

# Tackling Technical Debt: Managing Advances in DNA Technology that Outpace the Evolution of Law

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## Abstract

From its initial development in the 1980s as an identification tool, the use of DNA in criminal cases—both to convict defendants and exonerate the wrongly convicted—has been prolific. By the 1990s, Congress had focused on forensic DNA research and development. As DNA continues to expand its footprint as the ostensible “gold standard” in criminal investigations, an extraordinary amount of the federal funding allocated to crime labs was specifically earmarked for DNA expansion. Indeed, the funding abundance for DNA collection, testing, and retention far outstrip other crime lab allotments. Because of this, research and development of new DNA analytical techniques can be a lucrative business.

Indeed, the next generation of DNA technology already has or inevitably will find its way into criminal investigations and the courtroom. The high rate of return on DNA-based investment almost dictates this result: As of December 2015, CODIS has produced over 315,410 hits that assisted in at least 303,201 investigations. But DNA technology may advance and outpace the testimonial claims, which are not yet reliable and scientifically defensible. Technology does not wait for the legal system to catch up with it.

This article examines the new wave of DNA testing tools. It surveys the validity of these new forensic techniques, considers evidentiary uses in courts, and any addresses potential hurdles to admissibility. Part I covers the background of DNA testing. Part II assesses LCN DNA testing, Part III looks at phenotyping, and Part IV focuses on Rapid DNA testing. Finally, Part V concludes that additional validation studies are needed before these technologies become part of the routine criminal investigation process.

From its initial development in the 1980s as an identification tool, the use of DNA in criminal cases—both to convict defendants and exonerate the wrongly convicted—has been prolific. By the 1990s, Congress had focused on forensic DNA research and development. As DNA continues to expand its footprint as the ostensible “gold standard” in criminal investigations, an extraordinary amount of the federal funding allocated to crime labs was specifically earmarked for DNA expansion. Indeed, the funding abundance for DNA collection, testing, and retention far outstrips other crime lab allotments. Because of this, research and development of new DNA analytical techniques can be a lucrative business. Indeed, the funding abundance for DNA collection, testing, and retention far outstripped other crime lab allotments, despite the fact that DNA analysis only represented a small portion of crime lab work at that time. Two decades later, DNA testing is now a primary hub of many labs—forcing other traditional forensic lab departments (such as trace evidence or fingerprints) to cut back or close shop.

**Keywords:** Tackling; Technical debt; DNA technology; Evolution; Law

## Background

Despite the luminescent “gold standard” label, DNA profiling was not always so readily accepted. Like any scientific evidence, the process of DNA profiling must meet certain standards in order to be admitted at trial. The path to DNA’s widespread recognition and admissibility begins with the landmark case of *Daubert v. Merrill Dow Pharmaceuticals, Inc* [1]. In *Daubert*, the Supreme Court created a new standard to use when evaluating the admissibility of scientific evidence in federal court. In so doing, the court looked to Federal Rule of Evidence 702 and determined that federal courts must apply a relevance test to determine whether scientific evidence and testimony should be admitted.

Under the *Daubert* standard, judges must first find that DNA expert’s scientific evidence is “reliable and relevant, both in theory and in the expert’s methodology [2].” In its evaluation, courts may consider factors such as: (1) whether the underlying principles and methods are susceptible to empirical testing; (2) whether the underlying principles and methods have been subjected to peer review and publication within the relevant community; (3) whether there exists a known or potential error rate; and (4) the general acceptance of the principles and methods within the relevant community [1].

While DNA evidence can—and should—be tested prior to each trial, many courts skip the in-depth *Daubert* analysis, with some courts going so far as to take judicial notice of the reliability of DNA evidence [3]. After *Daubert*, the first federal court to recognize the ability for courts to take judicial notice of the reliability of DNA profiling was the Eighth Circuit in *United States v. Martinez* [3]. In *Martinez*, investigators recovered sperm from the clothing of a rape victim and conducted a DNA analysis to determine if the sperm matched Martinez, the defendant. The analysis yielded a match and prosecutors sought to admit evidence of the match during trial. The district court admitted the evidence of the DNA match, but refused to admit a statistical analysis that indicated the DNA profile could be found in “1 in 2600 American Indians.” Martinez appealed on the basis that the admission of evidence of a DNA match without the statistical probabilities that

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the DNA could have come from another individual was improper, and that all DNA evidence should have been excluded.

On appeal, in lieu of conducting its own independent *Daubert* analysis, the Eighth Circuit looked to the Second Circuit, which had recently concluded that DNA evidence survived *Daubert* and that the “reliability of the general theory and techniques of DNA profiling were valid.” The *Martinez* court went on to not only admit the DNA evidence, but also hold that future courts can take judicial notice of the reliability of DNA testing. The Eighth Circuit, however, provided an important limitation on the ability to take judicial notice of the reliability of DNA evidence. The *Martinez* ruling contained a contingency that a *Daubert* hearing would be required in order to determine admissibility of DNA evidence if the technology, methods, or procedures used developed or changed.

The upmarket peddling of DNA evidence in fictional television dramas has translated to real life courtrooms: judges and juries want more science, and the criminal justice system has responded. But maybe it was too much too soon. We have a vast amount of biological input into the DNA system. With more input, comes the need for more warehousing and output, and an explosion in the size of DNA databanks. As of August 2015, the National DNA Index (NDIS) contains over 11,917,028 offender profiles, and 2,087,760 arrestee profiles.

While the breadth of DNA databanks broadens, so too does the application of genetic research. The thirst to incorporate and accept technologies-like stem cell research, cloning, or genetic-based medicine—only increases as scientists continue to disentangle the human genome and intermingle the ever-evolving applications in criminal investigations.

This raises difficult questions about how to best apply that technology. DNA testing continues to advance and now encompasses several new types of DNA analyses that are being used in court cases. In particular, three new technologies are currently being piloted by some jurisdictions and could soon become widespread in use.

*Low Copy DNA* testing, or LCN DNA testing, can create a DNA profile from only a few skin cells. LCN DNA can be used on a sample that contains less than 200 picograms of DNA [4]. LCN DNA testing has been used in the United Kingdom, but that use has revealed some shortcomings in the test. In the United States, New York courts have begun to admit LCN DNA testing, although not all New York courts are in agreement on the reliability of LCN DNA analysis.

*Phenotyping* refers to a technique used in determining an individual’s physical characteristics based on his or her genetic profile. Early research demonstrates that some externally visible characteristics (phenotypes) can be linked certain genetic arrangements (genotypes). The characteristics that scientists have attempted to pinpoint include ancestry; ethnic origin; skin, eye, and hair color; facial shape; height; and even age. Several jurisdictions have experimented with this technology to generate sketches of suspects based upon DNA profiles. Of course, the accuracy of the profile created remains subject to the success of a criminal investigation. More importantly, given that DNA at a scene can come from a number of sources, the use of phenotyping may unduly implicate or profile otherwise innocent individuals.

*Rapid DNA* testing is among the newest of these technologies and refers to a new line of DNA testing machines that may be able to produce a DNA profile in as little as two hours. Traditionally, it takes a crime laboratory about two days to expedite DNA results (assuming

no backlog), so reducing that time to two hours could speed up an investigation. Additionally, the machines that create an STR profile are entirely automated, allowing law enforcement personnel to potentially do an analysis formerly restricted to laboratories. These machines, however, are not yet recognized as reliable alternatives to the standard DNA tests, nor are the results produced by them accepted by databases such as the National DNA Indexing System (NDIS).

The next generation of DNA technology will inevitably find its way into criminal investigations and the courtroom. The high rate of return on DNA-based investment almost dictates this result: As of December 2015, CODIS has produced over 315,410 hits that assisted in at least 303,201 investigations [5]. But DNA technology may advance and outpace the testimonial claims, which are not yet reliable and scientifically defensible. Technology does not wait for the legal system to catch up with it. From DNA to GPS, “the boon that new technology will provide to law enforcement is an engraved invitation to future expansion [6].”

This article examines the new wave of DNA testing tools. It surveys the validity of these new forensic techniques, considers evidentiary uses in courts, and any addresses potential hurdles to admissibility. Part I covers the background of DNA testing. Part II assesses LCN DNA testing, Part III looks at phenotyping, and Part IV focuses on Rapid DNA testing. Finally, Part V concludes that additional validation studies are needed before these technologies become part of the routine criminal investigation process.

## History of DNA Testing

DNA, an acronym for deoxyribonucleic acid, is the building block of all organisms [7]. Swiss scientist Friedrich Miescher originally identified nucleic material in white blood cells in 1869 [8]. In 1953, American biologist James Watson and English physicist Francis Crick discovered the three dimensional, double helix configuration of DNA that is well-known today [9].

The future of DNA changed forever, however, on the morning of September 10, 1984—the day Dr. Alec Jeffreys discovered genetic fingerprinting in the Genetics Department at the University of Leicester in the United Kingdom [10]. Almost immediately, Dr. Jeffreys realized the implications of his discovery: crime, paternity testing, and “work on conservation and diversity among non-human species.”

Jeffreys put his novel discovery to the test for the first time in 1985 after two young girls were raped and murdered in Leicestershire, located in Central England. The police had a suspect in custody who already had confessed to one murder but refused to confess to the second [11]. The police then asked Jeffreys to use his new technique, DNA profiling, to connect the suspect to both murders. The results were “completely unexpected:” they did not match the man in custody. Because the police now had DNA samples from semen found on both victims and the support of the police, a manhunt was initiated to find the man who matched the DNA fingerprint identified by Jeffreys’ work. The search eventually led to Colin Pitchfork, who was arrested and convicted of the crimes in 1988 [12].

The first person in the United States to be convicted using DNA evidence was in 1988 as well, when Tommie Lee Andrews was convicted of two violent sexual assaults/murders in Florida [13]. Two separate juries convicted Andrews of the two murders when DNA evidence was only an “emerging science.” In fact, at the time it was used to identify Andrews, DNA evidence had only been used once: in the conviction of Colin Pitchfork in Leicester.

Since the conviction of Tommie Lee Andrews and Colin Pitchfork, DNA evidence has become a crucial, if not necessary, part not only of the criminal justice system in the United States, but also of the justice system in the United Kingdom [14]. Globally, DNA was instrumental in recent war crimes and genocide investigations such in Kosovo and Bosnia [15].

The United States passed the DNA Identification Act of 1994 [16]. The Act detailed the requirements of maintaining a National DNA Index System (commonly known as “NDIS”) for convicted offenders, arrestees, and forensic casework. NDIS, in turn, is just one part of the larger system, the Combined DNA Index System (commonly known as “CODIS”), which is the generic term for the FBI’s program that supports criminal justice databases. Furthermore, all fifty states now have laws requiring the collection of DNA samples from certain categories of offenders [17]. According to the FBI, NDIS contains over 11,962,222 offender profiles, over 2,120,729 arrestee profiles, and over 657,298 forensic profiles [18]. As of September 2015, CODIS has “produced over 296,490 hits assisting in more than 282,490 investigations.”

Since the 1990s, Congress has devoted a large amount of funds to forensic DNA research and development [19]. This, of course, is directly related to the amplified use of DNA in criminal investigations. As DNA continued to become the so-called “gold standard” in law enforcement and this new reverence—bordering on obsession—meant that a tremendous amount of the federal funding was designated for DNA research and development.

Two decades later, DNA testing is the focal point of many labs—forcing other traditional forensic areas to reduce or even shut down their units. Police departments now include routine DNA swabs of evidence and persons because “the justice system’s hunger for DNA evidence just keeps growing [20].”

The current standard method for developing a DNA profile utilizes polymerase chain reaction analysis (“PCR”) [21]. Defined most simply, PCR is “molecular photocopying,” a fast, cheap, and most importantly, accurate, way to copy small segments of DNA [22].

## How DNA Testing Works

**DNA collection:** “Protection of the crime scene is essential to the protection of evidence [23].” Investigators may find samples of DNA from a number of sources, but because biological evidence is not always visible and can be mixed with other sources, there is always a chance that the evidence gathered may lead to imprecise results. Very little DNA is required in order to perform analysis (only 50 picograms) [24], but that does not mean that the quality of that small sample is adequate for testing. Sufficient amounts and types of DNA must be collected on the scene for this technology to work properly.

**DNA description:** Like a serial number is used to identify a particular product, people can be identified based on their specific genetic makeup [25]. Within a person’s cells, strings of nucleotides made up of Adenine, Cytosine, Guanine, and Thymine, match up with the corresponding proteins in the form of a double helix [25]. Though these patterns are highly predictable—A matches with T and C matches with G—but the discrete differences can distinguish each person’s genetic makeup.

Variations in DNA patterns may be seen at the single nucleotide level or through an unexpected, repetitive pattern of nucleotides. The addition, deletion, or unexpected change of one nucleotide is recognized as a single nucleotide polymorphism (SNP) [26]. The short

tandem repeat (STR) of a series of nucleotides may also be indicative of a person’s traits. Gender may be easily determined based on the presence or absence of a Y-chromosome in a person’s DNA [25]. But as DNA analysts delve further into these genetic details, they are uncovering more ways that parts of sequences and individual allele variances can be predictive of a person’s appearance.

**Short tandem repeats:** Short tandem repeats, repeat nucleotides within a sequence, is one phenomenon of DNA that is indicative of a person’s traits [27]. To find these STRs, a small sample of DNA (typically less than fifty base pairs) is obtained from a physical sample, copied through polymerase chain reaction, and analyzed for patterns of nucleotides [28]. STRs may be indicative of genetic history, as relatives and people from similar regions often share the same repeated pattern of nucleotides. The benefit to using STRs in analyzing DNA is the product may be a highly accurate match, but obtaining this match depends on the sample having decent quality DNA from which to create the STRs.

DNA genotyping based on the PCR amplification and electrophoretic analysis of Short Tandem Repeats (STRs) is the bread and butter of forensic DNA testing. An STR is a polymorphism found in mammalian DNA, a sequence of nucleotides (ranging between 2-10 base pairs) that is repeated at a gene locus [29]. By examining several STR loci one can establish the unique genetic profile of an individual, linking biological evidence from a crime to the perpetrator or to other crimes by the same person. Tetranucleotide repeats are the mainstay of forensic DNA analysis and criminal offender databasing. There are only 33 possible tetranucleotide motifs, and the consensus motif sequences, mostly AGAT and GATA, are ubiquitous in the human genome. The number of repeat units at these loci varies from as few as four to as many as 50.

Generally, DNA found from crime scene samples is tested in a lab and compared with known samples to exclude suspects. Traditional autosomal STR profiling involves taking certain loci in DNA [30] and comparing these STR patterns with a known match to discover whether there are variances. Thirteen loci in DNA are predesignated test sites for comparing the gathered sample to the CODIS profiles [31]. Side-by-side comparison of the samples shows whether the DNA produces a match. This technique is highly accurate, but also leaves the donor’s privacy intact since no other information is gathered from the unknown DNA sample [32]. That sample will either become known, based on information already legally acquired and stored [33], or the sample will remain unidentified.

**Coding and Non coding DNA:** Generally, the use of DNA evidence in crime solving involves a lab’s comparison of a known match, taken from a suspect or from the DNA database, with an unidentified sample taken from a crime scene. The type of DNA used for traditional autosomal STR profiling is noncoding DNA [25]. Noncoding DNA refers to the parts of DNA that do not code for protein creation. Its function is still somewhat unclear. Noncoding DNA is commonly referred to as “junk” DNA because it does not hold any genetic information. Long believed to have no evolutionary function, more recent studies show that at least some of these loci serve a regulatory function [34]. Because the purpose of this DNA is unclear, the information cannot be used to probe further into any additional traits of the donor. Analysis of this DNA is far less invasive than the use of coding DNA. Thus far, noncoding DNA has only been useful for comparison purposes [35].

Coding DNA is only a small percentage of the human genome, but it contains the most revealing information about the donor. These



base pairs are what make up a person's genes. Specifically, exons in the DNA strand create proteins that influence genetic features [36]. But coding DNA may also reveal personal genetic information, including information that the DNA donor may not even know about his or her health. And as scientists discover more about the relationship between coding and noncoding DNA, even noncoding DNA comparisons could potentially become invasive endeavors.

### DNA's impact on the jury

In terms of the biology, "DNA is the body's instruction manual [37]." It determines everything about an individual, from height to musical aptitude. Said another way, our DNA determines who we are and makes each one of us a unique being. Not only does our DNA make us unique as individuals, our DNA itself is unique. Other than identical twins, no two people share the same DNA. Because of this "distinctive" quality, forensic scientists are able to extract DNA from two samples and determine if they "match". Prosecutors then use this information to argue to a jury that because a defendant's DNA was found at a crime scene, that defendant is more likely to have been present at the scene and committed the crime being charged [38].

While in lay terms, a match means two things are identical, in the field of DNA, a "match" is not so cut and dry. When DNA is used in the forensic context, the term "match" is used to represent a probability, not a certainty [37]. DNA cannot tell a jury with 100% certainty that the DNA found at the scene of a crime came from a particular defendant. It can, however, tell the jury that the DNA is a close match and the likelihood of that DNA profile being found in another individual. That is, DNA evidence tells the jury that the DNA extracted from a defendant and the DNA found at the scene of a crime are very similar, but there is a chance, although typically very small, that the DNA came from someone other than the defendant. At minimum, a DNA match is able to "exclude large proportions of the population as potential contributors of genetic material (e.g. blood, semen, hair) that are recovered from violent crime scenes [39]."

Despite the fact that a DNA "match" does not provide incontrovertible evidence of guilt, DNA evidence remains powerful. One court went so far as to say that DNA matching is "the single greatest advance in the 'search for truth,' and the goal of convicting the guilty and acquitting the innocent, since the advent of cross-examination [40]." Moreover, while many prosecutors complain of increased difficulty in establishing proof beyond a reasonable doubt in criminal trials as a result of unrealistic expectations caused by television shows like CSI, the "CSI-effect" impacts defendants as well [41]. Having been trained, through television crime dramas, that DNA evidence is not to be questioned, juries place undue weight on any sort of DNA evidence brought forth by the prosecutor. Although difficult to explain, studies show that when juries are presented with specific evidence of high laboratory error rates alongside a DNA match, they are still just as likely to convict a defendant [42].

### Low-Copy Number DNA Testing

#### Origins

The techniques used in DNA fingerprinting have evolved significantly from the first method used by Dr. Jeffreys in 1985 [11]. Jeffreys initially used a technique called Restriction Fragmentation Length Polymorphism ("RFLP"). But this technique requires a large amount of sample of DNA, perhaps a "nickel sized spot of bodily fluid [21]." LCN DNA analysis can create a DNA fingerprint using only a few skin cells [43]. In fact, LCN DNA analysis refers specifically to the "analysis

of any DNA sample that contains less than 200 [picograms] of DNA."

The procedure for LCN DNA testing is similar to standard PCR DNA testing [44]: the DNA is extracted from the material, then analyzed to determine the amount of DNA extracted. If it is below a threshold amount (generally less than 0.5 ng), the sample is run through more amplification cycles and is considered LCN DNA testing.

The Forensic Science Service ("FSS"), a former United Kingdom government-owned forensic laboratory, developed the LCN DNA testing technique and used LCN DNA testing numerous times beginning in 1999 [45]. LCN DNA testing may refer to any testing where a small amount (less than <100-200 picograms) of DNA material is present [46]. Throughout its existence, the technique has had its critics, and in fact, only a few countries have allowed LCN evidence into their courtrooms [47].

Low copy number DNA testing could take a cue from the fates of PCR DNA testing and the more primitive Restriction Fragmentation Length Polymorphism ("RFLP") analysis. Both analyses had been consistently held admissible for a number of reasons. First, these two techniques use a larger initial sample of DNA than low copy number DNA testing [48]. Second, these techniques have already been recognized as the most common type of DNA analysis method across the world, thereby easily satisfying both the *Frye* Standard as well as the *Daubert* requirements. But they've also been found to be fallible. In the 1980s and 1990s, these two methods were thought to produce consistent, accurate, and reliable profiles "generally accepted" by forensic professionals throughout the world [49]. But ultimately, the methodology was not as discriminating as originally thought. This could be the outcome of an early adoption to LCN DNA. It is relatively new, not used consistently around the world, and produces DNA samples that are less reliable, less accurate, and less consistent due to an increased need for human interpretation.

Because of the small sample size used in LCN DNA testing, this method is prone to numerous analytical problems including stochastic effects/stutter, detection thresholds, allele imbalance, contamination, and profile interpretation; these problems will be discussed in depth below. LCN DNA testing is also subject to some analytical problems that PCR does not face; further, PCR has been in use for years, validated by forensic scientists across the world, and is generally accepted under both the *Frye* and *Daubert* standards. Admittedly, LCN DNA testing could become a valuable technique that has a place in courtrooms in the United States as a corroboration tool.

### Cases Involving LCN DNA Testing in Other Jurisdictions

**The Beginning:** LCN DNA testing has proved valuable in solving a number of high profile cases. One of the first such cases involved the murder of Swedish Foreign Minister Anna Lindh in 2003 [50]. Swedish authorities asked the FSS to assist and carry out LCN DNA testing on DNA found on a knife [51]. The mixed sample found on the knife partially matched Minister Lindh as well as Mijailo Mijailovic, a suspect who was later convicted. Due to the small amount of mixed DNA found on the murder weapon—a knife—the police had to use low copy number DNA testing to isolate the different profiles. Had LCN DNA testing not been available, Mijailo Mijailovic likely would have gone free [52].

LCN DNA testing was the only DNA evidence presented at trial, meaning that it was based on a very tiny quantity of DNA. Nonetheless, Mr. Mijailovic eventually confessed to the crime. But a confession may never have occurred without the weight of this DNA evidence facing

Mijailovic. Good evidence should effectuate a good confession. But we also know that bad evidence can compel a bad confession. Sometimes police are unable to get a confession from a suspect. Situations where the suspect does not confess necessitate a harder look at whether profiles obtained using LCN DNA testing should be the sole DNA evidence presented at trial.

Take the conviction of Bradley Murdoch in 2005, where the Australian police used LCN DNA testing to help convict Murdoch of the murder of Peter Falconio [53]. The technique successfully produced a DNA profile matching Murdoch from DNA found “deep inside homemade ties” made and used by Murdoch to restrain Falconio’s girlfriend, Joanne Lees. Here again LCN DNA testing helped get a conviction. But Murdoch did not confess [54]. In fact, Murdoch instead insisted that the police had “set [him] up.” Murdoch maintained his innocence; he even admitted that he could not have committed the murder because he was “running drugs hundreds of miles away at the time of the killing.” Not to say that Mr. Murdoch was actually innocent, but perhaps a better use for LCN DNA evidence is as corroborating evidence rather than the sole evidence against the defendant.

Finally, LCN DNA testing was used to convict Antoni Imiela, the M25 rapist, after a DNA link [51]. This case presents a situation where police in the United Kingdom used LCN DNA evidence along with other corroborating evidence to get a conviction [55]. Imiela, who was denied leave to appeal in 2013, was sentenced to seven life sentences for the rape of seven women. Here, in addition to the DNA profile obtained using LCN DNA testing, forensic scientists in the United Kingdom also found fabric fibers matching clothes worn by rail workers-Imiela was a rail worker-as well as fibers that matched the curtains in Imiela’s home. Further, mobile phone and bankcard records placed Imiela in the vicinity of the crimes. Lastly, a fingerprint belonging to Imiela was found on a bag used as a pillow during one of the rapes. Despite all of this evidence, Imiela maintained his innocence-and continues to do so today [56]. The Imiela case presents a situation where LCN DNA evidence was used in conjunction with other evidence placing a suspect within the vicinities of the crime. Granted, Imiela maintained his innocence, as many criminals likely would, but the use of LCN DNA evidence in conjunction with other evidence is a more appropriate use of the technique.

**Low copy number comes into the limelight:** Despite its prior use, LCN was really thrust into the spotlight during the trials held as a result of the 1998 bombing in Omagh, Northern Ireland [57]. Initially, police arrested Colm Murphy, but the case against him fell apart after questions arose related to evidence given by the two officers involved [58]. Interestingly, the next man arrested was Murphy’s nephew, Sean Hoey. Using LCN DNA testing, the FSS informed the presiding Justice, Justice Weir, they found Hoey’s DNA on items related to the bombing as well as other bomb scenes [49]. Hoey’s defense immediately set out to discredit the technique and prove Hoey’s innocence by demonstrating the significant shortcomings of the LCN technique.

### Defending hoey: problems with LCN

According to Professor Dan Krane, a DNA expert from Ohio, “low copy number tests are much more prone to flexible interpretation than with the conventional tests.” Problems that can arise with LCN include stochastic effects/stutter, detection thresholds, allele imbalance, and contamination [44]. All of these problems can significantly affect the interpretation of the resulting DNA profiles, which is left to a forensic scientist [44]. Because interpretation is necessary, a human element is present, resulting in inconsistencies. These inconsistencies are a

major concern for courtrooms deciding whether to admit LCN DNA evidence.

**Stochastic Effects/Stutter:** Essentially, stochastic effects are random variations that occur when amplifying small amounts of DNA [59]. A stochastic effect occurs when there is an imbalance in or a total loss of alleles caused by unequal sampling, resulting in the failure to detect one or both alleles [43]. “LCN DNA templates... will experience stochastic amplification that may result in either a substantial imbalance of 2 alleles... allelic dropout, or increased stutter.” These effects “manifest as a fluctuation” in the results when replicate analysis are conducted and compared. Stutter refers to the actual peaks that occur, which are caused by the stochastic effects as a result of the replication process. Stutter is caused by “miscopying or slipping” in the PCR process. Because the initial amount of sample used in LCN DNA testing is so small, extra cycles are conducted in the replication process, resulting in extra amplification. This added amplification, which is necessary in LCN DNA testing, makes discerning stutters and the actual DNA profile difficult, and thus, less reliable. These inconsistencies from one sample to other produce inconsistent effects, increasing the likelihood of a false match (or non-match) due to the required interpretation.

**Detection Effects:** When a small amount of DNA is used in testing, the heights of the resulting peaks that correlate to the allelic peaks are below the normal threshold used in other DNA profiling methods [43]. With LCN, those peaks are increased because of the additional replication cycles prior to interpretation. The standards for interpreting the peaks for the LCN DNA analysis are different from the “established and validated” methods used in other techniques, such as PCR and RFLP, as discussed above. Thus, the lack of these “established and validated” methods allows for possible inconsistencies in interpreting the resulting LCN DNA testing profiles. Again, the profiles obtained using LCN DNA testing may appear inconsistent because of problems inherent to the increased number of cycles adding to the interpretation problems.

**Allele Imbalance:** Alleles are alternative forms of the same gene; they manifest as difference characteristics of people, such as eye or hair color. But because of the differences in the molecular weight of alleles, the copying and amplification process can result in inconsistent amplification of these alleles [43]. These inconsistent effects are exacerbated in the case of LCN DNA testing because more amplification samples are needed due to the miniscule beginning sample size. Thus, the resulting sample has increased inconsistency as well as an increased unknown factor making the resulting sample more challenging to interpret [44].

**Contamination:** The minute amount of material used in LCN DNA analysis coupled with the extensive amplification cycles exacerbates any amount of contamination in the sample. Even reagents or other laboratory items could contain small amounts of DNA that would be replicated during the process leading to false results. A small amount of contamination can change a profile significantly, resulting in an inaccurate profile.

**Profile Interpretation:** Profile Interpretation is actually the culmination of all the above-listed problems, which can render actual interpretation of the resulting DNA profile problematic. Once the profile (or profiles) is compiled, the forensic scientist has to manually interpret the profile. As seen above, the increased number of amplification cycles results in many variables in the profiles. These variables have to be accounted for by the forensic scientist interpreting the sample. Thus, different forensic scientists may interpret the

resulting profiles differently, which means that the use of an LCN DNA profile as the sole DNA evidence against a suspect is problematic.

Unlike the scientifically established and accepted methods of PCR or RFLP, which use a larger DNA sample initially, LCN DNA testing uses a smaller sample, which results in a greater need for profile interpretation. A standard interpretation method for LCN DNA analysis will make interpretation uniform and result in more consistent results. But currently, too much room for error exists in the interpretation of these samples for LCN DNA testing to be the sole DNA evidence presented against a suspect. Thus, while a valuable tool, LCN DNA testing should only be used in conjunction with or as corroboration for other evidence.

### Aftermath of Hoey

To make matters worse, at the time of Hoey's trial, only FSS scientists had validated the LCN DNA testing technique, not outside experts [45]. The defense had a strong argument because Sean Hoey had been accused of another bombing, but was eventually acquitted. DNA on that defused device was profiled using LCN DNA testing as well; however, the initial DNA profile produced matched a teenage boy, not Sean Hoey. The prosecution encountered further problems when one of the inventors of the LCN technique himself called the prosecution's DNA results "valueless". He further described LCN DNA testing analysis as complex, adding that the technique existed in "shades of grey".

After Hoey was found not guilty in 2007, the Crown Prosecution Service announced it would "review live prosecutions in England." Northern Ireland also instituted an "immediate review" of cases that utilized LCN DNA testing [60]. A spokesman for the Association of Chief Police Officers announced a suspension of the technique, adding, "In England and Wales, DNA evidence has to be corroborated by other evidence."

But this suspension did not last long. After only one month, the technique was reinstated after a government-commissioned study by Professor Brian Caddy found the technique to be "scientifically robust" and "fit for purpose" [61]. A spokesman from the FSS called the report a "ringing endorsement" of the technique. Also, despite "high" failure rates, the same FSS spokesman said, "broad-brush statements about its reliability are somewhat inaccurate." Caddy's report concluded that "LCN typing was basically sound;" however, he "cautioned that it should be undertaken with extreme care by outlining specific steps and recommending that juries should be presented with information regarding its limitations."

As seen above, low copy number DNA testing has had a rollercoaster of an existence. Despite being used to help solve high profile crimes committed around the United Kingdom, the government suspended its use due to evidentiary problems. But that suspension seems a mere administrative formality as LCN DNA analysis was reinstated only a short month later, though LCN DNA testing still faces an uphill battle before it will be considered again as standalone evidence. Scientists in the United Kingdom were the pioneers of the technique; if they themselves urged caution in its application, perhaps courtrooms in the United States should heed their warnings.

### Low Copy Number DNA Testing in the United States

Low copy number DNA testing has only been addressed in a few jurisdictions: primarily New York, California, and New Mexico. In fact, "The New York City Office of Chief Medical Examiner (OCME) is the

most prominent U.S. laboratory that undertakes deliberate, routine LCN testing."

### New York: setting the standard

**Megnath:** One of the most significant cases discussing low copy number DNA testing is *People v. Megnath*, a New York Supreme Court case decided in Queens County in 2010 [48]. In *Megnath*, the New York courts considered the admissibility of low copy number DNA testing for the first time. The defendant was charged with Murder in the First Degree and "other related offenses." During a search of the defendant's vehicle, police recovered DNA evidence, which eventually linked Megnath to the crime. But because the OCME used low copy number DNA testing to process the collected samples, Megnath moved for a *Frye* hearing to explore the reliability of the evidence, which the court granted [49]. The court noted that LCN DNA testing "has been used worldwide for over 10 years and is currently used in many other countries including Australia, Austria, England, New Zealand, Italy, the Netherlands, Spain, Portugal and Switzerland."

The New York courts looked at the following factors before making their decision. The OCME used the established protocols and techniques from these countries to develop New York's LCN DNA testing technique. Further, New York instituted additional safeguards in their testing procedures to ensure accurate test results: in addition to renovating their laboratory in 2004 to accommodate LCN DNA testing, the city also built a brand new facility in 2007 to "accommodate advances made in the area of LCN testing." Additionally, scientists in the OCME measure the amount of DNA transferred from one person to another (during contact) to ensure accurate interpretations, conduct "extensive validation studies," and increase the number of cycles used in amplification from twenty-eight to thirty-one.

With respect to some of the problems seen with LCN DNA testing discussed above—specifically stochastic effects—New York takes an interesting approach. New York uses a "consensus profile method." Basically, this method involves testing the sample multiple times and comparing the results. Because there are now multiple profiles from one sample, the stochastic peaks can be compared, which allows the stochastic peaks to be removed, thereby resulting in a sample that has a "higher percentage of correct loci" with less allele dropout. Allele dropout occurs when one peak (out of two) is significantly imbalanced, giving the appearance that one of the alleles has dropped out [62].

In holding LCN DNA evidence was not only credible, but also admissible, the *Megnath* Court noted that LCN DNA testing uses the same techniques, steps, equipment and machinery as High Copy Number ("HCN") DNA analysis—the standard method in DNA analysis, which has been held admissible in New York Courtrooms.

New York has set the standard for LCN DNA testing in the United States. New York's individual validation studies coupled with their brand-new state-of-the-art facility demonstrate its commitment to understanding and perfecting this relatively new procedure. It would be unreasonable, however, to expect every state to undergo such drastic updates. New York's "consensus profile method" may help in the interpretation of the samples because processing the sample numerous times exposes the stochastic effects and helps eliminate them. Although still not perfect, New York's novel approach to this method has clearly set the stage to understand and perfect LCN DNA testing.

**Revisiting Megnath: Morgan and Garcia:** New York revisited LCN DNA testing in *New York v. Garcia* in February 2013. In *Garcia*, the Supreme Court of Bronx County analyzed the admissibility of low



copy DNA evidence recovered from a piece of duct tape used to bind the victim's ankles [63]. Relying on *Megnath*, the court stated that "when properly performed, [LCN] is generally accepted as reliable in the scientific community." The court also acknowledged that LCN DNA testing had been admitted in "New York trial courts over 125 times, in a federal district court in the Southern District of New York and in courts of multiple other countries including Germany, The United Kingdom, Sweden and Switzerland."

In *U.S. v. Morgan*, the District Court for the Southern District of New York also held LCN DNA testing admissible for similar reasons discussed in *Megnath*, including the OCME's validation studies and accreditation [64]. The Court placed great weight on the OCME's validation studies, especially the fact that the "scientific community—a number of independent experts intimately familiar with the criteria for scientific validity—ha[d] repeatedly endorse[d] the sufficiency of OCME's validation studies and protocols."

In these two cases New York seems to embrace the concept of the "scientific community," noting the numerous validation studies conducted around the world and adding that the test is used in various countries. The idea of the scientific community is an important concept, especially when evaluating new technologies. New York embraces other jurisdictions' approval of the technique; however, ignoring the numerous potential problems that plague LCN DNA testing seems irresponsible. New York should continue to evaluate and improve their technique with respect to LCN DNA testing. Doing so will increase the awareness and effectiveness of the technique.

**The District court of new Mexico disagrees:** In *United States v. McCluskey*, the District Court of New Mexico disagreed with the *Megnath* court. The Court in *McCluskey* held an evidentiary hearing on the admissibility of the LCN DNA testing results under *Daubert*. The Court noted that LCN DNA testing may produce "unreliable and non-reproducible" results because of the increase in stochastic effects, allele drop-out, and stutter: the same problems that were discussed above. The Court also noted that the profiles produced using LCN DNA testing is open to interpretation and such interpretation is "not straightforward;" further nothing that "additional guidelines may be required." The Court stated that "most laboratories in the U.S. do not perform LCN testing," resulting in only a "few reported U.S. cases on LCN testing." The Court then added that, apart from private and academic laboratories conducting such testing, New York's OCME is the only government facility that does so [63].

Next, the court noted that the New Mexico Department of Public Safety ("NMDPS") does not use any of the special procedures or interpretation methods used by New York's OCME, including increased amplification cycles [49]. Also, the NMDPS had not conducted "extensive internal validation" of the technique or received "certification and approval for it."

In the end, the court in *McCluskey* held the LCN DNA evidence inadmissible specifically because the method is "not the product of reliable principles and methods" and is neither credible nor reliable. Further, LCN DNA testing did not even meet the "admittedly relaxed standard of *Daubert*." That, coupled with the significant problems facing interpretation of profiles obtained using LCN DNA testing (specifically the need for interpretation standards because of the numerous stochastic effects) plagued LCN DNA testing with a lack of reliability.

*Megnath* and *McCluskey* demonstrate two very different approaches to LCN DNA testing. While New York and the OCME

appear dedicated to testing, perfecting, and validating the technique [49], New Mexico appears to take the opposite approach. Comparing these two cases gives the impression that the admissibility of LCN will depend not on LCN DNA testing itself, but on the individual lab conducting the testing. Given the sensitivity and potential problems associated with LCN DNA testing, the NMDPS is acting appropriately. But inherent value as a corroborating tool still exists in LCN DNA testing, as will be explored below. Thus, New Mexico and other states should not continually rule out all LCN DNA testing [65].

The most recent case involving LCN DNA testing, New York's case against Andrew Peaks and Jaquan Collins further complicates the future of LCN DNA testing. The two suspects in the case were accused of choking, robbing, and sexually abusing a woman in the hallway of her apartment building four years prior. Police obtained one of the suspect's samples from a small amount of DNA the accused left on a bike he rode during a non-fatal crime he committed nearly four years ago. Police obtained the other accused's sample from sweat found on a hat left at the scene. Judge Dwyer "toss[ed]" out low copy number DNA results used to link the two named suspects to a sexual abuse and robbery in 2010.

Interestingly, this case is not Judge Dwyer's first experience with LCN DNA testing. In 2007, police found a gun on the tour bus belonging to rapper, Lil' Wayne. New York's OCME used LCN DNA testing to tie Lil' Wayne to the gun, a 40-caliber semiautomatic pistol [66]. In October 2009, Lil' Wayne pled guilty to attempted criminal possession of a weapon in the second degree and sentenced to a year in jail. After his sentencing, Chief Assistant District Attorney, Mark Dwyer-now Judge Mark Dwyer-stated "the one-year sentence was appropriate" rather than the two-year sentence permitted under the statute because there were "difficult evidentiary issues" in the case." Judge Dwyer's opinion of LCN DNA testing appears not to have changed in the four-plus years since Lil' Wayne's plea deal.

**What about the other 48 States?:** Other states, namely Maryland and California, have discussed LCN DNA testing but have not ruled on its admissibility. In *United States v. Williams*, the District Court for the Central District of California ruled that LCN DNA testing was not performed because defendant's sample recovered from latex gloves was over the 200 picogram maximum for LCN DNA testing [67]. The District Court of Maryland also did not have to rule on the admissibility of a LCN DNA testing profile in *United States v. Davis* because it similarly ruled that the government had not conducted LCN DNA testing since the sample tested surpassed the maximum amount necessary for LCN DNA testing.

**What to make of the differing results:** The approach taken by New York is incredibly different from the approach taken by other courts. For the time being, it appears that at least some New York courts have embraced LCN DNA testing and New York has invested a decent chunk of change into validation studies, updated lab spaces, renovated laboratory facilities, and structured interpretation techniques. Most states have not performed validation studies nor have they taken any proactive measures to advance LCN testing in their jurisdictions. No other state has made an explicit ruling on LCN DNA testing. Can other states rely on New York's validation studies? On the one hand, it would be redundant for each individual lab to conduct its own individual validation study. On the other hand, no two laboratories are alike, so it would make sense to such a requirement would both eliminate the collegiality of the scientific community and diminish the *Frye* and *Daubert* standards, which both consider the general acceptance of the scientific community in making admissibility determinations.

The forensic DNA community cannot just ignore these validation studies, but it also cannot view them in a vacuum. LCN DNA testing suffers from interpretation problems. Whether New Mexico believes its facilities are equipped to conduct the studies in an accurate manner is another consideration [49]. New York instituted many measures to build a state-of-the-art laboratory for LCN DNA testing. New Mexico is free to deem its facilities unable to accommodate the high demands of LCN DNA testing; however, these two issues—the reliability of the results and the procedures used to obtain a profile—should be two separate considerations.

LCN DNA testing in the United Kingdom suffered its own problems in the wake of the Sean Hoey exoneration and ultimately suspended the use of LCN DNA testing. Because of the work of Professor Brian Caddy, however, the technique was reinstated after numerous validation studies. Nonetheless, Professor Caddy recommended that, in using LCN DNA evidence at trial, juries should be “presented with information regarding its limitations.” The few published cases discussing LCN DNA testing in the United States make one thing clear: LCN DNA testing faces an uphill battle before it will be admitted in every United States Courtroom. But is that a bad thing? Although LCN DNA analysis is a valuable addition to existing DNA profiling techniques, its admissibility should be limited to use as corroborating evidence because of its inherent ability to compile a profile from such a small amount of DNA. Also, LCN DNA profiling should not be the sole DNA evidence presented in a trial because its results continue to face significant interpretation challenges.

#### How to Deal with LCN DNA testing going forward:

**Limit low copy number DNA testing to corroborating evidence:** In England and Wales, “DNA evidence has to be corroborated by other evidence.” After England suspended the technique in 2007, the Crown Prosecution Service instituted a review of all cases that used LCN DNA testing to ensure that none of the cases had been affected by lack of corroboration. The corroboration is especially important with LCN DNA testing because LCN DNA testing can provide a DNA profile from DNA left on a single fingerprint—sometimes called “touch” or “contact” DNA.

This simple fact is what makes LCN DNA profiling both powerful and scary. Take a recent Georgia proceeding, for example. A woman was fatally shot during the commission of a carjacking at a transit station [68]. Witnesses described the assailant as a black male with a backpack, and the police acquired surveillance footage of a man matching that description from a nearby gas station. Additionally, police found a cigarette butt on the ground near the scene of the crime.

After analyzing the DNA on the cigarette butt, the police identified Donald as the DNA donor. Donald also matched the description given by witnesses, and was arrested. But when the police showed him the video evidence, Donald claimed it was his twin brother Ronald. Luckily, the police were also able to lift fingerprints from the car that was stolen, and they matched Ronald, so Donald was exonerated. But it is easy to imagine a scenario in which police do not have fingerprints or other evidence to make a distinction, and it would be Donald’s word against Ronald’s.

Individuals lose 30,000 to 40,000 skin cells in an hour [69]. The ability to compile a profile from a single skin cell likely increases the chances of falsely placing someone at the scene of a crime. But LCN DNA testing may be a useful tool in reinforcing or confirming the placement of a suspect with respect to the crime. For these reasons, LCN DNA testing evidence should be limited to situations where the

profiles attained are for corroborating purposes.

**Tread lightly regarding significant interpretation challenges:** Next, although great advances have been made in LCN DNA testing since its inception in 1999, LCN still faces significant interpretation challenges. These interpretation challenges, described above, were the basis for some courts to hold LCN DNA profiles inadmissible. The stochastic effects that plague profiles obtained using LCN DNA testing must be interpreted to “see through” these problems and obtain an accurate profile. The United Kingdom and New York have worked hard to conduct validity testing and ensure the procedure is conducted cleanly and properly; however, the profiles are still not perfect, and a significant amount of necessary interpretation remains.

By using their “consensus method,” New York has made strides to improve their interpretation of profiles attained using LCN DNA testing. But more jurisdictions must also improve their interpretation models to reduce the amount of uncertainty and allow widespread use of the technique. DNA research is not static, and the development of best practices in interpretation has been ongoing. For example, progress in analysis and data interpretation techniques have caused analysts to modify how they calculate probabilities when it comes to individualizing a suspect from a DNA mixture. This is both good and bad: better science equates to more reliable convictions; but cases that used LCN DNA testing before these developments were subject to substandard practices.

In August 2015, the Texas Forensic Science Commission publicly revealed that there are some serious issues with DNA mixture interpretation [70]. Among the revelations: in May 2015, the FBI notified crime laboratories it had identified “minor discrepancies” in its population databases that have been used by labs in DNA analysis since 1999 [71]. Minor or not, these discrepancies could create major problems, including the shocking admission that in one case the new method reduced a 1 in a billion probability that the evidence implicated a particular suspect to roughly 1 in 50 [72]. The FBI attributed the discrepancies to human error and technological limitations.

**LCN validation studies:** Validation studies are also an important aspect of utilizing LCN DNA testing in United States courtrooms. Professor Caddy recommended that, when using LCN DNA evidence at trial, juries should be “presented with information regarding its limitations.” This should absolutely be a requirement in our courtrooms. Juries should be informed of the interpretation necessary to produce a sample using LCN DNA testing. Until LCN DNA testing becomes as dependable as high-copy number DNA testing, it should not be used as the sole DNA evidence presented in a courtroom.

**Does LCN DNA testing have a future?:** Thirty years ago, DNA profiling was a fledgling technology; now, it is “the most powerful investigative tool since the advent of fingerprint analysis [73].” LCN DNA testing has the potential to be valuable and exciting new development in DNA profiling technology.

The use of LCN DNA testing is well documented in the United Kingdom; furthermore, the technology is in use in other countries including New Zealand, Sweden, and Switzerland [49]. The United States, however, has not embraced the technology in nearly the same way. In fact, New York is the only state that has embraced LCN DNA testing, even going so far as to conduct its own validation studies and construct a new lab specifically designated to the advancement of the technique. But a Brooklyn Court recently held DNA profiles sequenced using LCN DNA testing inadmissible [65]. LCN DNA



testing is obviously not without its challengers. While the technique has its merits, its advantage is also its downfall. Procuring a DNA profile from such a small sample requires interpretation of the samples as well as specialized techniques to ensure an accurate profile. For these reasons, LCN DNA testing cannot be the sole DNA profile presented as evidence. And profiles obtained by LCN DNA testing should be limited to use as corroborating evidence, not the sole evidence connecting a suspect to a crime, and juries should be informed of the limitations of the technique.

There are other considerations, of course. One such consideration should be the cost associated with conducting LCN DNA testing versus the more popular and verified method of HCN DNA testing used in laboratories around the country. This includes not only the cost of conducting the test itself, but also the costs associated with conducting the validation studies and, potentially, building a new facility dedicated to the advancement of the procedure, like New York's OCME did. While this new procedure certainly has the potential to help solve more crimes, the costs of getting local laboratories ready to conduct such research may outweigh the costs of having the evidence eventually held inadmissible or duly challenged.

Another consideration should be judicial efficiency. While most evidence presented at trial is likely to be challenged, because LCN DNA testing is so new, the resulting profiles will likely face guaranteed challenges. More validation studies, uniform interpretation guidelines, and overall awareness of the technique will help bring LCN DNA testing into the courtrooms.

DNA evidence was, at one time, a novel science with its naysayers, just like LCN DNA testing is now. LCN DNA testing is simply a technology that is too new to be perfect. But as technology progresses, and the technique is perfected, the DNA profiles produced by the LCN method will become more accurate. At that time, its admissibility in United States Courtrooms should be reevaluated.

### Putting a Face with a Profile: Phenotyping DNA

Litterbugs in Hong Kong are now finding genetically-derived portraits of their faces posted around the streets of the city [74]. Bragging about their ability to "put a face to an anonymous crime" the company in charge of project "Hong Kong Cleanup," Ogilvy & Mather Hong Kong, submitted trash containing DNA to Parabon NanoLabs in Virginia and the lab sent back an image of the person to whom the DNA belongs. This technology, known as phenotyping, can predict a person's physical traits based on DNA [75]. The science has quickly developed and has been used in recent years for creating gene-specific medical treatment [76]. The private entity in Hong Kong utilized their services to shame people into picking up their trash. Now, private labs are starting to offer phenotyping services to law enforcement as a tool for stopping crime. But as embarrassing and invasive as this anti-littering campaign may seem, it has far fewer consequences than the potential use by local law enforcement agencies throughout the United States.

New research reveals that particular characteristics in DNA can reveal a lot about the physical characteristics of the DNA donor. Proponents of phenotyping argue that this evidence is essentially the same as offering eyewitness testimony of a criminal suspect. But there are key differences between an eyewitness identification and a scientific identification of a suspect [77]. Even the most unreliable eyewitness can be subject to cross-examination and can offer an explanation as to what the suspect was doing at the crime scene. The generated image of a suspect cannot. DNA phenotyping has been readily accepted in the

forensic investigation field in Europe, but as the process makes its way into the United States, concerns over reliability, admissibility, privacy, and racial profiling may prevent government use of phenotyping before it even takes off. These concerns are valid, but stronger regulation of law enforcement's use of DNA could mitigate concerns of its potential for abuse and allow for its use to serve justice.

The danger of relying too heavily on the accuracy of the description, and the inclination of jurors to attribute the same reliance to the prosecutor's explanation that the person must be guilty if their DNA was at the scene, compel the exclusion of this evidence from trial. In spite of the negatives, this technology should be available as a resource in criminal investigations, but its use should be subject to more regulation than the current landscape allows. The technology and relative accuracy of predicting physical traits from DNA has some modern uses in criminal investigations. But the drawbacks of using phenotyping require limits (and perhaps tabling it all together) to prevent misuse.

Genotypes, the set of genes found in a person's DNA, can be indicative of certain physical properties. Scientists have recognized certain genes observed across populations of people are linked with specific physical traits [78]. These observable physical properties are known as a phenotype. The next section details how studies have identified genes that code for the individual's physical traits.

**Finding the genes:** Research of the connection between genetic material and physical attributes is rapidly developing, and scientists believe they are able to accurately predict externally visible characteristics or traits. Using this technology, labs may generate a complete image of a suspect by taking DNA from a crime scene and looking to each of these genetic markers to build a physical profile. But the connections between genes and various traits are not all equally reliable.

The features analyzed for phenotyping involve complex genes and how the nucleotides produce proteins that affect physical traits. Coding DNA, though it makes up a smaller portion of a person's DNA, is necessary to predict phenotypes. The sample must contain coding and noncoding DNA for the lab to analyze genotypes, which would then tell the investigators about phenotypes. Most states do not limit DNA testing to noncoding portions, but traditional testing has also been limited to the comparison with CODIS samples of thirteen recognized loci in noncoding DNA [79]. Introducing the use of coding DNA to forensic investigations would completely change the nature of DNA analysis in the criminal law context.

Single nucleotide polymorphisms (SNPs) [78], variances in an individual's nucleotides at certain points in a DNA sequence, are the most revealing genetic markers [75]. The effect of SNPs on the human genome works similarly to variations in phone numbers, just on a much larger scale. A phone number that varies by only one number will connect a dialer to a different individual on a different line, and DNA that differs by only one nucleotide may translate to an entirely different physical feature. SNPs are the most common type of genetic variation. The amount of variety between DNA profiles, though the majority of any individual's DNA is the same, is immense. But by combing through donated DNA samples, scientists have observed that many SNPs can be highly indicative—some would say determinative—of a person's physical traits.

**Ancestry and national origin:** The first traits gathered by someone's DNA were parentage and geographic region. DNA may be

used to determine paternity with 99.99% accuracy [80]. The presence of certain STRs, specific SNPs, or genetic mutations is telling as to the geographic origin of a person's ancestry [25]. A pattern of DNA polymorphisms within a region of a chromosome, called a haplotype, can quickly indicate a person's traits [78]. Haplogroup refers to the group of haplotypes with the same polymorphism, unique to an individual's ancestors or regional group [78]. Thinking about the polymorphisms in the context of a phone number, the haplogroup is comparable to an area code. The same numeric series will be common to many telephone numbers in an area, so the phone number with that area code indicates the person with that number is from that region. People who have the same haplotype will generally belong to the same haplogroup. The similarities in these DNA nucleotide variances help analysts predict parentage and often a person's national origin.

As people have adapted to certain environments, their genetic makeup reflects those adaptations [81]. Also, sharing common ancestry means the same genetic traits will pass from one generation to the next [82]. The continent, country, and possibly even a specific village can be narrowed down by examining certain repeats and mutations in one's DNA [83]. People with multiple ethnic backgrounds may be more difficult to match based on genetics, but even mixed-raced individuals can probably trace their geographic history from their DNA. Once the likely geographic origin has been detected, certain physical traits may be assumed based on the typical traits of others from that same region. But even though this profile may be the predominant phenotype, scientists recognize it is not determinative of physical traits.

**Iris color:** Iris color is the externally visible trait predicted by genes with the most accuracy, but the accuracy of this prediction diminishes when an individual's eye color is not blue or brown [36]. The OCA2 gene and the nearby HERC2 gene are highly indicative of eye color [36]. The theory developed by researchers is that variations in the alleles in the HERC2 gene, specifically HERC2 rs 12913832, change production rate of melanin, affecting pigment. For example, if the OCA2 gene change stops the *p* protein release, then there would be a lack of melanin and blue iris color in that individual [84].

Even though this trait is highly predictable, researchers have not yet discovered the reason for the high number of variations: "the SNP rs12913832 is found to be associated with the brown and blue eye color, but this single DNA variation cannot explain all the brown eye color variation from dark brown over hazel to blue eyes with brown spots [36]." Although iris color may be predicted with a relatively high level of accuracy, these SNPs may only be reliable for some eye colors and will not predict with any certainty someone who changes his or her eye color with cosmetic contacts. One report noted: "most of the eye color predictive value was provided by the HERC2 rs916977 alone [75]." The rate of accuracy for blue or brown eye color in these samples is high, but these results still deal in probabilities, not definite results. So while these results may be considered a success in the controlled environment of the lab, the margin of error may not adequately reflect the risk of error in the criminal justice context.

**Hair color and skin color:** From some of the same pigmentation genes, as well as other commonly-recognized SNPs, scientists may accurately predict hair color and skin color. The Melanocortin-1 receptor (MC1R) protein indicates sensitivity to sun and is indicative of skin pigment. Much like the release of melanin from the HERC2 gene, the release of melanin indicates a person's skin pigment, as well, but with much less accuracy. Hair color may also be predicted with a helpful degree of accuracy, but some hair types are more easily identified than others. Researchers have found 12 MC1R DNA variants determined

red hair phenotype. Red hair is the easiest to identify genetically, but the percentage of people with red hair in the world is also incredibly small [85]. The likelihood of predicting hair color for other hair colors decreases [75], and these percentages do not account for the possibility that someone has changed his or her hair color. The original hair color, however, may be able to help identify even if the person no longer has the trait. But the variance in predictability in hair color emphasizes the weaknesses of phenotyping.

**Facial shape:** Researchers have also identified five genes that they believe influence facial shape [86]. Ancestry and sex are influential on these traits and help with predictions. Even though there is a common link between these genes and facial structure, any predicted facial structure will not come with any guarantee of accuracy. Facial structure, like other complex externally visible traits, depends heavily on external factors [77]. Additionally, distinctive features such as scars, moles, and tattoos would not be reflected in DNA and would not be found in any projections from that DNA.

**Height:** Height cannot be predicted with the same level of accuracy as the pigmentation identifiers, but some genes may signify relatively how tall the donor is. The problem with height, similarly to facial shape, is that these traits are much more heavily influenced by external factors [77]. A person's lifestyle, nutrition, and environment may lead to a taller or shorter individual than that person's genetic coding suggests. Therefore, this incredibly important physical trait is absent from any genetically produced prediction.

**Age:** Age is another important identifying trait, but age cannot be accurately predicted based on the donor's DNA. Age may be predicted within about ten years of accuracy. But, much like height, any number of external factors such as health, injury, and cosmetic changes could influence a person's appearance to make that person look younger or older. The predicted age, already over-inclusive for developing a pool of suspects, may not provide any additional guidance on whose DNA was found at the scene.

An overview of each of the individual traits is necessary to show exactly how much variation can occur within each trait and the relative predictability of physical traits. Eye color, for example, is generally known to be the most reliably predicted phenotype other than gender, but even within predicting eye color, the rates fluctuate depending on what shade of eye color the person possesses. Even though many genomics enthusiasts express positive findings of how to identify physical traits from DNA, this enthusiasm cannot be reduced to simple probabilities. Furthermore, these statistical probabilities should be viewed as suggestions, not certainties.

## Modern examples of use of phenotyping in criminal investigations

**Foreign Use:** The Netherlands has pioneered the use of DNA for predictive purposes. Home to the Erasmus Medical Center's Department of Forensic Molecular Biology, the Forensic Laboratory for DNA Research of Leiden University Medical Center, and the Netherlands Forensic Institute, the Netherlands is pooling efforts to find new ways to improve on older crime-solving techniques. Not only was the Netherlands the first country to explore phenotyping in forensic investigations, the Netherlands is also the only country to regulate the use of phenotyping [87]. The law limits the use to ascertaining externally visible traits and may only be used for crimes punishable by at least four years in prison, unless otherwise listed. But the first use of DNA to try to gather information about the donor preceded this legislation.

In 2000 Peter de Knijff took DNA from a sample at a crime scene to try to glean information from genetic material [77]. The police had turned this evidence over to him in a cold case concerning the rape and murder of a sixteen-year-old girl, in hopes of finding the suspect's geographic ancestry. The test results revealed that the person was most likely from northwestern Europe. Although this revelation of geographic origin may not seem helpful for a crime that happened in a northwestern province in the Netherlands, the primary suspects at the time were two asylum seekers of Middle Eastern descent. After eliminating them as suspects, the prosecutor took DNA samples from over 8,000 local men and successfully obtained a match in 2012. The trait discovered from the DNA helped police find a suspect because the information helped rule out a different suspect. This use of DNA phenotyping, for purposes of exclusion, seems to be the only use of the technology serving any benefit to law enforcement.

**United States:** The use of phenotyping in the United States is beginning to draw attention because of the developments in the studies over recent years, additional results confirming the links between isolated genes and certain physical traits, and the introduction of this technology into the forensic field [88].

Phenotyping was first used in Louisiana in 2003 and dramatically changed the direction of a homicide case. At the scene of one in a series of local murders, police gathered DNA evidence of the person they believed raped and murdered several women in Louisiana throughout the 1990's and early 2000's [89]. The primary suspect was a white male, but after the suspect's DNA was analyzed, the genes revealed the perpetrator was of African descent [90].

The first use of phenotyping to create the image of a person of interest occurred in the United States in 2015 [91]. The image was generated after police in Columbia, South Carolina submitted a DNA sample to Parabon Labs in an attempt to gain a lead in a case. A mother and her daughter were brutally murdered in their home, but no suspects were identified and the DNA sweep revealed no match with the DNA evidence found at the crime scene. The lab produced an image of a young African American male. The image has been released in the news and states that the generated image resembles a person of interest.

This technique serves the most benefit in cases where law enforcement has fewer leads to follow, but the use of phenotyping in those cases could accentuate the harms affiliated with the process.

#### Problems with predictions:

**Legality:** Gathering an individual's DNA from a crime scene does not constitute a Fourth Amendment violation because it is considered "abandoned property." This theory is dependent on the notion that there is no reasonable expectation of privacy for genetic material left behind. But, for the most part, people do not intend to leave genetic material anywhere. Though DNA may be comparable to a fingerprint or a footprint, those forms of evidence may only be used to identify a suspect and cannot reveal any additional information about the person to whom the print belongs. And shouldn't the expectation of privacy extend to genetic traits the individual himself may not even know? As the potential uses of DNA remain uncertain, courts should revisit whether a person has a privacy interest in genetic material she had no intention of leaving behind and which could actually reveal highly personal information that she would not want to share [92].

Knowing someone is diabetic or prone to cancer may, arguably, help police find a suspect, but this information may not even be

known to the DNA donor. The side effect of investigating what DNA reveals about how human phenotypes, and even behavioral traits, is the erosion of privacy. Suddenly, what was once thought to be private (and relatively unattainable) information is discoverable. Most often, people do not intend to leave DNA anywhere, but even if the collection is justified at a crime scene for limited investigative use, this use should not open the door for law enforcement to gather DNA anywhere and then use personal details of the individual's medical history to obtain a suspect with the same symptoms. The tenuous connection between the two is not sufficient cause to justify an invasion of privacy or an improper search [92].

The collection of the evidence may be on sound legal footing, but the use of inadequately gathered DNA may also lead to the infringement of constitutional rights. Most states do not regulate the collection or use of DNA material unless legislation involves when law enforcement may collect samples [79]. When the sample submitted for testing is already tarnished, the chances of accurately predicting the person's physical traits diminish. There is already a risk that low quality DNA will create a false positive when matching the sample with a database [59]. The same risk exists when using samples to try to put together an image of a DNA donor [30]. Regulation of what DNA samples may be sufficient for testing and what role phenotyping may play in investigations could help prevent the wrongful accusation of a suspect who was linked to a crime because of bad DNA and mistaken technology. Absent these regulations, phenotyping should not be used by law enforcement as it threatens to deprive individuals of their Fourth Amendment freedoms and due process of law.

Largely because of privacy concerns, some states have already imposed legal limitations on DNA gathering and the storage of samples [93]. Eight states have limited the use of DNA to prohibit testing for physical traits. Indiana, Rhode Island, South Dakota, Texas, Utah, Vermont, Washington, and Wyoming each have statutes that limit law enforcement's use of DNA evidence to identification or matching purposes. These laws seem to be directed at preventing the state from engaging in research using non-consenting DNA donors. For example, if states pass statutes limiting the use of DNA evidence to the more reliable autosomal STR matching use, it would curtail the risks of abuse of phenotyping, but this limitation could also prevent its helpful use to guide investigations or eliminate the wrong suspect.

The regulation of DNA use amongst states may slow some investigations, but the lack of regulation poses a real threat to the rights of many individuals. Although the federal government regulates its DNA databank, most states also have databases and they do not regulate the collection methods and use of DNA to the extent they should.

**Inflated expectations:** The accuracy of a prediction based on crime scene DNA is contingent on many variables between the collection of DNA, the preservation of DNA, and the interpretation of that DNA. Crime scene samples are not perfect, nor are the lab technicians who handle these samples [94]. Even though very little DNA must be gathered to have an adequate sample for testing, it is important to make sure none of that DNA is impaired before it is brought in for testing.

Any degradation of samples obtained from a crime scene will lead to less reliable results, or no results at all. Law enforcement officers need to first be realistic about the results that will come from turning over unreliable samples before seeking help from phenotyping.

After a sample has been tested, the real implications of the results must be treated with skepticism if the results are to be used in criminal investigations. If given a proper sample, Parabon claims to "accurately



predict genetic ancestry, eye color, hair color, skin color, freckling, and face shape in individuals from any ethnic background, even individuals with mixed ancestry.” But as Manfred Kayser, who has made significant strides in the research of phenotyping, states, “association is not prediction.” The influence of genes on these traits cannot be fully understood at this time, and until and unless more genetic samples have been tested, particular genes cannot be said to be wholly outcome determinative of physical traits. And even if the predictions were highly accurate on each characteristic, these probabilities do not account for the changes people make to their own appearances. News reports, probably getting their information from commercial DNA labs or enthused scientists, applaud the accuracy of these advancements [88]. But accepting (or promoting) overstatements about the accuracy of this testing essentially obfuscates the necessary questions and reservations we should have.

**Racial profiling:** When DNA indicates the donor has African ancestry, knowledge of this phenotype may encourage law enforcement to search for a black suspect, though this search is based on two major assumptions: 1) the person is black because his or her genes resemble those of other Africans, 2) because the person’s DNA was present at the scene, that person should be suspected of having committed the crime. Phenotyping, when it serves as the basis for improper inferences, provides no scientific value. And the weakest aspects of phenotyping largely come into play in the context of racial profiling. Race is generally not a recognized category for genetic traits [81]. Furthermore, results have shown that expectations about skin pigmentation and geographic ancestry are not reliably connected. Appearance of a phenotype indicating African ancestry does not necessarily equate to the DNA donor having black skin. So the phenotyping image may not be reliable and these methods could further stereotypes about inherent criminality in certain ethnic groups [87].

### Future use of phenotyping in criminal investigations

This technology may still prove helpful in otherwise difficult criminal cases involving violent offenders, where no eyewitnesses were present and public safety is a concern in the absence of a suspect [82]. The technology has already assisted in ruling out suspects in Europe and in America. But learning physical characteristics about a DNA donor should be limited as a predictive means. It is hugely important that these predictions do not get inflated importance and that scientists explain the uncertainty in this process. The physical prediction created from DNA should not be the only evidence police use to further the case, nor should it be so heavily relied upon if it is the most informative lead in the case.

**Probable cause:** With no way of knowing how the DNA arrived on the crime scene and no guarantee that the generated image even accurately resembles the DNA donor, the use of phenotyping must be limited to exclusionary use. A DNA-deduced mugshot should not be sufficient to establish probable cause to search or arrest someone. Although at least one scholar suggests that DNA phenotyping could be sufficient basis for probable cause if the physical prediction could only apply to a very limited number of suspects [87], the inaccuracy of the prediction is what should keep the evidence from enabling law enforcement to search or arrest. After obtaining a lead based on a description, officers have other means to further investigate (through cooperation, for example) without taking away rights based on data they potentially corrupted.

**As evidence at trial:** Phenotyping analysis should not be introduced as evidence in a criminal trial. Convictions can be sustained

by circumstantial evidence, but this evidence would probably be received more like direct evidence than circumstantial evidence because it is so closely compared to eyewitness testimony. Contrary to the obvious comparison, the presence of a person’s DNA at the crime scene is circumstantial; phenotyping cannot explain why a person’s DNA was there any more than fingerprints or other forensic evidence presented in a prosecutor’s case in chief. Scientists who analyze DNA can be subject to cross-examination, and perhaps must be after the Supreme Court’s holding in *Melendez-Diaz v. Massachusetts* [95], but that scientist cannot account for why the DNA was on the crime scene. The description of the person at the scene of the crime may be more exact than an eyewitness who provides an inaccurate description of a suspect, but even if the image produced can be said to definitely identify the person whose DNA was found on the scene, the person may not have been on the scene when the crime happened. And with no one else to confirm the person was not present at that time, someone who accidentally “abandoned” DNA somewhere could be wrongly implicated in a crime.

Jurors often rely too heavily on scientific evidence [96]. The tendency of jurors to look for scientific proof of criminal liability would lead to the worst-case-scenario in use of phenotyping. Jurors would place undue reliance on the results without accounting for the fact that at every step in the process, the inaccuracies have compounded to produce what may look like someone who’s DNA was, at least in part, found on the crime scene. This technology is too inaccurate and too unregulated to be credible enough for introduction at trial.

**Limitations on the use:** Legislators should allow law enforcement to use phenotyping in violent cases, where there is a greater need for such measures, and then only when it would be beneficial. States must limit the use to investigative and not adjudicative purposes. Similarly to the policy in the Netherlands, the traits extracted from the genetic information should be limited to externally visible characteristics and not to any genes that may be used to diagnose medical conditions. A phenotype profile should be treated like any other eyewitness for the purposes of law enforcement use; the scientific method behind it should not be given undue influence. Even if used in an investigation, the technology would be most helpful if used for eliminating suspects. If used to generate a profile that vaguely resembles a police suspect with no other ties to the crime, phenotyping should not create probable cause. That evidence could create a “person of interest” for the police to seek out to question, but it should not give them grounds to search or seize an individual. Setting aside the enthusiasm for the scientific advancements, phenotyping may be helpful when no other evidence points to a suspect and the evidence is used with a realistic understanding of its capabilities.

### Faster Isn’t Always Better: Rapid DNA

The use of DNA in criminal investigations and trials has become routine [97]. Presenting a jury with the results of DNA evidence serves as powerful evidence that often sways jurors toward a guilty verdict. While traditional DNA analysis has suffered for decades, in today’s modern age speed and convenience win the day. As a result of the lengthy waiting periods for DNA analysis to yield results, as well as a backlog of cases in a majority of DNA laboratories, developers have begun looking for faster alternatives to the traditional approach to DNA analysis [98]. Currently, several major developers are working to perfect (and have already sent to market) a variety of Rapid DNA machines, which may yield results in less than two hours [99]. The Global Alliance for Rapid DNA defines this new technology as:

*Noun. Genetics.* Rapid deoxyribonucleic acid, also known as R-DNA: the use of portable kits to quickly and accurately analyze human DNA for swift identification (60-90 minutes versus the industry standard of several hours); enables identification without the need for time-consuming laboratory environments [100]. While Rapid DNA technology seems to present nothing more than positive change and forward movement in the field of DNA, a closer look at this new way of analyzing DNA reveals a host of concerns.

Proponents of Rapid DNA tout the developing science as the second-coming of DNA analysis, but a closer look at the issues surrounding the technology reveals that what glitters may not be gold. Specifically, the federal DNA Identification Act of 1994, which not only provided the national recognition traditional DNA analysis needed in order to maintain traction but also established CODIS, does not contemplate Rapid DNA technology [101]. Additionally, the development of traditional DNA analysis as the “gold standard” in criminal proceedings tends to highlight the untested and ultimately unproven abilities of this fledgling technology [102]. Lastly, the publicizing and popularity of Rapid DNA technology is not achieved through scientific literature, but through promotional and marketing materials [99].

### The process

A swab containing a suspect’s cheek cells is inserted into a plastic cassette known as a BioChipSet Cassette, or a “lab-on-a-chip.” This cassette contains all of the necessary reagents and completes the entire DNA typing process. Once typing is complete, the samples and BioChipSet are loaded into the Rapid DNA machine, the door is closed, and a touch-screen monitor “provides easy-to-follow instructions” as the analyst completes the process of loading the samples. Notably, this process is unseen by the analyst, as the machine remains closed.

Once the samples are analyzed, software preloaded into the Rapid DNA device processes the information and creates data files that may be revisited later for additional analyses. These data files consist of an STR profile, “which provide the individual’s unique genotype based on 16 STR regions on the chromosome, called loci. These loci were selected because they have a high degree of variability from person to person.”

The Rapid DNA machine creates a data file containing the raw data extracted from DNA analysis, which is “compatible with commercially available genotype analysis software programs used by forensic analysts.” The other type of file created is in a “CODIS-compatible common message format that can be uploaded to a DNA database and used to search for DNA matches.” These complete data files are produced in less than 90 minutes.

### CODIS and rapid DNA: Do we have a match?

Rapid DNA equipment developers herald the ability for Rapid DNA results to filter directly into CODIS. For the time being, however, these statements may be nothing more than wishful thinking. The requirements for including DNA profiles in the CODIS database are strict. Specifically, included profiles must be analyzed and contributed by laboratories accredited by a professional, nonprofit forensic science association. Additionally, the laboratories must, at minimum, undergo biennial audits that indicate satisfaction of standards established by the Director of the FBI.

While a current majority of Rapid DNA users are developers working out of accredited laboratories, promotional and marketing materials describe the future-and perhaps merely envisioned use of

Rapid DNA technology as an in-house investigatory tool for federal, state, and local law enforcement agencies [103]. Moreover, the portability and user-friendly interfaces of the developing Rapid DNA devices increase the pool of individuals with the ability to operate the system. At first glance, these attributes are both beneficial and efficient.

If, however, the end-goal of Rapid DNA technology is to serve as a conduit for a larger, more expansive CODIS database, hurdles abound. When Congress enacted the DNA Identification Act of 1994 and authorized the FBI to establish the CODIS database, traditional DNA analysis was the standard procedure [101]. In no way does the Act contemplate the remote, internet-based uploading of DNA profiles from Rapid DNA devices. Additionally, the strict standards imposed by the Act require that accredited laboratories, which conform to national standards, conduct the DNA profiling-not field operatives from federal, state, and local law enforcement agencies.

Absent a change in the current law surrounding the inclusion of DNA profiles in the CODIS system, extensive research and development is required in order for Rapid DNA profiles to successfully-and legally-upload into CODIS. The FBI, charged with developing laboratory and practical standards for CODIS-acceptable DNA profiles, will need to scrutinize the new technology to determine whether it is a valid form of DNA identification and develop criteria for accreditation of the various Rapid DNA devices. Proponents of Rapid DNA technology are aware of this legal and logistical hurdle, but seem hopeful that Rapid DNA devices can not only meet the stringent requirements of the DNA Identification Act, but supplement and assist the Act’s goal of a complete, useful national DNA database.

### Applying *Daubert* to Rapid DNA Analysis

However, the pedigree of traditional DNA analysis should not be imputed to Rapid DNA technology. While Rapid DNA analysis parallels traditional DNA analysis, the two are not the same. As a result of the drastic shift in process and procedure, in order to be properly admitted at trial, Rapid DNA technology must survive a *Daubert* inquiry. Proponents of this new technology should not be allowed to rely on the decades of acceptance shown to traditional DNA analysis. Those seeking to admit the results of Rapid DNA technology at trial must prove that this new technology is reliable-independent of the reliability afforded to its more traditional cousin.

This new technology, however, does appear to have a permissible present use in a criminal investigation. In *Maryland v. King*, the Supreme Court determined that the collection of a suspect’s DNA sample using a buccal swab and the subsequent analysis of the suspect’s DNA did not violate the Fourth Amendment [98]. The Court notes that scientific advancements, like fingerprinting and DNA identification, play a significant role in police investigations as law enforcement officers work to identify suspects [98]. Specifically, the Court states that the use of DNA identification as a post-arrest, investigatory tool is supported by the fact that the “the FBI has already begun testing devices that will enable police to process the DNA of arrestees within 90 minutes.” While Rapid DNA technology, in its current state, can play an important part in the early portions of an investigation, absent a full-fledged *Daubert* inquiry, Rapid DNA matches have no place in a criminal trial.

### Science or salesmanship?

“Rapid DNA technology stands to revolutionize DNA profiling, the gold standard of forensic identification, by dramatically decreasing time to results.” “DNA scan Rapid DNA Analysis System is . . . fast,

rugged, and easy-to-use [104].” “RDA enables the identification (by fragment sizing or nucleic acid sequencing) of the most informative subset of a given human or pathogen genome, allowing end users to make decisions in real time.” “Rapid DNA Service™ -Sample to DNA Profile in Less than 90 minutes.” The exciting descriptions and adjectives above are being used to describe scientific equipment. The majority of the available literature and information pertaining to Rapid DNA comes in the form of marketing materials, commercial websites, and press releases. Instead of providing empirical, scientific data regarding the usefulness of Rapid DNA technology, consumers are provided with nothing more than flashy publications and bold promises. Though the science underlying Rapid DNA technology may be sound-the manner in which this new technology is being presented, with a noticeable absence of hard science, breeds doubt as to the efficacy of this new method.

The impact of Rapid DNA developers’ failure to provide scientific support for the abilities of their product becomes clear in light of the Supreme Court’s 2013 decision in *Maryland v. King*. While the majority supported its holding in part by citing to the development of Rapid DNA technology, Justice Scalia, in dissent, correctly points out that “the Court’s proof, however, is nothing but a pair of press releases-each of which turns out to undercut this argument.” The lack of empirical evidence supporting Rapid DNA technology is, on its own, unsettling. But considered in tandem with the rampant use of promotional and marketing materials, the public should question whether to buy what these commercial labs are selling.

### Limiting the use of rapid DNA

As the Court in *King* noted, the ability for law enforcement officials to quickly and efficiently determine the true identity of an alleged criminal is something on their bucket list. Accordingly, Rapid DNA technology, even in its current state, is useful. Law enforcement officials should employ this new technology during the preliminary steps of criminal investigations. The ability for investigators to either quickly rule out or implicate the individuals charged would make investigations much smoother and more efficient. But a prosecutor seeking to admit DNA evidence at trial should be required to turn back to traditional DNA analysis until Rapid DNA is properly vetted and able to withstand a *Daubert* analysis.

### Conclusion

DNA used to be corroborating evidence. Now, cases are bought and sold to juries with nothing more than just the DNA evidence. Essentially, DNA has been translated to “Do Not Acquit” in the minds of jury members, and we have foregone evidence produced by old-fashioned investigative work. Instead, we are about to embrace a criminal justice system in which science is purportedly able to determine a person’s physical characteristics and perhaps do so faster and with less DNA than ever before. This is not a far cry from using genetic markers to assess an individual’s propensity for crime or violence. Forget judge and jury, instead untested science will determine the fate of individuals-possibly for the duration of their lives. Given the near-religious embrace of DNA, this is not a far-fetched concern [105].

DNA evidence is a powerful tool. While efficiency and speed are critical to a successful police investigation, the integrity of a criminal trial must be maintained. In order to maintain a defendant’s right to a fair trial, the evidence presented must be relevant, reliable, and not unduly prejudicial. Until new techniques including LCN DNA testing, Phenotyping, and Rapid DNA testing can be properly vetted, their use should be limited to preliminary police investigations.

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