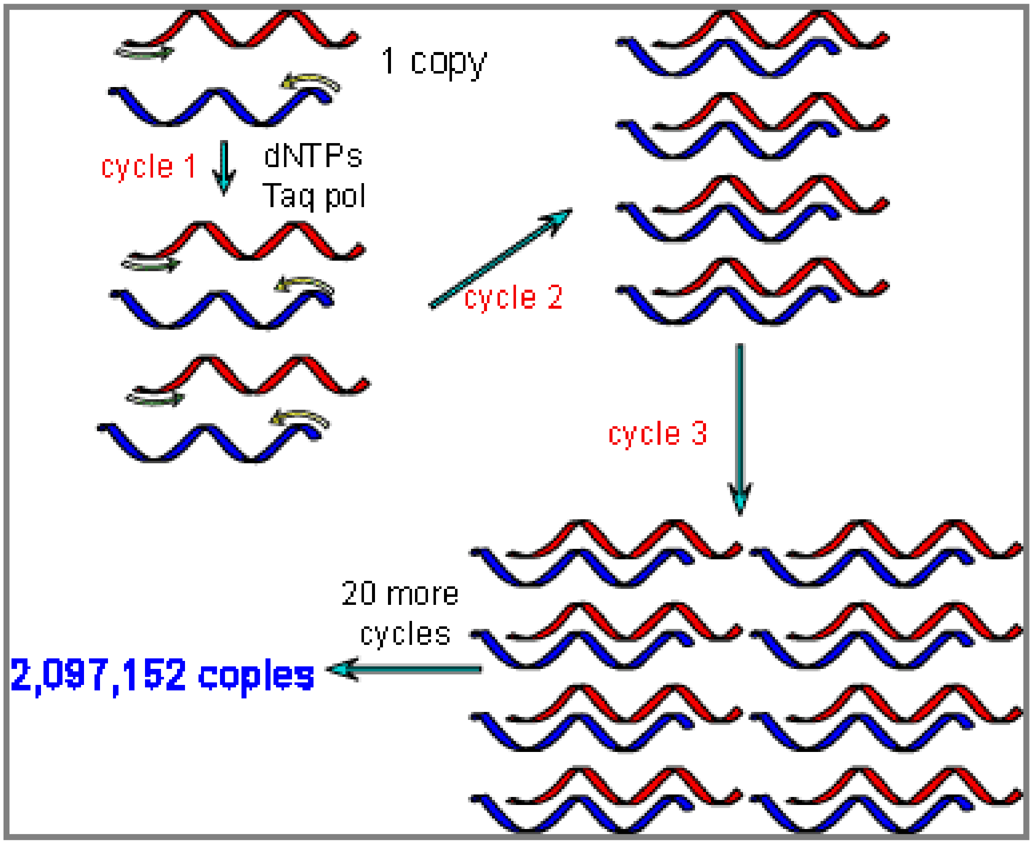

Figure-3: Diagram of PCR Amplification of DNA (Bioteach, 2006).

PCR requires three main steps, each occurring at a different temperature (Figure 4). First the DNA sample is separated into strands from heat (second panel in the figure). The separated strands are now able to accept a primer. Excessive amounts of a primer are added to the separated strands, and as the temperature is lowered (third panel in the figure) the DNA strands anneal to the primer. Because primer is in 10-fold excess, they anneal first to the DNA, instead of allowing the DNA strands to self-anneal. Now a Taq DNA polymerase enzyme is added to the mixture which synthesizes the DNA in opposite directions (fourth panel). The Taq enzyme is normally found in hot springs, its ability to survive in extreme temperatures allow the DNAF to be created (Brown, 1995).

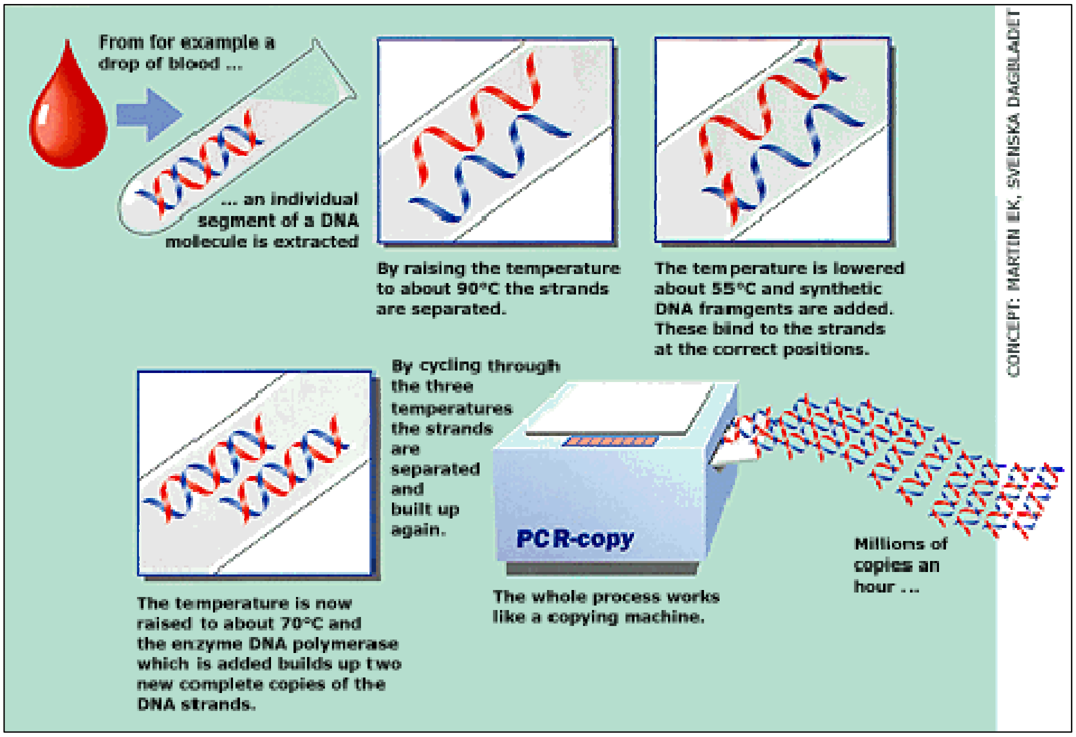

Figure 4: The Three Main Temperature Steps of PCR (Nobel Prize, 2006).

Now that the DNA sample has been multiplied exponentially, a STR can be used. As stated previously, the current STR procedure analyzes 13 core loci. By identifying the genotype at each of the thirteen loci (Figure 5) and running a frequency analysis the sample can statistically be identified as excluded from or identical to another sample. (The Biology Project, 2000b).

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 5: Example of an STR DNA Analysis on 13 Core Loci Plus an XY Analysis (University of Arizona, 2006).

Each core locus is identified by a code, i.e. D3S1358. The genotype at this locus is given by the numbers 15 and 18, which indicate the type of STR found at this location. The frequency for each genotype in the general population is represented by the percent number underneath the locus name. For example the locus vWA has the genotype "16, 16" this genotype is shared with about 4.4% of the population. The frequency for this particular profile for all thirteen loci is one in 7.7×10^{15} or one in 7.7 quadrillion. This rises to the level of statistical certainty that two samples either came from the same person except for identical twins, or are from different individuals (The Biology Project, 2000b).

Advantages and Disadvantages of Each DNA Analysis Technique

Each DNA analysis process has advantages and disadvantages. When using RFLP's or VNTR's, there is less worry about contamination because small amounts of contamination will not show up on the final analysis. There is no amplification of the contaminating DNA relative to the original source DNA. However a relatively large amount of DNA is needed to create a RFLP or VNTR type DNAF, and the process (requiring radiation during probe hybridization) can take two to three days. With the STR method, a much smaller sample can be analyzed in a matter of hours without radiation. But the STR is more susceptible to contamination because only a small sample is needed any contaminant of the sample could be amplified by the PCR method instead of the sample itself. PCR cannot be used with the RFLP and VNTR methods.

As a matter of practice, usually samples are first analyzed using the STR/PCR method for convenience and rapidity, then later analyzed by RFLP or VNTR if time allows or if there are any contamination issues. Different situations call for different methods of creating a DNAF. When a quick result is needed, or there are large numbers of samples to analyze, the STR is used. When there is a hit from the STR if enough DNA was obtained, the more proven reliable RFLP or VNTR methods are used to verify the STR. If there is only a small DNA sample, the STR method is the only way to create a DNAF using PCR amplification. STR fingerprints are stored in electronic format, which simplifies collaboration in databases such as CODIS.

Examples of DNA Fingerprinting Applications

DNA fingerprinting has been used to both convict the guilty, and to exonerate the innocent. There are many instances of exoneration from conviction of a crime through DNAF's. Two women were abducted at knifepoint from a mall parking lot and raped, in two separate instances. In 1987 Glen Woodall was sentenced to two life terms in prison without parole plus an additional 203 to 335 years. The prosecution had strong evidence against Woodall. A state police chemist testified that a sample of Woodall's blood matched a sample of semen taken from the crime scene. Hair found in the victim's car was consistent with Woodall's. One of the victims had made a partial identification, including that of clothing found in Woodall's home. At the time of the pretrial hearing, DNA testing was a new science and not admissible, but in 1989 PCR amplification was run on semen samples taken from vaginal swabs from the two victims. The results indicated the same perpetrator committed both of the rapes, however the DNA was not a match for Woodall. In 1992 a RFLP-type fingerprint was used to verify that Woodall was innocent (President's DNA Initiative, 2006a).

In another case, Ronald Cotton was convicted of rape and sentenced to life in prison. While in prison an inmate bragged about how he committed the crime that Cotton was convicted of. There was a retrial and both of the victims testified against Cotton who received two life sentences plus 55 years in prison. In 1994 Cotton learned about DNA testing, and in 1995 PCR was used to amplify DNA from a small amount of semen found on a vaginal swab from the victim. The DNA profile did not match Cotton's DNA. After almost ten years Cotton was released from prison (President's DNA Initiative, 2006b).

CHAPTER-2: DNA FORENSICS

DNA forensics allows biological evidence to be collected, stored, and eventually linked directly to a specific person either as a suspect, victim or witness. Problems with the improper handling of DNA evidence have caused the evidence to be thrown out in many court cases. This chapter documents some of the currently approved DNA handling procedures concerning sources of DNA at a crime scene, prevention of DNA evidence contamination, DNA collecting and packaging methods, storage transport and documentation of DNA evidence, and several examples of DNA forensics at work.

Sources of DNA at a Crime Scene

Different types of tissues and body fluids contain different amounts of DNA. There are certain types of tissue that are preferable to others for the collection of DNA to create a DNAF. Blood is a good source for DNA. The DNA is present in white blood cells, red blood cells have no nuclei therefore have no DNA. One of the best sources of DNA as evidence of a sexual assault is the sperm head, the sperm head contains ten times as much DNA per cell as blood. DNA can also be found in saliva extracted from a multitude of places such as cigarette butts, bite marks, postage stamps or anything that would leave a trace of saliva. Hair follicles on hair pulled from the body not cut or broken also contain DNA. Any un-degraded body tissue is a good candidate for a DNA sample. One of the best sources for DNA in a decomposed case is bone and teeth, incongruously these are the parts that can outlast other body parts by thousands of years

(Biology Project, 1997). The table in Figure-6 shows examples of crime scene evidence, the likely location of the DNA on the evidence, and the biological sources of DNA.

Evidence	**Possible Location Of DNA on the Evidence**	**Source of DNA**
baseball bat or similar weapon	handle, end	sweat, skin, blood, tissue
hat, bandana, or mask	inside	sweat, hair, dandruff
eyeglasses	nose or ear pieces, lens	sweat, skin
facial tissue, cotton swab	surface area	mucus, blood, sweat, semen, ear wax
dirty laundry	surface area	blood, sweat, semen
toothpick	tips	saliva
used cigarette	cigarette butt	saliva
stamp or envelope	licked area	saliva
tape or ligature	inside/outside surface	skin, sweat
bottle, can, or glass	sides, mouthpiece	saliva, sweat
used condom	inside/outside surface	semen, vaginal or rectal cells
blanket, pillow, sheet	surface area	sweat, hair, semen, urine, saliva
"through and through" bullet	outside surface	blood, tissue
bite mark	person's skin or clothing	saliva
fingernail, partial fingernail	scrapings	blood, sweat, tissue

Figure-6: Table of DNA evidence sources (National Commission on the Future of DNA Evidence, 1999).

Approved DNA Handling Procedures

Keeping the sample protected and documented is important for the DNA to have merit as evidence. The sample must be protected sometimes for decades to prevent environmental or malicious damage. Documentation of the manner in which the DNA is identified, preserved, collected, packaged, transported, and stored is of extreme importance for the evidence chain**.** Procedures have been developed to help seamlessly follow the sample and the DNA from the crime scene to the courtroom. Also protocols have been established by the President's DNA Initiative, for the protection and prevention of DNA evidence contamination, collection and packaging and storage, transport and documentation of a DNA evidence collected at a crime scene for the use of DNA as evidence.

Protection and Preventing of DNA Evidence Contamination

Law enforcement personnel can cause crime scene contamination; hair, skin, sweat and possibly blood can accidentally be left at the crime scene. Whenever two objects come in contact with each other trace evidence is exchanged. Each time an investigator enters a crime scene, they not only possibly leave trace evidence behind, but also evidence may be taken away from the crime scene. Considering this as more personnel are exposed to a crime scene there is a greater risk for contamination and evidence to be inadvertently carried out.

There are pre-secured crime scenes and post-secure crime scenes. Challenges to law enforcement for a pre-secured scene include the potential for contamination, and destruction of evidence. The actions that took place in between the time the crime was committed and the time the scene is secured cannot be fully accounted for. Public pre-secured scenes are more likely to be contaminated than private pre-secured scenes because of greater access of the general public. In the private pre-secured scene it is generally the investigating personnel who cause contamination. Post-secured scenes would ideally prevent any further contamination of the crime scene. Again this is easier in a private residence, outdoors and public crime scenes offer many points of access that are difficult to secure. Some of the reasons are large areas, difficult terrain, and weather factors. Often limited law enforcement personnel are available, leaving the scene unsecured from intrusion (Baldwin, 2005).

Regarding the chance of an infection transferring between a collected DNA sample and the collector, in practice all samples are considered to be contagious (Presidents DNA Initiative, 1999a). Contact with the sample should be kept to a minimum. Gloves are worn at all times, and measures are undertaken to prevent aerosolization of the sample. Because DNA can be extracted from a very small sample, contamination can occur when DNA from a different source gets mixed with the DNA from the forensic sample (Presidents DNA initiative 1999c). By touching the sample or coughing into it, the individual who is collecting the sample could inadvertently cause contamination through direct or indirect contact.

Figure-7: Photo of a technician in protective clothing (Presidents DNA Initiative, 1999k).

Touching anything with bare skin leaves skin cells behind, and a misdirected sneeze could easily contaminate a small drop of blood (Presidents DNA initiative 1999d). The use of latex gloves, shoe covers, gowns and facial masks reduce the risk of contamination (Fig 7) (Presidents DNA initiative 1999e).

Collecting and Packaging DNA Evidence

There are general procedures for collecting and packaging samples for shipment to the lab. The evidence should be allowed to dry if possible, and each piece of evidence should be collected and packaged individually, and properly labeled (Presidents DNA initiative 1999b). To help prevent contamination while collecting evidence, an order of collection has been established; hairs and fibers are collected first, followed by biological fluids, tool marks, visible fingerprints or footwear patterns (Baldwin, 2005).

Several techniques are implemented in the collection of evidence for DNA analysis. Cotton tipped swabs are used to collect DNA evidence from crime scenes. Either the swab is directly used to collect fluids, or for dry stains the swab is slightly moistened with clean water and worked into the stain absorbing evidence. Extreme care is exercised to prevent sample-to-sample contamination. The swab is then air dried and placed individually in a clean properly labeled paper container. Another method used specifically to collect dried blood uses tape much like collecting a traditional fingerprint. Tape is pressed onto a dried bloodstain to attain a good adhesion of the evidence. The tape is then placed evidence side down on a clean paper card and placed in a clean properly labeled paper container (Kramer, 2002).

Either the entire item can be sent to the lab for analysis, or items that are too large can have a sample cut from them, or a swab can be used to collect evidence along with a control sample (Presidents DNA Initiative, 1999f). The control samples are collected near the sample sources but do not contain any obvious fluid evidence. Control samples are analyzed along with the DNA sample to see if there are any effects of the sample processing on the DNA sample (Presidents DNA Initiative, 1999g). Evidence such as paper and clothing should not be folded to help prevent cross contamination (Fig 8) (Presidents DNA Initiative, 1999h).

Figure-8: Photo of improper evidence collection techniques (Presidents DNA Initiative, 1999l).

Storage, Transport, and Documentation of DNA Evidence

DNA should be stored and transported in a cool environment. Sunlight and heat may cause the degradation of the DNA (Presidents DNA Initiative, 1999g). Plastic bags should only be used for very short-term storage, if left for too long bacterial growth becomes a problem that could render the sample more difficult or impossible to get DNA from (Presidents DNA Initiative, 1999h).

The proper storage of biological evidence is important to reduce the risk of damage to what could be possibly the only evidence in a criminal case. Harmful substrates like tanic acid treated leather can destroy a biological sample. A dried bloodstain on a smooth coffee mug could fall off, and the potential for a DNA analysis could be lost. Anytime a physical object containing biological evidence is at risk a swab or other method should be used to collect a sample from the evidence and placed into controlled storage.

Although your common sense says to store DNA in a freezer, DNA evidence is stable at room temperature. Freezer storage can result in hydration over time and degradation. Evidence should be kept at room temperature until the analysis is complete. A preservative can be added to liquid blood samples to extend the stability of refrigerated samples over an extended period of time. For long-term storage, add bloodstain drops onto paper cards and place in a freezer. Clothing with biological stains should also be placed in a freezer to best preserve the evidence (Spear, 2004).

Every sample should have the proper documentation of every person who comes in contact with the crime scene or the sample (chain of custody), the time and date the DNA was collected, who collected the sample, where the sample was collected, how the sample was collected, possible locations and sources of other DNA, whether or not the sample was wet or dry, and other factors relevant to the collection of the sample. A full documentation and adhesion to the collection protocols is imperative for the DNA to have credibility (Presidents DNA Initiative, 1999i).

Examples of DNA Forensics at Work

On May 25, 2003, a Yakelev-42 Spanish military airplane crashed into Turkey on a return flight from Afghanistan. On board were sixty-two Spanish soldiers returning home from a peacekeeping mission. Thirty of the bodies had a DNA analysis, and were documented as unidentified by the Turkish and returned to Spain. The Spanish without completing a further identification to each of the remains returned them to the families. The following year a DNA analysis was performed correlating DNA data from the Turkish with DNA reference samples taken from the soldier's families. The analysis revealed that each of the thirty families received the wrong remains. The remains were exhumed and reanalyzed against the family reference samples. Through the proper documentation on behalf of the Turkish forensics team, the errors could be corrected and each of the families were able to receive the proper remains (Alonso, 2005).

On July 25, 1984, Dawn Hamilton was viciously raped and murdered in Maryland. In March 1985 without any physical evidence Kirk Bloodsworth was arrested, convicted, and sentenced to death. In 1992 Bloodsworth and his attorney requested a DNA analysis on the evidence from his trial, Hamilton's shirt and underpants. Two DNAF tests were conducted one by the Forensic Science Associates and the other by the FBI. Each agreed that the DNA on the underpants was not the same as Bloodsworth. On June 28, 1993 Bloodsworth was released from prison and compensated $300,000 by the state of Maryland. However prosecutors were not convinced that Bloodsworth was innocent, he lived for ten years under a shroud of suspension. On September 5, 2003, Kimberly Shay Ruffner a convicted sex offender was implicated as the rapist and murderer of Hamilton and charged with first-degree murder. The prosecutors who previously refused to accept Bloodsworths innocence went to his home to personally apologize to him (NACDL, 2003). The preservation of the evidence from this closed case not only allowed an innocent man to be un-imprisoned, but also allowed the conviction of the perpetrator of the crime. This case illustrates the importance of the preservation of evidence from the moments after a crime is committed to years or even decades following.

May 30, 1995, the O. J. Simpson trial was in its nineteenth week. The Defense (Sheck) was questioning Colin Yamauchi a police crime scene technician on the manner in which he collected and analyzed the evidence. Sheck tried to show that Yamauchi did not change his gloves between collecting and analyzing different pieces of evidence, failed to properly document blood testing and avoided safe-guards established to prevent contamination of evidence. Sheck tried to illustrate that Yamauchi may have transferred some of Simpson's blood inadvertently from a vile to a glove collected as evidence. Supposedly Yamauchi spilled some of Simpson's blood onto his plastic glove. Then without knowing the blood was on his plastic glove Yamauchi picked up the evidence glove to label it, in the process transferring Simpson's blood to the glove. If proper documentation existed with the time each piece of evidence was handled, it could have been determined whether or not Yamauchi handled the glove before or after the vile of Simpson's blood (CourtTVnews, 2004). The importance of properly collecting and documenting evidence used for DNA analysis cannot be overstated. Haphazard collection and documentation can render the evidence useless. This not only wastes valuable law enforcement resources, but also could let potentially dangerous people free to walk the streets.

CHAPTER-3: LANDMARK DNA CASES

The introduction of DNA evidence into the venue of legal proceedings has not been quick or easy. Like any complicated method of information gathering, the accuracy and validity of identification via DNA is not easily understood by the average person, and so DNA evidence has had to win acceptance in courts. This chapter explains the process by which a complex procedure like DNA analysis, which requires a high degree of specific scientific background to understand, can establish itself in the legal system and earn general approval and acceptance. The chapter also discusses examples from cases involving the use of DNA evidence.

The Burden of Proof

Clearly in any organized legal system, society strives to avoid meting out justice at random. Before convicting someone of a crime, particularly a serious one carrying a severe punishment, the court expects a high degree of certainty that the suspect actually committed the crime. As suspects are generally assumed to be innocent until guilt has been established, an obligation known as the burden of proof is placed on the accusing party to establish that their accusations are in fact true. The arguments of the party bearing this burden must be deemed to exceed a given standard of proof in order to be considered valid. There are several such standards, each of which describe a varying degree of certainty.

Most residents of the United States have likely heard the phrase “probable cause.” This is an example of a relatively lenient standard of proof. Used not to obtain convictions but rather just to gain warrants for arrests or searches, this standard merely establishes potential causation. Evidence that satisfies this standard is often used to gather further evidence in order to assemble proof that meets a higher standard.

In civil cases, a common standard is the "preponderance of evidence." Unlike probable cause, which just shows that something could have happened, preponderance of evidence attempts to show likelihood. This standard is satisfied if it is more likely that an argument is true than false. Despite the abundant room for error left by this standard, it is actually used in rendering judgments, as losing a civil case does not constitute a criminal offense. Civil cases can be and are decided by satisfying this standard alone.

Another standard used in civil proceedings is that of "clear and convincing evidence." Largely exclusive to the United States, it is derived from preponderance of evidence. Instead of asking that a proposition is likely to be true, it is satisfied only if the probability that the proposition is valid substantially exceeds the chances that it is not. While stricter than preponderance of evidence, this standard is still less strict than that used in criminal cases, and still has abundant potential for uncertainty.

Finally, in criminal courts the standard of proof demanded for conviction is "proof beyond a reasonable doubt." This exacting standard does not rely on a probability of truth, unlike the earlier examples. It is only satisfied if the truth of any and all counters to a proposition would stretch the bounds of believability in the view of an 'average' citizen. Because this standard is so demanding, it is entirely possible for the same facts, presented in both criminal and civil venues, to produce different verdicts. A prominent example of this was the 1995 murder trial of O.J. Simpson. He was acquitted in criminal court, but in 1997 in a separate civil case, was found responsible for the wrongful death.

A factor in his acquittal may have been inappropriate usage and handling of DNA evidence by detectives, as noted in Chapter-2.

The most demanding standard of proof would be "beyond all possible doubt." This can be an essentially impossible standard in practice, and it is not used in courts. This standard would demand that there be no possibility of a mistake or alternative viewpoint when presenting an argument (Wikipedia, 2006).

Plainly, in order for DNA evidence to be useful, it must itself meet, or contribute to a larger presentation which would meet, the standard of proof for the type of proceeding in which it is involved. The lowest standard, that of probable cause, routinely uses DNA forensics. The collection of DNA at crime scenes, as explained in Chapter-2, is a major factor in obtaining warrants for searches and arrests. DNA sees use under higher standards as well, but as with all proof under those standards, a higher degree of confidence is demanded in those situations.

The Frye Test

In 1923, a man by the name of James Alphonzo Frye was accused and convicted of second degree murder (Great American Court Cases, 2006). In a United States Federal Appeals Court, his defense counsel attempted to introduce the results of a systolic blood pressure test, as well as related expert testimony, as support for Frye. This test was essentially a primitive precursor to the modern polygraph test (the "lie detector"). The test results were presented demonstrating that Frye's readings, when questioned during the test about his innocence, were consistent with human emotional and chemical reactions when telling the truth. This evidence, if introduced, could have presented doubt that the state's assertions of his guilt were correct.

The court refused to allow the introduction of the evidence from the blood test or the testimony from the supporting witness based on their finding that the blood test in question did not have widespread acceptance in the scientific community from which it derived (Nordburg, 2006). This expectation of "general acceptance" became the Frye test or Frye standard, which was used to determine the admissibility of complex scientifically-based evidence and testimony (such as the usage of DNA), for approximately 70 years (Fiatal, 2006).

Federal Rule of Evidence 702 and The Daubert Standard

The United States Supreme Court, under the direction of then-Chief Justice Earl Warren, in 1965 created an advisory committee to create organized rules of evidence for federal courts. In 1975, Congress ratified the Supreme Court's proposal, creating the Federal Rules of Evidence. Prior to this, federal courts had relied on specific case precedent and common law (Wikipedia, 2006).

Among the new rules introduced was 702, which codified the introduction of "specialized knowledge" into court evidence when it was necessary by using "a witness qualified as an expert by knowledge, skill, experience, training, or education" to testify in order for the jury to be able to make a reasonable judgment. This rule did not demand the "general acceptance" provision of the Frye case, thus in theory making the official rules more lenient than the 1923 Frye case precedent (Cornell Law, 2006).

In 1993, William Daubert and his family took the Merrell Dow Pharmaceuticals company to court over the drug Bendectin. The family claimed that the drug was responsible for birth defects present in their children. During summary arguments, both the plaintiff and the defendant introduced testimony from experts concerning the scientific viability of the plaintiff's claim. The judge ruled that the plaintiff's expert testimony could not be admitted, despite having a potentially valid scientific basis, because the expert's conclusions were not generally accepted – the rigid criteria of the Frye standard. The judge issued summary judgment in favor of the defendant, the Merrell Dow company.

The decision was appealed, and eventually went all the way to the Supreme Court who ruled that the Frye standard had been superseded by the Federal Rules of Evidence, which, as noted earlier, was more lenient. The Supreme Court further laid out new rules for determining the admissibility of scientific evidence. The case was remanded, and the Supreme Court set out a five part test to be carried out by the judge in determining the admissibility of the evidence. This became the Daubert Standard, although the new case would also be decided against the plaintiffs.

The Daubert Standard does not rely on the principle of "general acceptance," and instead tries to test reliability according to a series of criteria. First, it asks if the technique or process in question has been subjected to empirical testing. Second, Daubert questions whether the scientific procedure has undergone peer review within its field. Third, it checks for the existence of a rate of error, whether tested or hypothesized. Fourth, the existence of experimental standards within the field are questioned. Finally, it asks how widespread the support in that field for the theories and conclusions presented is. In a further case, in 1999, the Supreme Court clarified that these Daubert guidelines extended beyond science to any sort of specialized field requiring expert testimony (Wikipedia, 2006).

The Federal Rules of Evidence were officially revised in recent years to reflect the Daubert Standard, with the inclusion of a clause in Rule 702 that stated that the expert witness testimony already provided for was admissible "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." The Daubert Standard continues to be employed to this day (Moenssens, 2005).

Downing and Relevancy

In a federal case in 1985, John W. Downing was convicted of multiple types of fraud. His conviction relied more or less exclusively on eyewitness identification equating him with a con artist who went by various false names. His defense during the trial tried to introduce testimony from an expert that questioned the reliability of eyewitnesses. This expert testimony was denied, but in appeal the grounds on which the court had rejected the testimony were held to be erroneous. Although the decision to exclude the expert witness would eventually be upheld, leaving Downing found guilty, the Downing case laid down some relevancy guidelines that had bearing on the Frye standard and on Federal Rule of Evidence 702.

In the decision to remand, the Third Circuit Court of Appeals specified that the reliability criteria that were addressed by Frye were insufficient. This opinion would be expressed again in Daubert and later guidelines to address this were incorporated into Rule 702, as explained just prior. The court also declared that expert testimony could be excluded on the grounds that it would be misleading to the jury, or if it was not at all related to the facts of the case (Green, Nesson, and Murray, 1990). This relevancy test proved to be significant to DNA evidence very quickly.

The Andrews Case: DNA Evidence at Work

The 1988 case *State of Florida v. Tommie Lee Andrews*, in which the defendant was charged with multiple counts of sexual assault, marked the first successful usage of DNA evidence in a United States court (Future of Identity in the Information Society (2006). In this case, the prosecuting attorney was successful in introducing the results of a DNA test that linked the defendant to the crimes. Other, conventional, forensic evidence was scanty and inconclusive. However, the defense attorney successfully challenged the state's expert, whose testimony concerning the statistical reliability of DNA matching was excluded. The trial went on to end in a hung jury.

A second trial was ordered, and the DNA evidence was again found admissible. This time, however, arguing on relevancy grounds, the prosecution was able to introduce testimony on the reliability of the test. The state court applied a standard similar to that of the Federal Rules of Evidence in declaring that the testimony would not be excluded. This time, Andrews was convicted. However, there were concerns about the quality of the defense and whether the contested expert testimony was accurate (Genetic Witness, 1990). Nonetheless, the first successful usage of DNA in any sort of United States court was significant.

The Castro Decision: Challenge and Acceptance

The 1989 murder case *Jose Castro v. New York* is notable for several reasons. The first of these is that it was the first United States court case in which the judge performed an exhaustive inquiry into DNA evidence collection and analysis. Prior to the trial, 3 months of evidentiary hearings were conducted in which testimony was heard from multiple experts in the field. Moreover, at the conclusion of the hearings, some of those experts, including representation from both the prosecution and the defense, collaborated in producing a consensus document. Later that year, the judge published a sizable document on the subject of the admissibility of DNA evidence under the Frye standard (which New York used).

This judge, Gerald Sheindlin, laid out a “3-prong” test for determining whether DNA evidence should be admitted in the case (Genetic Witness, 1990). First, it asks whether there was general acceptance (as per Frye) for the reliability of the theories underlying DNA forensics. Second, were there actual tests capable of producing reliable results that had also gained that acceptance? Finally, did the testing in the specific case conform to the established testing guidelines? Under these exhaustive Castro standards, the court admitted DNA evidence to be reliable, at least in theory (Patton, 1990).

However, the second notable feature of this case was that despite conceding the reliability of DNA forensics, it excluded the actual evidence itself in this case. The reasoning was that while the first two prongs of the above test had been adequately satisfied, the third had not. Lifecodes, a private company which had been responsible for the DNA testing done in the case, was held to have used improper methods in their labs which cast doubt on their results.

The third interesting fact about the *Castro* case was that after all the deliberation about the admissibility of the DNA forensic evidence, and the decision to exclude it in this instance, it all became moot anyway because the case was not decided at trial. Castro, the defendant, confessed to the murders of his neighbor and her baby daughter even though the potentially damning DNA evidence (which had linked blood found on his watch to the victims) had been shut out of the trial (Genetic Witness, 1990).

The case of *United States v. Two Bulls* in 1990 affirmed the methodology laid out in *Castro.* Two Bulls was convicted of rape with the assistance of DNA evidence, which his counsel tried to challenge but was admitted. In appeal, the Eighth Circuit Court of Appeals reversed the decision, saying that although DNA evidence might have achieved validity in the eyes of the courts, it still needed to be evaluated for reliability in each specific instance, as per *Castro's* 3 prong test. The appeal was eventually dismissed when the defendant died prior to the full conclusion of the case (Genetic Witness, 1990).

Martinez and Daubert

Prior to 1993, DNA cases, like those mentioned so far, had largely involved the Frye standard. The Daubert decision had superseded Frye, at least at the federal level, so DNA forensic evidence would need to be tested again. It didn't wait long, as later that same year, the case of *United States v. Fernando Martinez* took place, a case which involved DNA testing done by Lifecodes. In this case, the Eighth Circuit Court of Appeals conducted an analysis under Daubert, and admitted the evidence and its supporting testimony about statistical reliability (Lancaster County Public Defender's Office, 2001).

The Robinson Case

In 2000, a series of unsolved rape cases conducted in California in 1994 were nearing their six year statute of limitations, after which they could no longer be prosecuted. Instead of letting the cases die, Sacramento prosecutor Anne Schubert filed "John Doe" warrants that identified the suspect only by his DNA. Only a month later, a DNA sample from a man named Paul Eugene Robinson was identified as a match for the DNA from the rapes. Although there was some question as to whether his DNA should have been collected, this evidence, along with other forensic evidence, was admitted in court (Delsohn, 2001).

The defense challenged the warrants, but the California Supreme Court denied the motion to dismiss and affirmed the validity of the warrants. It took until 2003, but Robinson was eventually convicted of five counts of sexual assault and sentenced to 65 years in prison. The successful prosecution of the case was notable, as it was based almost solely on DNA evidence, but it raised questions for some as to whether Robinson's civil liberty had been violated (Gribben, 2005).

The Journey of DNA Evidence

From untried technology to a technique that could put criminals away solely on its own merits, DNA has come a long way in the legal arena. Though there are still controversies on the legality of such things as exploitation of the statute of limitations rules (as mentioned in the Robinson case just prior) or the creation of national DNA databases (explored in Chapter-4), DNA forensics has firmly made a place for itself in the investigation of crime in the United States. The confidence of its reliability under the burden of proof is high, even for those who do not understand it, and, though individual situations can always create exceptions, its admission into courtrooms has become well established.

CHAPTER-4: DNA DATABASES

The creation of DNA databases has allowed the storage of information from past and current crime scenes, and from convicted criminals, for comparison to help solve crimes with no leads and to protect the innocent. However, many debates have occurred on who should be required to store their information in such databases. At what point are privacy rights violated, and how can we protect the integrity of the information gathered? This chapter will help explain how DNA databases were created, describe what type of information is stored on DNA databases, list a few success stories, present arguments for the need of DNA databases, and present privacy rights arguments against the necessity of such DNA databases.

DNA Database Information in the U.S.

Instituted in 1990 as a pilot program, the FBI implemented a new system referred to as the Combined DNA Index System, or CODIS for short. The purpose of CODIS was to allow states to communicate both locally and nationally to help solve a variety of crimes by sharing criminal profiles with each other through the new technology. Begun in 14 laboratories, CODIS slowly expanded throughout the United States. One major event that helped allow CODIS to expand was the passing of the DNA Identification Act of 1994 which allowed the FBI to create a national DNA database for helping law enforcement. Currently, CODIS contains over 3.4 million profiles on its database nationwide (CODIS, 2004), and is the world's largest DNA database. CODIS has two separate indexes which are divided into three separate hierarchy levels within its system

(Figure-9). The first index is the forensic index. This index contains evidence collected from crime scenes. The other index is the offender index which contains information from all offenders of sex crimes and other violent felons (Wikipedia, 2006).

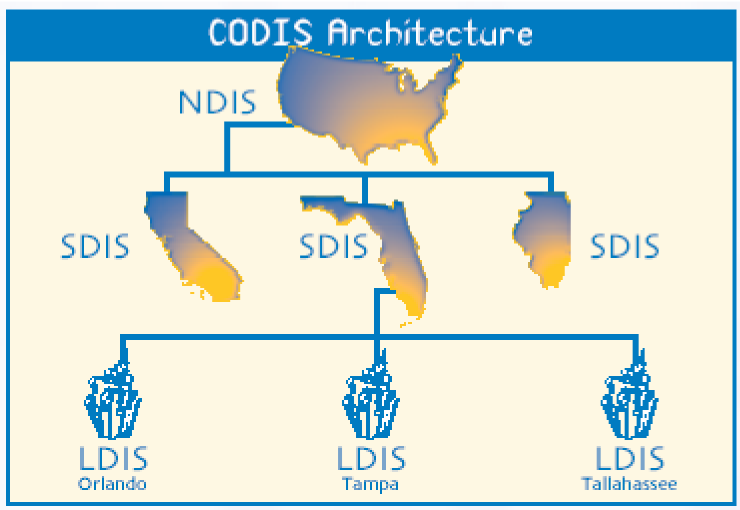

Figure-9: CODIS Structure (The FBI's Combined DNA Index System Program, 2000).

As for the hierarchy levels, on the national level, the FBI's National DNA Index System (NDIS), established in 1998, serves as the highest level and allows states and participating laboratories to share criminal information for the purpose of solving crimes. These profiles begin in the Local DNA Index System (LDIS) and then move to the State DNA Index System (SDIS), allowing each level to run on its own laws and regulations (CODIS, 2004). For example, individual states vary in who they require to provide DNA samples. For the state of Massachusetts, as of November 2003:

> "Any person convicted of an offense punishable by imprisonment in the state prison, and any person adjudicated a youthful offender by reason of an offense punishable by imprisonment in the state prison if committed by an adult, who is incarcerated in any prison… shall, within 1 year of the effective date of this act or before release from custody or from the department of youth services, whichever first occurs, submit a DNA sample to the department" (Massachusetts General Laws, Chapter 107 of the Acts of 2003).

Other states require DNA samples from convictions of the following types of crimes:

	Sex Offenses	Offenses Against Children	Murder	Assault & Battery	Robbery	Kidnapping	Burglary	Attempts	Juveniles
Alabama	x	x	x	x	x	x	x	x	
Alaska	x	x	x	x	x	x	x	x	x
Arizona	x	x	x			x	x	x	x
Arkansas	x	x	x	x	x	x	x		x
California	x	x	x	x	x	x	x	x	x
Colorado	x	x	x	x	x	x	x	x	x
Connecticut	x	x				x			
Delaware	x	x						x	
Florida	x	x	x	x	x	x	x	x	x
Georgia	x	x	x	x	x	x	x	x	
Hawaii	x	x	x			x			
Idaho	x	x	x	x	x	x		x	x
Illinois	x	x	x		x	x	x	x	x
Indiana	x	x	x	x	x	x	x		
Iowa	x	x	x	x	x	x	x	x	
Kansas	x	x	x			x	x	x	x
Kentucky	x	x	x	x	x	x	x	x	x
Louisiana	x	x	x	x		x		x	x
Maine	x	x	x	x	x	x	x	x	
Maryland	x	x	x	x	x	x	x	x	
Massachusetts	x	x	x	x	x	x	x	x	
Michigan	x	x	x	x	x	x	x	x	x
Minnesota	x		x	x	x	x	x	x	x
Mississippi	x	x				x			
Missouri	x	x	x	x		x			
Montana	x	x	x	x	x	x	x	x	x
Nebraska	x	x	x			x		x	
Nevada	x	x	x	x	x	x	x	x	
New Hampshire	x								x
New Jersey	x	x	x	x		x		x	x

New Mexico	x	x	x	x	x	x	x	x	x
New York	x	x	x	x	x	x	x	x	
North Carolina	x		x	x	x	x			
North Dakota	x	x	x	x	x	x		x	
Ohio	x	x	x			x	x	x	x
Oklahoma	x	x	x	x	x	x	x		
Oregon	x	x	x	x	x	x	x	x	x
Pennsylvania	x	x	x					x	x
Rhode Island	x	x	x	x	x	x	x		
South Carolina	x	x	x	x	x	x	x	x	x
South Dakota	x	x	x	x	x	x	x	x	x
Tennessee	x	x	x	x	x	x	x	x	x
Texas	x	x	x	x	x	x	x	x	x
Utah	x	x	x	x	x	x	x	x	x
Vermont	x	x	x	x	x	x	x	x	x
Virginia	x	x	x	x	x	x	x	x	x
Washington	x	x	x	x	x	x	x	x	x
West Virginia	x	x	x	x	x	x	x	x	
Wisconsin	x	x	x	x	x	x	x	x	x
Wyoming	x	x	x	x	x	x	x	x	
Department of Denfense	x	x	x	x	x	x	x	x	
District of Columbia	x	x	x	x	x	x	x	x	
Federal	x	x	x	x	x	x	x	x	
Puerto Rico	x	x	x	x	x	x		x	
Total	54	51	50	43	40	50	40	43	28

Figure-10: Table of Qualifying DNA Crimes By State (Adams, 2002).

For our state of Massachusetts, Figure-11 below shows that as of 2006, 361 investigations have been aided by a state database containing 6,374 offender profiles.

Statistical Information	Total
Offender Profiles	6,374
Forensic Samples	1,687
Number of CODIS Labs	2
NDIS Participating Labs	2
Investigations Aided	361

Figure-11: CODIS statistics for Massachusetts as of 2006 (Massachusetts, 2006).

Another large database within the United States is the Integrated Automated Fingerprint Identification System (IAFIS). Fingerprints had been used prior to the creation of the IAFIS, but because the fingerprints had been stored on index cards rather than electronically, it could take several months before officials received the necessary information to convict or release criminals. Therefore, the FBI decided to work with law enforcement to begin to create a technological storage system for normal fingerprints, which was finally put into operation in July of 1999, and is now maintained by their Criminal Justice Information Services Division. It currently holds over 47 million records, and has narrowed the time of receiving a criminal fingerprint request to just two hours (IAFIS, 2002).

DNA Database Success Stories

The creation of DNA databases has identified many criminals for unsolved crimes, and freed many who are innocent. One such case occurred in October 1987 in Virginia where a woman had been brutally stabbed to death. With no witnesses or suspects, law enforcement collected DNA samples from the scene. Nearly 12 years later in March 1999, the crime scene profile was matched on CODIS to a prisoner previously arrested in Virginia in 1989 (Success Stories, 2004).

Another story involved Kevin Green, a man accused of beating his wife to death in 1979. Green was imprisoned for over 16 years after being found guilty. It wasn't until 1996 when his DNA wasd tested that authorities realized they had arrested the wrong man. Tests showed that the true criminal that raped and killed Green's wife was the "Bedroom Basher" Gerald Parker, a former Marine who had his DNA profile on record after being convicted of several crimes in the 1980s. Because of this, Green was released, and in a retrial, found completely innocent of all chargers placed against him (Goodyear and Hallissy, 1999).

During 1997, Sarasota, Florida was the site of multiple violent sexual assault cases. Each case targeted single women, and the criminal always seemed to enter through the back door or rear screens of the homes/apartments. At one such incident in June, a semen sample and fingerprints were obtained from the crime scene. After unsuccessfully searching the SDIS state DNA database, Florida sent out the profile nationally and found a hit in Virginia on the NDIS. As a result, Mark Daigle was arrested in November of 1997 on multiple counts and put on trial, all thanks to the creation of CODIS.

Arguments Against DNA Databases

Although DNA databases have already shown their ability to solve crimes and protect the innocent, many people are against forced donations to databases. These arguments can usually be split into three main categories all revolving around constitutionality.

Unreasonable Search and Seizure

Who should be required to give DNA samples? When individuals are arrested, police officials commonly take your normal fingerprints and store them in IAFIS, whether you are convicted or found innocent those fingerprints will always stay in the system. The question that arises with DNA samples is whether it is just for authorities to keep your personal DNA or DNA profile on file even if you have never been convicted of a crime; if a mistake had not been made they would not have your DNA in the first place. People in the United States are supposed to be considered innocent until proven guilty. If this is the case, then why do they have to surrender personal information without consent (Rosen, 2004). Many critics believe that their DNA should be covered under the fourth amendment due to Katz v. the United States, stating that if they wish to keep their DNA and fingerprints private, they should have the right not to have such information stored in a public database.

Privacy Rights

Many individuals also argue that genetic medical predispositions can be determined from DNA samples, and they don't want insurance or medical companies getting their hands on such personal information, perhaps denying them medical coverage (Rosen, 2004). Scientists have mapped some genetic predispositions, Alzheimer's disease is one example with early onset cases mapping to a mutation on chromosome-21.

And more such medical dispositions are being discovered each year. However it is very important to note that no medical predispositions can be deduced from any of the 13 core forensic loci analyzed using current FBI standards (Figure-12). These loci help identify individuality, but not predisposition to medical diseases. However it is a valid argument that medical some predispositions could be determined by a non-forensic analysis of the DNA. If legislation was enacted mandating the destruction of the original DNA sample after the 13 core loci were analyzed, much of the criticism is negated.

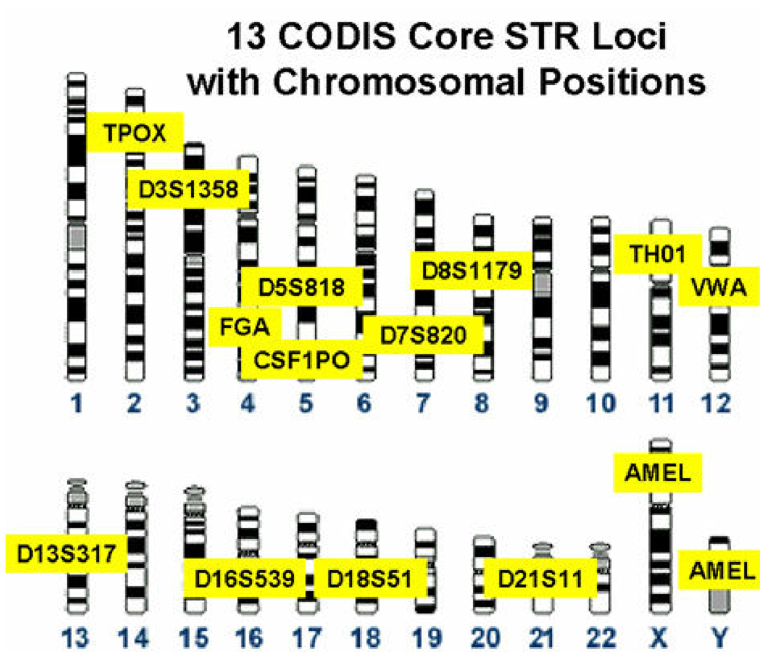

Figure-12: The 13 Core Loci Analyzed for CODIS (Wikipedia, 2006).

Cruel and Unusual Punishment

When it comes to the argument of cruel and unusual punishment, many take issue with the forcible way the DNA sample is collected, and the quantity of blood required. Courts, however, refuse to recognize such trivial claims, and view them as unwillingness to cooperate with administrative orders, so they have permitted the use of force to obtain such samples. The “force” required to take a mouth swab with a cotton tip (simple restraint at the worst) is nothing compared to the trauma to the victims of violent crimes. Therefore, such Cruel and Unusual Punishment arguments are often not successful (Privacy International, 2006).

Self-Incrimination

Another point often brought up by critics of DNA databases is that once the DNA is donated, if the individual is later proven innocent the entered information can never be truly made anonymous. One such example occurred in 2003 where a Scotland native was convicted of knowingly giving HIV to another woman. The reason the prisoner was convicted was because he had donated some DNA to be tested with the assumption that his identity remained anonymous, which it obviously didn’t, so he was aquitted, but his DNA profile remained in the database. This questions whether or not these databases can truly keep donors anonymous if necessary, or instead serve as a breach of privacy and self-incrimination (Rosen, 2004).

Criminals are not the only individuals required to provide DNA to databases. Anyone who joins the military is required to give a DNA sample to the Pentagon so that it can be stored into the database in case something happens to the recruit during wartime the body can still be identified. This application has already helped identify many fallen soldiers for their families. However, one has to question whether it is really necessary to keep these records in the database after the soldier has left the military. Also, DNA samples are now being taken from infants immediately after they are born to test for possible genetic defects, however, it is unknown whether or not that DNA will be stored for future usage. In one case in 2002, it was revealed that the state of Virginia would be storing 300,000 DNA profiles indefinitely collected from infants. This could later be used as a way to self-incriminate these individuals without them even knowing it (Rosen, 2004).

Arguments for DNA Databases

Unreasonable Search and Seizure

While critics feel that the fourth amendment should cover unlawful invasion of their bodies, the law often refers just to personal property. Sometimes a warrant is required for a mouth swab, but other times it is deemed unnecessary. But the judiciary system continues to argue that the fourth amendment right does not cover DNA (Privacy International, 2006). One of the main reasons the government feels it is not necessary to cover DNA under the Fourth Amendment is that it is not a big invasion to take a mouth swab and therefore is not really a "physical intrusion" as claimed by critics. Also, the justice system feels that criminals, the main population of the databases, have less of a right when it comes to privacy, having given up some rights the moment the violent crime was committed (Privacy International, 2006).

Self-Incrimination

Though many critics still stick by the idea that a DNA profile in a database can result in self-incrimination of a suspect, the government and supporters feel otherwise. Their main argument is the wording of the Fifth Amendment. The wording of the amendment states that no person is required to speak against themselves or provide physical evidence against themselves. However, the law does not specifically include fingerprints or biological evidence, such as DNA. Therefore, many judges have ruled that such evidence is non-testimonial and is not affected by the Fifth Amendment.

CONCLUSIONS

The authors of this IQP chapter agree with those U.S. states that require individuals convicted (not arrested) of violent crimes to provide a DNA sample for analysis. Whatever Right to Privacy that individual had (to withhold his DNA from analysis) was given up the moment he or she committed the violent crime. We also agree that the Cruel and Unusual Punishment argument is not very strong for those individuals convicted of violent crimes since the pain associated with taking a mouth swab with a cotton tip can not compare to the pain inflicted on the innocent victim of his violent crime. We also agree with Privacy Rights arguments that medical predispositions could be determined from the original DNA sample, so agree that laws should be passed mandating destruction of the DNA sample once the 13 core forensic loci have been analyzed. We also agree that methods should be created to ensure the anonymous identity of all profiled samples until after an individual's conviction, and erased if the individual is found innocent.

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d. http://www.dna.gov/training/letraining/adv/dna/dna-2-14.htm
e. http://www.dna.gov/training/letraining/adv/dna/dna-2-17.htm
f. http://www.dna.gov/training/letraining/adv/dna/dna-2-27.htm
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