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

Background

Despite the luminescent "gold standard" label, DNA pro ling was not always so readily accepted. Like any scienti c evidence, the process of DNA pro ling must meet certain standards in order to be admitted at trial. e 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 scienti c 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 scienti c evidence and testimony should be admitted.

Under the *Daubert* standard, judges must rst nd that DNA expert's scienti c 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]. A er *Daubert*, the rst federal court to recognize the ability for courts to take judicial notice of the reliability of DNA pro ling 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. e analysis yielded a match and prosecutors sought to admit evidence of the match during trial. e district court admitted the evidence of the DNA match, but refused to admit a statistical analysis that indicated the DNA pro le could be found in "1 in 2600

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].

e United States passed the DNA Identi cation Act of 1994 [16]. e Act detailed the requirements of maintaining a National DNA Index System (commonly known as "NDIS") for convicted o enders, 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 y states now have laws requiring the collection of DNA samples from certain categories of o enders [17]. According to the FBI, NDIS contains over 11,962,222 o ender pro les, over 2,120,729 arrestee pro les, and over 657,298 forensic pro les [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]. is, of course, is directly related to the ampli ed 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]."

e current standard method for developing a DNA pro le utilizes polymerase chain reaction analysis ("PCR") [21]. De ned 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 nd 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. Su cient 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 identi ed based on their speci c genetic makeup [25]. Within a person's cells, strings of nucleotides made up of Adenine, Cytosine, Guanine, and ymine, match up with the corresponding proteins in the form of a double helix [25]. ough these patterns are highly predictable-A matches with T and C matches with G-but the discrete di erences 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. e addition, deletion, or unexpected change of one nucleotide is recognized as a single nucleotide polymorphism (SNP) [26]. e 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 nd these STRs, a small sample of DNA (typically less than y 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 o en share the same repeated pattern of nucleotides. e bene t 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 ampli cation 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 pro le 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 o ender databasing. ere are only 33 possible tetranucleotide motifs, and the consensus motif sequences, mostly AGAT and GATA, are ubiquitous in the human genome. e 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 pro ling involves taking certain loci in DNA [30] and comparing these STR patterns with a known match to discover whether there are variances. irteen loci in DNA are predesignated test sites for comparing the gathered sample to the CODIS pro les [31]. Side-by-side comparison of the samples shows whether the DNA produces a match. is technique is highly accurate, but also leaves the donor's privacy intact since no other information is gathered from the unknown DNA sample [32]. at sample will either become known, based on information already legally acquired and stored [33], or the sample will remain unidenti ed.

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 unidenti ed sample taken from a crime scene. e type of DNA used for traditional autosomal STR pro ling 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. us 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. ese

Mijailovic. Good evidence should e ectuate 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 pro les 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]. e technique successfully produced a DNA pro le 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, a er a DNA link [51]. is 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 pro le obtained using LCN DNA testing, forensic scientists in the United Kingdom also found fabric bers matching clothes worn by rail workers-Imiela was a rail worker-as well as bers that matched the curtains in Imiela's home. Further, mobile phone and bankcard records placed Imiela in the vicinity of the crimes. Lastly, a ngerprint 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]. e 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 a er questions arose related to evidence given by the two o cers 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 signi cant 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 exible interpretation than with the conventional tests." Problems that can arise with LCN include stochastic e ects/stutter, detection thresholds, allele imbalance, and contamination [44]. All of these problems can signi cantly a ect the interpretation of the resulting DNA pro les, which is le to a forensic scientist [44]. Because interpretation is necessary, a human element is present, resulting in inconsistencies. ese inconsistencies are a major concern for courtrooms deciding whether to admit LCN DNA evidence.

Stochastic E ects/Stutter: Essentially, stochastic e ects are random variations that occur when amplifying small amounts of DNA [59]. A stochastic e ect 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 ampli cation that may result in either a substantial imbalance of 2 alleles… allelic dropout, or increased stutter." ese e ects "manifest as a uctuation" in the results when replicate analysis are conducted and compared. Stutter refers to the actual peaks that occur, which are caused by the stochastic e ects 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 ampli cation. is added ampli cation, which is necessary in LCN DNA testing, makes discerning stutters and the actual DNA pro le di cult, and thus, less reliable. ese inconsistencies from one

resulting pro les di erently, which means that the use of an LCN DNA pro le as the sole DNA evidence against a suspect is problematic.

Unlike the scienti cally 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 pro le 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. us, while a valuable tool, LCN DNA testing should only be used in conjunction with or as corroboration for other evidence.

A ermath 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]. e defense had a strong argument because Sean Hoey had been accused of another bombing, but was eventually acquitted. DNA on that defused device was pro led using LCN DNA testing as well; however, the initial DNA pro le produced matched a teenage boy, not Sean Hoey. e 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".

A er 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 O cers 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. A er only one month, the technique was reinstated a er a government-commissioned study by Professor Brian Caddy found the technique to be "scienti cally robust" and " t 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 speci c 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 pro le crimes

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 scienti c community." e 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, e 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]. e Court placed great weight on the OCME's validation studies, especially the fact that the "scienti c community—a number of independent experts intimately familiar with the criteria for scienti c validity—ha[d] repeatedly endorse[d] the su ciency of OCME's validation studies and protocols."

In these two cases New York seems to embrace the concept of the "scienti c community," noting the numerous validation studies conducted around the world and adding that the test is used in various countries. e idea of the scienti c 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 e ectiveness of the technique.

e District court of new Mexico disagrees: In *United States v. McCluskey*, the District Court of New Mexico disagreed with the *Megnath* court. e Court in

e forensic DNA community cannot just ignore these validation studies, but it also cannot view them in a vacuum. LCN DNA testing su ers 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 pro le—should be two separate considerations.

LCN DNA testing in the United Kingdom su ered 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 a er numerous validation studies. Nonetheless, Professor Caddy recommended that, in using LCN DNA evidence at trial, juries should be "presented with information regarding its limitations." e 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 pro ling techniques, its admissibility should be limited to use as corroborating evidence because of its inherent ability to compile a pro le from such a small amount of DNA. Also, LCN DNA pro ling should not be the sole DNA evidence presented in a trial because its results continue to face signi cant 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." A er 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 a ected by lack of corroboration. e corroboration is especially important with LCN DNA testing because LCN DNA testing can provide a DNA pro le from DNA le on a single ngerprint-sometimes called "touch" or "contact" DNA.

is simple fact is what makes LCN DNA pro ling 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.

A er analyzing the DNA on the cigarette butt, the police identi ed 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 li ngerprints 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 ngerprints 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]. e ability to compile a pro le from a single skin call 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 con rming the placement of a suspect with respect to the crime. For these reasons, LCN DNA testing evidence should be limited to situations where the pro les attained are for corroborating purposes.

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

By using their "consensus method," New York has made strides to improve their interpretation of pro les 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. is 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 noti ed crime laboratories it had identi ed "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]. e 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." is 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?: irty years ago, DNA pro ling was a edgling technology; now, it is "the most powerful investigative tool since the advent of ngerprint analysis [73]." LCN DNA testing has the potential to be valuable and exciting new development in DNA pro ling technology.

e 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]. e 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 speci cally designated to the advancement of the technique. But a Brooklyn Court recently held DNA pro les sequenced using LCN DNA testing inadmissible [65]. LCN DNA

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used to determine paternity with 99.99% accuracy [80]. e presence of certain STRs, speci c 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]. inking about the polymorphisms in the context of a phone number, the haplogroup is comparable to an area code. e 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. e similarities in these DNA nucleotide variances help analysts predict parentage and o en a person's national origin.

As people have adapted to certain environments, their genetic makeup re ects those adaptations [81]. Also, sharing common ancestry means the same genetic traits will pass from one generation to the next [82]. e continent, country, and possibly even a speci c village can be narrowed down by examining certain repeats and mutations in one's DNA [83]. People with multiple ethnic backgrounds may be more di cult 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 pro le 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]. e OCA2

In 2000 Peter de Knij took DNA from a sample at a crime scene to try to glean information from genetic material [77]. e 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 nding the suspect's geographic ancestry. e 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. A er eliminating them as suspects, the prosecutor took DNA samples from over 8,000 local men and successfully obtained a match in 2012. e trait discovered from the DNA helped police nd a suspect because the information helped rule out a di erent suspect. is use of DNA phenotyping, for purposes of exclusion, seems to be the only use of the technology serving any bene t to law enforcement.

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

Phenotyping was rst 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]. e primary suspect was a white male, but a er the suspect's DNA was analyzed, the genes revealed the perpetrator was of African descent [90].

e rst use of phenotyping to create the image of a person of interest occurred in the United States in 2015 [91]. e image was generated a er 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 identi ed and the DNA sweep revealed no 591.7 Dirq rew ee. BT/T10 1 Tf08 (wiEMCofIUdwan <</MCID 1302 BDC BT/T1uis

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 signi cant strides in the research of phenotyping, states, "association is not prediction." e in uence 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 the accuracy of this testing essentially obfuscates the necessary questions and reservations we should have.

Racial pro ling: 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 scienti c value. And the weakest aspects of phenotyping largely come into play in the context of racial pro ling. 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

is technology may still prove helpful in otherwise di cult criminal cases involving violent o enders, where no eyewitnesses were present and public safety is a concern in the absence of a suspect [82].

rugged, and easy-to-use [104]." "RDA enables the identi cation (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 Pro le in Less than 90 minutes." e exciting descriptions and adjectives above are being used to describe scienti c equipment. e 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, scienti c data regarding the usefulness of Rapid DNA technology, consumers are provided with nothing more than ashy publications and bold promises. ough 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 e cacy of this new method.

e impact of Rapid DNA developers' failure to provide scienti c 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." e 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 o cials to quickly and e ciently determine the true identity of an although criminal is something on their backside. Accordingly, rapid DNA technology, even in its current state, is useful. Law enforcement o cials should employ this new technology during the preliminary steps of criminal investigations. e ability for investigators to either

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