Chapter

Probabilistic Genotyping: A Possible New Legal Avenue to Prevent and Redress Miscarriages of Justice

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Abstract

This chapter delves into the relatively new DNA technique of probabilistic genotyping, which aims to a more precise determination of complex DNA profiles of multiple contributors. It explains the forensic value of this methodology compared to traditional DNA techniques such as Combined Probability of Inclusion (CPI). In particular, this forensic value is demonstrated in light of the reversal of several wrongful convictions in the USA and Europe. Apart from having a potential exculpatory effect, the advance of probabilistic genotyping can also contribute to discerning the real perpetrator of a crime. As a result, this chapter emphasizes the relevance of probabilistic genotyping for both defense lawyers and prosecutors in criminal cases.

Keywords: Mark Perlin, Greg Hampikian, DNA evidence, forensic evidence, probabilistic genotyping, DNA mixtures, wrongful convictions, defense lawyers, prosecutors, Lydell Grant, Dutch Proveniers case

1. Introduction

This chapter discerns the implications for law practitioners of the DNA technique of probabilistic genotyping. This method was developed in the late 1990s. It uses statistical methods and mathematical algorithms in DNA profiling, instead of applying manual methods to determine very small DNA samples or DNA mixtures of multiple individuals, and it calculates likelihood ratios while inferring genotypes of a DNA profile based on computer software, "Probabilistic Genotyping Software (PGS)", models by intricately unraveling all parts of the mixture. Before addressing the implications, one should first look at the limitations of current DNA techniques.

In their article of March 2014, Perlin et al. stated that "DNA analysis is the gold standard of human identification" [1]. This observation can also be found in other academic publications such as the 2011 article of Dror and Hampikian [2]. The latter experts note that "DNA has been held as objective and immune to subjectivity and bias". However, they add that "(...) at the least in complex situations (such as with DNA mixtures) DNA does require and rely on human examiners making a variety of subjective judgements, that are susceptible to bias (...)". Thus contrary to what one may expect from a gold standard of forensic science, DNA cases pertaining to complex mixed profiles may create subjectivity and trigger contextual bias.

1.1 The current pitfalls of DNA evidence for criminal cases

Dror et al. demonstrated this phenomenon with an experiment, using a DNA mixture analysis from a real criminal case. Their analysis was presented to seventeen independent DNA experts in the USA, without the potentially biasing contextual case information. The test was to examine the DNA mixture along with DNA profiles of the victim and three suspects. The focus was suspect three. This suspect was labeled by the DNA experts who were assigned in the real criminal case as "cannot be excluded." These experts were given the actual contextual potential biasing information. The seventeen experts in the test were only provided the sperm fraction electropherograms from the victim's vaginal swab after amplification with cofiler (ABI) and the DNA concentration in the sperm fraction extract and injection times and were asked to give one of the following three conclusions: "cannot be excluded," "excluded" or "inconclusive." The outcome of this test was quite revealing: one expert arrived at the conclusion that suspect three "cannot be excluded," while four experts held the analysis to be "inconclusive" and twelve experts determined this to "exclude" suspect three. These differences are especially striking in light of the fact that these seventeen experts all worked in the same accredited government laboratory and applied the same interpretation guidelines.

Two conclusions can be derived from this experiment. First, there is an element of subjectivity in the assessment of DNA evidence by—even qualified—DNA experts who even used the "golden DNA standard" and identical evidence. If total objectivity would have existed, all the experts should have arrived at same conclusion, because the experts work at the same laboratory and use the same guidelines. Second, there was a pertinent difference between the assessment made by the DNA experts in this experiment who had limited contextual information of the criminal case and the original experts who had access to the biased context of the criminal case. The experiment of Dror et al. shows that only one out of seventeen experts arrived at the same conclusion as the original experts, while sixteen other experts came to a different and conflicting conclusion. The conclusion of this experiment study is that "(...) the extraneous context appears to have influenced the interpretation of the DNA mixture (...)" [2].

This study illustrates that when it concerns DNA mixture analysis, the "golden standard" qualification must be nuanced in that DNA mixture interpretation inheres subjective elements and is exposed to bias and even contextual influences. It is therefore of paramount importance that prosecutors, defense counsels and trial judges are aware of these potential subjective influences when confronted with criminal cases where low numbers of template molecules are amplified or where complex mixtures are examined. Notably, quantitative conclusions as "cannot exclude" are mostly presented by forensic experts without quantitative measuring [2]. To remedy this pitfall, the 2010 scientific working group on DNA analysis methods (SWGDAM) in Section 4.1 of their guidelines promulgated that "the laboratory must perform statistical analysis in support of any inclusion that is determined to be relevant in the context of the case, irrespective of the number of alleles detected and the quantitative value of the statistical analysis" [2]. The International Society for Forensic Genetics (ISFG) also endorses the same approach in respect to the interpretation of mixtures [2]. However, scientific research also shows the inclusion of statistical analysis in support of certain DNA conclusions and does not remedy the element of subjectivity and potential bias [2]. After having observed that the "golden standard" of DNA evidence is less "golden" and might be "silver," the question arises as to the implications thereof for the criminal law practice.

1.2 The importance of erasing contextual bias: the Lydell Grant case

"To error is human, to correct error is responsible science." These are words of Greg Hampikian, Professor in Biology and Criminal Justice at Boise State University [3], which trigger the question whether and how criminal law practitioners might be able to correct such errors. This question first refers to the moral-ethical perception as to the functioning of the system of a criminal law in our society and second it refers to which legal avenues are available to remedy such errors.

One may illustrate this on the basis of the case of Lydell Grant, who was convicted of murder in a 2010 stabbing, which resulted in the killing of a 28-year-old man outside a Houston (USA) nightclub, in Montrose District, the center of Houston gay cultural life, and sentenced to life imprisonment. In November 2019, the Harris County District Attorney's office ordered the 42-year-old Lydell Grant be released on bond, pending a reinvestigation of the case. The events leading up to this decision were remarkable. The night after the assault, the barback of the nightclub spotted a tall, masculine black man with short hair, stepping out of a white Pontiac Grand Prix. The man entered a different nightclub. The barback seemed to recognize the assailant of the previous night. He wrote down the license plate number of the Pontiac and tipped the Houston Police. The license plate number belonged to Lydell Grant, at that time 33 years old, who had a criminal record. The Houston Police Department therefore had access to his photo. Based upon a photo spread including Grant's photo and five other young black men, six eyewitnesses, who at the time of the attack watched the whole incident unfold in just a few minutes from the second floor patio of the nightclub, identified Grant as the person who killed the victim, who was named Aaron Scheerhoorn.

The prosecution's evidence against Grant thus relied on six eyewitnesses who testified at trial with high degrees of certainty that Grant stabbed Scheerhoorn. Out of these six, three testified that they were "positive," two stated they were "one hundred percent sure" and another witness was "very sure," saying that Grant's face "was burned into my memory immediately" [4]. The relevance of the Grant case for the topic of this chapter relates to the rule of DNA evidence. Apart from the six eyewitnesses, the prosecution's case against Lydell Grant was built upon DNA analysis conducted by a DNA expert from the Houston Police Department's crime lab. This analysis had retrieved DNA profiles of two individuals under Scheerhoorn's fingernails. However, this expert was only able to detect a full profile of one of them, which according to this expert, belonged to the victim [4]. At trial, this expert provided "muddled" information as to her findings regarding the second profile [4]. Testifying that she could not exclude Grant, this expert therefore suggested that Grant's DNA was potentially to be found under Scheerhoorn's fingernails. Grant's defense counsel neither presented any contraexpertise to the jury nor challenged the DNA results, apart from obtaining the admission made by the expert at trial that Grant could not be "associated" with the DNA mixture [4].

Grant's defense counsel, in its defense case, called only one witness, Mr. Paul Rodriguez. This person testified that on the night of the assault in December 2010, Lydell Grant had been in his company the whole night, going from bar to bar without visiting the bar where Scheerhoorn was attacked, which was called "Club Blur." After three days of trial, the following day the jury only needed a four-hour deliberation: Grant was found guilty and sent to prison for life. Thereafter Grant started the "Herculaneum" endeavor to proof his "factual innocence" [4] within the prison where he stayed. He began to write dozens of letters to lawyers and several Innocence Projects in the USA, including the Innocence Project of Texas. Only few responded [4]. With his younger half-brother Alonzo Grant, he discussed his case, while spending every free minute in the library of the prison with an inmate he met

in the library. Grant went through the nine volumes of trial transcripts, searching for loopholes and inconsistencies in the witness statements [4]. It was at that time that his library inmate discovered that the DNA results that were seemingly "muddled" were actually to Grant's advantage. To his surprise, Grant read in the DNA expert report that "(…) no conclusions will be made regarding Lydell Grant as a possible contributor" [4].

It was at that moment that Lydell Grant realized that his defense counsel at trial had missed an opportunity to prove Grant's innocence, namely by not retaining an independent DNA expert to challenge the report of the Houston Police Department's crime lab. It took Grant till January 2018, 8 years after his conviction, and a turning down of his appeal in 2014, to find a defense counsel who was willing and able to file a motion to the court for a review of the DNA evidence ([4]: see Hall, o.c. at 10–11, who refers also that one lawyer was appointed to Grant in 2016 and wrote that he was "unsure of how DNA could help you"). It was also in 2019 that one of the letters Grant distributed arrived at the Executive Director of the Texas Innocence Project (IPTX), Mr. Mike Ware. Since 2006, when this nonprofit organization started, it achieved to exonerate 27 wrongly convicted inmates in Texas. Grant's case was accepted by this project and allocated to one of the students of the "Actual Innocence Clinic," which was part of the Texas A&M School of Law in Forth Worth. Research of the Innocence Project and the National Registry of Exonerations indicated that mistaken eyewitness identification is one of the most prominent causes of wrongful convictions, while discerning that people of one race have serious problems with identifying persons of another race [4]. This element that contributes to wrongful convictions features in some two-fifths of all exonerations based on DNA [4]. Interestingly, in the case of Lydell Grant, one of six eyewitnesses was a black person, two were persons of Latino descent, one was Asian-American and two were white people. Moreover, research reveals that showing witnesses a photo lineup of multiple photos such as in the Grant case could also result in mistaken eyewitness identification in that the witness identifies a person merely because that individual resembles the suspect more than anyone in the photo lineup [4]. At the time that Lydell Grant was arrested in 2010, the Texas legislature did not yet implement a law that required for "double blind" lineups. This means that the police officer conducting the lineup is not aware who the suspect is. Accordingly, he or she cannot influence the eyewitness by, for instance, making a comment during the lineup or making a certain gesture toward the witness [4]. The Texas Innocence Project detected several errors in the lineup procedure in Grant's case, while at the same time discovering that the DNA profiles in this case contained several alleles (i.e., the repeating genetic variations that result in the profile) and were not related to either the victim or to Lydell Grant [4].

In 2019, the Texas Innocence Project presented these findings to Dr. Angie Ambers, a forensic DNA expert and Associate Professor of Forensic Science at the University of New Haven in Connecticut and Assistant Director of the Henry C. Lee Institute of Forensic Science. Dr. Ambers converted the DNA data from the original test into an Excel spreadsheet, and based upon this review, she determined that 26 alleles in the mixture were not related to either Grant or the victim, but to someone else [4]. To confirm her analysis, in March 2019, the data were sent by Dr. Ambers and the IPTX to Cybergenetics Corporation in Pittsburgh. Cybergenetics is the developer of the leading software program TrueAllele, which is a new method to analyze DNA mixture with more precision, based on a software system, using statistical methods. This method, named "probabilistic genotyping," was developed in the late 1990s. It uses statistical methods and mathematical algorithms in DNA profiling, instead of applying manual methods to determine very small DNA samples or DNA mixtures of multiple individuals, and it calculates likelihood

ratios while inferring genotypes of a DNA profile based on computer software, "Probabilistic Genotyping Software (PGS)," models by intricately unraveling all parts of the mixture. It therefore advances the statistical analysis of DNA mixtures. Cybergenetics was not only able to exclude Lydell Grant but also was also able to deduct a second profile of an unknown DNA contributor. After deducting this profile, it was uploaded in the Combined DNA Index System (CoDIS) of the FBI. This additional database contains the data of approximately 14 million convicted people in the USA. It was in July 2019 that the FBI database connected the profile to a prisoner named Jermarico Carter, who had a criminal record in Houston and had moved to Atlanta a few months after the incident. The mistaken witness identification of Grant was to be explained by the fact that Carter—similar to Grant—was black, had a similar posture and was of the same age [4].

After Carter had been arrested in Atlanta on a parole visitation, he denied to be the perpetrator of the deadly stabbing of Scheerhoorn. However, when the police detectives told him that his DNA was found under the fingernails of the victim, Carter admitted that he had fought with Scheerhoorn and chased him to the nightclub where he, as he asserted, only hit him. Three months after Carter's confession, the defense for Grant filed a writ of habeas corpus based on "actual innocence," arguing that inaccurate DNA evidence and mistaken eyewitness identification had violated Grant's due process rights. The DNA results and Carter's statement led the Houston Police Department to reinvestigate the Scheerhoorn case. The results were astonishing: no link whatsoever was found between Grant and Scheerhoorn, while it was established that Carter had indeed lived in Houston in 2010 at the time of the crime [4]. Moreover, Carter was arrested in the Montreal District on another occasion. Four months after the Scheerhoorn incident, he was also arrested for stabbing a person in Atlanta. As a result of this new evidence, Lydell Grant was released from Harris County Prison based on a bail-bond of $ 100.000 USD. In the meantime, the investigation by the police and the office of the District Attorney continued, which in December 2019 resulted in the District Attorney's office dropping Grant's case and charging Carter for the Scheerhoorn case. At the same time, the Houston Police Chief issued a public apology to Lydell Grant and his family [4]. One week later, the trial judge accepted the habeas corpus writ filed by Grant's defense counsel and held that he proved to be actual innocent [4]. However, with writs, as opposed to direct appeals, when both the prosecution and the district court agree on the actual innocence, this solely results in a recommendation for the Texas Court of Criminal Appeal (CCA), which has the final say in exonerations. In April 2020, the CCA overturned this decision of the district court and requested additional evidence, namely Carter's confession tape. This was very unusual, but the Texas Innocence Project complied and waited. Then, on July 1st, the CCA first ordered the case to be remanded back to the District Court, second that the District Court ask the DA's office to get the six eyewitnesses' accounts at Grant's trial to respond to Grant's innocence claims and third that the District Court provide the CCA with a photo of Jermarico Carter, dated from the approximate time of the crime [5]. In fact, the CCA—comprised of nine judges—all elected—conveyed the message that the presented evidence did not yet establish Grant's innocence.

Experts, former CCA judges, prosecutors and also Dr. Ambers, the DNA scientist who was instrumental in exonerating Lydell Grant, were puzzled with the CCA ruling. Dr. Ambers commented that she does "(...) not know what else Grant could do—it doesn't get any more definitive than that" [4]. The Grant case is but one example of many, whereby the methodology of probabilistic genotyping was decisive in the last decade to exonerate a convicted person. In May 2020, the Boise State Laboratory (USA) led by Professor Greg Hampikian was able to exonerate Johnnie

Lee Gates, a Georgian man who turned out to be wrongly convicted of rape, armed robbery and murder in 1977, based upon a new DNA review using probabilistic genotyping [6]. The advent of probabilistic genotyping has therefore contributed considerably to establishing actual innocence within the USA [7].

1.3 Differentiating common DNA methods from probabilistic genotyping as a means to prevent and redress miscarriages of justice

After having determined that several exonerations in criminal cases were predominantly fueled by advancing probabilistic genotyping, the question arises whether empirical evidence exists to the extent that common DNA methods can wrongly include innocent individuals as contributors to mixed DNA profiles as opposed to probabilistic genotyping. The question can be answered in the affirmative. In 2019, the National Institute of Standards and Technology (NIST) demonstrated that common DNA methods such as the Combined Probability of Inclusion (CPI) have wrongly included innocent persons as being contributors to DNA mixtures [3]. Three years prior, in 2016, the President's Counsel of Advisor's on Science and Technology issued a report that concluded that "In summon, the interpretation of complex DNA mixtures with the CPI statistics has been an inadequately specific—and thus inappropriately subjective—method. As such, the method is clearly not foundationally valid" [8]. Hampikian describes an interlaboratory study based upon a fictional scenario, conducted by Butler [9]. Several North American Forensic DNA labs were asked to analyze a ski mask from a bank robbery with a complex DNA mixture of at least three contributors, suspects A, B and C. The main question was whether the specific laboratory deemed the mixture as too complex to make any findings. The second test was to determine if one of the labs wrongly included a person in this mixture (false positives). The results were similarly striking. Out of the 108 accredited labs, 68% of them wrongly included suspects C, who was—for the purposes of this test—innocent. As to the question whether the DNA mixture was too complex to draw conclusions from it, 27 (25%) of the labs held the mixture to be inconclusive. Only seven labs (6%) correctly excluded the suspect. However, notably 74 of the 108 labs (68%) included an innocent person based on a match statistic. Professor Hampikian qualifies these results as a "chilling conclusion" [3]. He also refers to the "Georgia case" study, mentioned in paragraph 1, to conclude that "(...) the good news is that the only lab that used probabilistic genotyping software (TrueAllele by Cybergenetics) in the NIST study, got the right answer and excluded suspect C. To sustain this conclusion, Hampikian mentions the Virginia study of 2014 by Perlin in which 144 old cases, which were based on CPI methodology, were reexamined on the basis of the TrueAllele program [3]. In five of these cases, the TrueAllele program excluded the profile that was included by the manual CPI method. As a result, Hampikian concludes that probabilistic genotyping can often tell if their claims (convicts who claim to be innocent) are true [10]. The next paragraph will delve into the question as to the implications for the criminal law practice, that is, for defense counsels and prosecutors in criminal cases.

2. Implications for the criminal law practice

2.1 Introduction

The advent of probabilistic genotyping began in 1999, when Mark Perlin of Cybergenetics Corporation in Pittsburgh (USA) developed the program "TrueAllele." Since then, it has served criminal cases both to the benefit of defense and also to the interest of the prosecution.

2.2 Probabilistic genotyping as a defense tool

For the defense, probabilistic genotyping has demonstrated its relevance in overturning wrongful convictions. The first use of probabilistic genotyping to redress a wrongful conviction was the exoneration of Darryl Pinkins and Roosevelt Glenn in 2016. These persons were convicted of rape and robbery in 1990 and were sentenced to 65 years imprisonment. The case against Pinkins was built upon an eyewitness identification by the victim as being one of the assailants and a statement from an inmate who shared a prison cell with him, alleging that Pinkins had confessed the rape to him. The case against Pinkins lacked forensic evidence, more specifically DNA evidence. After the conviction, the DNA traces from unknown persons found on the victim's clothes were examined with probabilistic genotyping. The result was that none of the five DNA traces found on the victim's clothing matched with Pinkins' DNA [11]. The 2016 Pinkins case was the first example whereby the TrueAllele software analysis developed by Dr. Mark Perlin was able to completely exclude the convicted person Darryl Pinkins and Roosevelt Glenn from the semen evidence that was a mixed profile stemming from a multiple perpetrator sexual assault case. After 23 years in prison, both persons were exonerated [12].

Soon thereafter, the defense of Mr. Johnny Lee Gates was able to achieve a similar exoneration based on probabilistic genotyping. Gates was wrongly convicted in 1977 for rape, armed robbery and murder. He was found guilty of shooting and killing a 19-year-old victim in her apartment where she lived with her husband. Also here, probabilistic genotyping showed that Gates' DNA was not to be found on crucial pieces of evidence. In particular, it was not detected on the white belt from the victim's bathrobe and black neckties that was used by the perpetrator to blindfold the victim. Had Gates been the perpetrator, his DNA had to be left on these items [4]. The method of probabilistic genotyping ensured that Johnny Lee Gates after 40 years of imprisonment was released from prison and found innocent.

Following the Gates case, more exonerations emerged in the USA based on probabilistic genotyping. Mention is made of the exonerations of Freddy Lawrence and Paul Jenkins who were wrongly detained for 23 years. They were convicted of robbing, abducting and eventually killing a 34-year-old Donna Meagher in the Jackson Creek Saloon in Montana City in 1994. The crime went unsolved for some time, until Lawrence's father-in-law Dan Knipschield stated that his son-in-law was involved in the crime. The police then asked him to wear a tape recorder to record a confession. The tape recorder malfunctioned, and no recording was made. Nonetheless, Knipschield told the police that Lawrence confessed to having committed the crime along with Paul Jenkins. As a result of this, Lawrence was questioned by the Montana Police Department. That's when Lawrence stated that he had no involvement in the crime, but Jenkins and Jimmy Lee Amos, a mentally challenged man who lived with Jenkins and his wife, did. Lawrence later recanted this statement, but the police officers interviewed Jenkins' wife Mary, as well as Amos, anyway. Mary made an incriminating statement, but she also had a severely diminished mental capacity. There was no recording of Mary's interrogation, although she was interrogated for 8 hours straight. Amos was declared incompetent to testifying because of his diminished mental capacity, but Mary's statement was included at trial. Lawrence and Jenkins were convicted by separate juries and sentenced to 100 years in prison, merely on the basis of two statements, of which there were no recordings. There was no physical evidence linking either man to the crime at all. In 2015, the Montana Innocent Project filed a motion seeking DNA testing of the physical evidence. Meanwhile, Fred Nelson came forward, who said that his uncle, David Nelson, had admitted to having committed the crime. He could also provide details about the crime that matched the police's details of

the crime. Fred Nelson had already told the law enforcement about this a couple of months after the crime, but the police told him nothing could be done because there was no evidence. In 2018, the Montana Innocent Project filed a motion to vacate the convictions. Also in this case, probabilistic genotyping proved that the DNA evidence did not match either Lawrence or Jenkins. However, the DNA profile recovered from a piece of rope found near Meagher's body did match David Nelson, whose DNA profile was already stored in the Montana State DNA database. District Court Judge Kathy Seeley granted the motion in April 2018 [13]. The exonerations demonstrate that it is of perennial importance that defense counsel representing defendants who are charged based upon DNA inclusion pertaining to complex DNA mixtures of multiple persons or perpetrators endorse probabilistic genotyping.

In other countries probabilistic genotyping could serve as a more precise alternative for the traditional DNA methods as well. Another example of a possible wrongful conviction based on erroneous DNA evidence emerged in the Netherlands, where real estate broker Victor 't Hooft was shot and killed on the 7th of November 2007. There was only one witness in this case, Mr. 't Hooft's wife, Mrs. Emmy van Dijk. She testified that the killer rang the doorbell, and when she opened the door, there was an intruder, who was described as a white male, around 1.90 meter tall. Immediately, a fight between Mr. 't Hooft and the shooter began, and Mr. 't Hooft was shot right away. Mrs. van Dijk had testified there being a moment when she and the shooter were alone in a room. Yet, no injuries were found on her. The defendant Remond Proveniers' DNA was found on the gun and on the casings of some of the bullets that were found at the crime scene. Remarkably, not all the bullet casings that were found at the crime scene were originating from the gun that was found. Consequently, there must have been a second gun, being (one of the) the murder weapon(s). The court ruled that the DNA evidence did not match the other evidence, and therefore he was acquitted in first instance. However, in appeal, the court came to a different evaluation of the DNA evidence and Mr. Proveniers was convicted purely based on the DNA evidence [14]. The defendant provided two explanations for the DNA on the gun, which should have exonerated him. First, he stated that a few months prior to the shooting, his gun, gloves and some other munitions were stolen from his safe and these items could have been used for the shooting. That way, the real perpetrator would have had access to his gun and Proveniers' DNA would also be on the gun. The second explanation pertained to the fact that Proveniers had been to a gas station prior to the crime. He had sneezed over the cashier desk and therefore his DNA would be on the cashier desk. The video cameras from the gas station displayed that Mr. 't Hooft's wife, Mrs. Van Dijk, arrived at the same gas station's cashier desk about 7 to 9 minutes later than Mr. Proveniers. Proveniers states that because he and Mrs. Van Dijk have stood behind and touched the same cashier desk, his DNA could have been on Mrs. Van Dijk's hands, and therefore it could be possible that the DNA was found at the crime scene. Besides, Proveniers is a so called "strong shredder," meaning that his DNA transfers to other surfaces really easily in comparison to other people. The only evidence linking Proveniers to the case is his DNA evidence, while the two possible explanations of Mr. Proveniers were not sufficiently ruled out. New DNA methods, such as probabilistic genotyping, could assist in determining this potential miscarriage of justice. This approach was also affirmed by Dr. Greg Hampikian, who has drafted an affidavit in 2020 recommending further analysis of the DNA evidence in this case with the probabilistic genotyping method.

The Proveniers case reveals some other pitfalls in regard to (traditional) DNA methods being considered the "golden standard" of evidence. First of all, there's a possibility of secondary transferring. Proveniers' explanation of "the sneeze on the

cashier desk" remains forensically possible. If someone's DNA is found on a crime scene, it does not automatically mean that the person was the perpetrator, or even that the person was present at the crime scene. DNA can be easily transferred from object A to object B or from person A to person B. The second issue relates to the first, in the sense that it is possible that DNA evidence can be contaminated, meaning that DNA traces from the crime scene can be inadvertently mixed with DNA of third persons (e.g., by not properly storing), who have no relation to the specific crime [15]. That way, DNA samples can be retrieved from the evidence, without the donor being the perpetrator. These limitations illustrate that not only at the stage of judging the evidence mistakes are made and caution is advised, but also in the stage of retrieving evidence from the crime scene.

Yet, a critical remark about probabilistic genotyping is to be made. According to Richard Torres, a staff attorney in the DNA unit of the New York Legal Aid Society in New York City, and scientists such as Dan Krane, who is a professor of biological sciences at the Wright State University, there is a problem with the lack of transparency. Organizations like Cybergenetics provide the tool and supplemental materials such as validation studies to defense counsels, but the provided information is incomplete to protect the company's intellectual property. Torres argues that the defense had a right to confront and question the algorithm, not just the scientist who made it [16]. To remedy this potential problem, the defense could seek for a court order to disclose the algorithms and the underlying source codes in order to verify this information and to question the forensic expert about the use of these source codes. Actually, the defense should have access to all source materials relating to DNA methods. The study of Thomson et al. [17] already indicated the importance of the defense having full access to the underlying source materials, which can not only reveal forensic errors but also DNA traces of unknown persons. **Figure 1** displays electropherograms from a rape and homicide case. In that case, the defendant admitted having intercourse with the victim, but the defendant also said that another man had raped and killed the victim afterwards. The crime lab only reported the defendant's DNA profile in the vaginal samples from the victim, but a review of the electronic data by a defense expert revealed low-level alleles

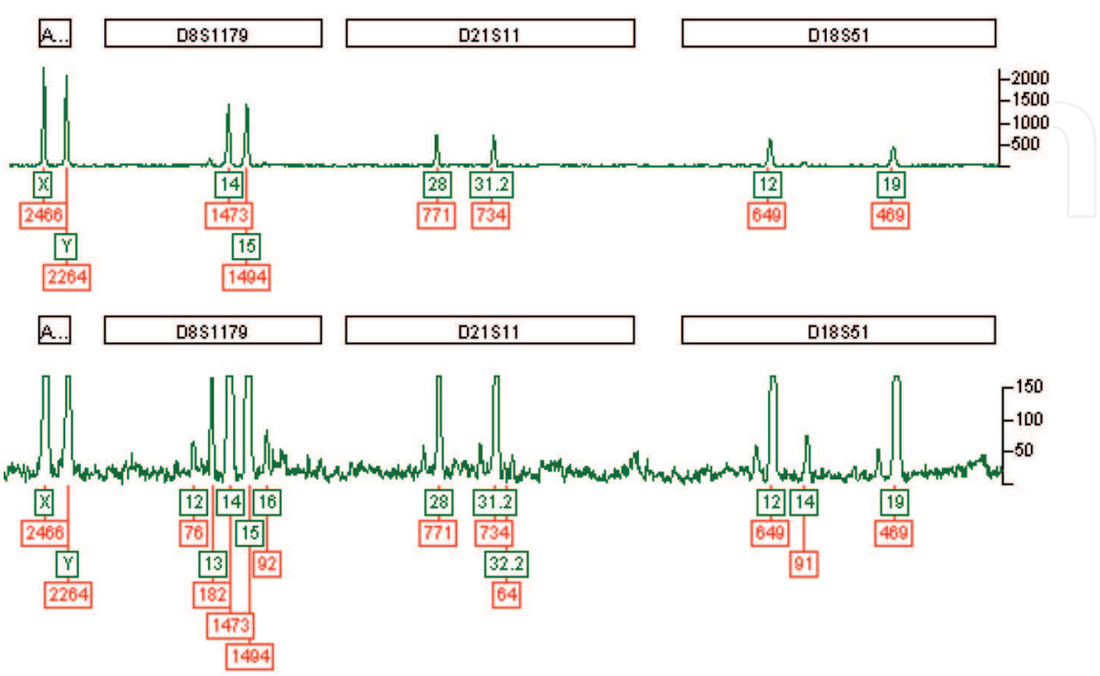

Figure 1.
Defense examination of electronic data [17].

consistent with those of the second man, which contributed to the exoneration of the defendant. The low peaks are revealed in the lower electropherogram, where the defense expert set the software with a lower threshold of detection and produced an electropherogram with a lower scale. Even though this case does not relate to probabilistic genotyping, it is a clear illustration of the importance of the defense having access to all the source code information [17].

Finally, while probabilistic genotyping can be instrumental in unraveling a cold case, it has to be stressed that a DNA profile as such, without corroborating evidence, should never be the sole piece of evidence. In a criminal case, it simply does not tell the judge who is the real perpetrator. DNA evidence therefore should be just one part of the evidence in a criminal trial. However, as indicated by Dr. Mountain "A DNA profile is rarely the sole piece of evidence; it is not allowed to be in the UK" [18]. However, probabilistic genotyping should be admissible as evidence when it serves an exculpatory purpose, when it that is excludes the defendant from the crime.

2.3 Probabilistic genotyping as a prosecutorial tool

Contemporary criminal law practice also reveals that probabilistic genotyping can assist law enforcement officers in solving cold cases as well as assist in pending prosecutions. An illustration thereof is the Syracuse case. The case related to Frank Thomas who had pleaded not guilty to charges pertaining to illegal possession of a weapon, reckless endangerment and threatening a police officer. In 2014, on the 21st of August, two Syracuse police officers tried to stop a car driving without headlights. The driver and the passenger fled and fired two gunshots at the police officers. The officers were unable to find the car that night, but they did find the gun with which the shots were fired. On the gun, five different DNA samples were found. The mixture of DNA on the gun was too complex to analyze with traditional DNA methods, so the prosecution endorsed the application of TrueAllele software analysis, which ultimately showed that one of the five DNA samples did match Frank Thomas. Thomas was ultimately found guilty of criminal possession of a weapon, reckless endangerment and menacing a police officer. He was sentenced to $15\frac{1}{2}$ years in prison [19].

One has to bear in mind that during the last decade, the number of cold cases has increased. In the Kingdom of the Netherlands alone, in 2019, around 1500 severe criminal cases remained unsolved [20, 21]. According to Project Cold Case, a non-profit organization with the goal to help solve cold cases, nearly 185,000 cases of homicide and nonnegligent manslaughter went unsolved from 1980 to 2008, a total that still increases every year [22]. A more systematic application of probabilistic genotyping on cold cases could contribute to the unraveling of perpetrators who otherwise might remain forensically undetected.

3. Conclusion

This chapter first has outlined some of the limitations of traditional DNA methods within the contemporary field of forensic evidence. Moreover, this chapter has illustrated the danger of a lack of objectivity when it comes to evaluating DNA evidence. Research suggests that contextual information of the crime especially can lead to subjective outcomes, which can result in experts in the field having different opinions about the same DNA sample. One can imagine that this might have a damaging effect on the legal system. One of the reasons for this is that DNA evidence

is still seen as the "golden standard" of all evidence by law enforcement officers. However, it has been shown that one DNA sample can lead to different conclusions about who the donor is. As a result, the "golden standard" rule should be nuanced. At the least, it is to be recommended to always seek for a second opinion as a standard when using the traditional DNA methods. As an alternative for the traditional DNA research methods, this chapter also determined the effects of a relatively new method named probabilistic genotyping for the criminal law practice, while foreshadowing its relevance for, in particular, the redressing of wrongful convictions as well as resolving cold cases. As such, the TrueAllele software program advances an important goal in the truth-seeking nature of criminal law, namely the exclusion of subjectivity and (contextual) bias in the identification of the real perpetrator of crime, while excluding the innocent.

This chapter arrives at the following conclusions. First, for defense counsel in criminal cases, it is to be advised that particularly in cases involving DNA mixtures entailing profiles of two or more profiles of individuals other than the victim's profile, recourse to probabilistic genotyping can be a forensically powerful instrument. This is specifically relevant when the DNA results based on the traditional methods are not conclusive or, even, when the DNA of the defendant is found in the mixture, while the defendant nonetheless claims to be innocent. Secondly, the studies mentioned in this chapter demonstrate that the interpretation of complex DNA profiles by forensic experts is not hard science, that is, susceptible to a certain level of subjectivity. Not only the defense lawyers but also prosecutors and the judiciary should be conscious about the phenomenon. By timely acknowledging these potential DNA evidentiary pitfalls, one can prevent miscarriages of justice. Specifically, it implicates that the precise context information the DNA expert is given for this assessment should be disclosed in order to ensure that both the inculpatory but also the exculpatory context information was made available to the experts. The disclosure therefore might be decisive for the judicial appraisal of the DNA evidence. Thirdly, in criminal cases in which the prosecution relies on DNA evidence based on traditional methods, it is important that defense lawyers have access to all source materials, as well as call for contraexpertise. The case of Lydell Grant demonstrates that a review of DNA evidence by a second expert might prevent wrongful convictions.

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Conflict of interest

The authors declare no conflict of interest.

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