Post-Conviction DNA Testing and Wrongful Conviction

John Roman, Ph.D.
(202) 261-5774
JRoman@urban.org

Kelly Walsh, Ph.D.
(202) 261-5434
KWalsh@urban.org

Pamela Lachman
(202) 261-5514
PLachman@urban.org

Jennifer Yahner
JYahner@urban.org

Urban Institute
Justice Policy Center
2100 M St. NW
Washington, DC 20037

This project was supported by Contract No. 2008F-08165 awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. Points of view in this document are those of the authors and do not necessarily represent the official position or policies of the U.S. Department of Justice.

RESEARCH REPORT June 2012

research for safer communities

URBAN INSTITUTE
Justice Policy Center

URBAN INSTITUTE
Justice Policy Center

2100 M Street NW
Washington, DC 20037
www.urban.org

This project was supported by Contract No. 2008F-08165 awarded by the National Institute of Justice. The National Institute of Justice is a component of the Office of Justice Programs, which also includes the Bureau of Justice Statistics, the Bureau of Justice Assistance, the Office of Juvenile Justice and Delinquency Prevention, and the Office for Victims of Crime. Points of view or opinions in this document are those of the authors and do not represent the official position or policies of the United States Department of Justice, the Urban Institute, its trustees, or its funders.

Acknowledgements

The Post-Conviction DNA and Wrongful Conviction Project was funded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The authors are grateful to Bethany Backes, Katharine Browning, Eric Martin, and Carrie Mulford for their guidance and assistance. We also wish to thank the staff of the Virginia Department of Forensic Science, especially Brad Jenkins and Deborah Collard, for their support during our data collection phase. At the Urban Institute we would like to thank our project team and report reviewers, including Douglas Gilchrist-Scott, P. Mitchell Downey, Joshua Markman, and Carey Nadeau. Finally, Rayanne Hawkins, Shalyn Johnson, and Katie Johnson were irreplaceable in their assistance bringing this project to completion.

Table of Contents

List of Figures and Tables

Glossary

ABO typing - Testing blood or other physiological fluids to determine if the person they came from carries the A antigen (Type A), the B antigen (Type B), both (Type AB), or the H antigen (Type O).

Akaike information criterion (AIC) corrected - A diagnostic tool used in statistics to reflect how well a model fits the observed data. When comparing multiple models, the best fitting model will have the lowest AIC value.

Bivariate comparison - A model that tests the significance of two variables: one predictor (independent variable) and one outcome (dependent variable).

Determinate - Allowing a conclusion to be drawn as to whether the person convicted was a possible source of the DNA developed from the original evidence.

DNA profile - The final product of DNA testing as it was performed in this study. The profile is a series of numbers that describe a person's DNA at specific locations (loci) on the genome. A full profile is produced when testing yields numbers at every targeted location. A partial profile may occur when data are generated only a few loci. In general, the more loci represented in a profile, the stronger the association or "match" that can be made.

Enzyme typing - A generic term used in this study that includes all non-ABO typing systems, including other antigen markers, protein markers (Hb, Hp), and actual enzyme markers (such as PGM, Esd, EAP). In the pre-DNA era, the more types used to link questioned and known items, the higher the likelihood that they came from the same source.

Exculpatory - Evidence that reduces certainty that a person committed a criminal act.

Exculpatory and supportive of exoneration - The results of the DNA testing that exclude the convicted offender as the source of DNA developed from old evidence. This result would support a claim of wrongful conviction. However, this alone may not be sufficient to prove wrongful conviction.

Exculpatory but insufficient for exoneration - The DNA testing eliminated the convicted offender as the source of DNA developed from old evidence. However, due to the context of the case, this result does not support a claim of wrongful conviction.

Exoneration - Applies to a person who has been legally exonerated by the state of Virginia as of April 1, 2012.

Inculpatory - Describes evidence that adds strength to the assertion that a person committed a criminal act.

Indeterminate - (1) No new DNA evidence was developed in the case or (2) no conclusion can be drawn about the source of DNA evidence that was developed.

Individualizing - Establishing uniqueness or the source of questioned evidence.

Multivariate logit - A statistical model that evaluates the covariation of multiple independent variables and one binary dependent variable.

Nagelkerke R-square - A value between 0 and 1 that describes how much of the variation in the dependent variable is explained by the statistical model. As the value approaches 1, more variation is explained and the better the model fits the observed data. A Nagelkerke R-square value of 1 means the model perfectly fits the data.

Physical evidence recovery kit/"PERK" - This is the term used for the swabs and other materials used to collect physical evidence (both reference and questioned) from persons of interest in a case. These kits were frequently used to collect biological evidence from suspects and victims of sexual assault.

Probative - Information that tends to prove an assertion.

Questioned evidence - Physical evidence whose true source is unknown (e.g., a bloodstain found on a wall at a crime scene).

Reference sample - Physical evidence that has been collected directly from a person (e.g., blood drawn from a suspect or a cheek swab from a victim).

Statistical significance - Describes a relationship between two variables in which the difference in means is large enough that it is unlikely to have occurred by chance.

Executive Summary

Forensic evidence, particularly fingerprints, has been used for more than a century to aid law enforcement investigations. However, only in the past decade has the use of deoxyribonucleic acid (DNA) testing to include or eliminate suspects and exonerate those convicted in serious crimes become relatively common. DNA evidence is said to be individualizing because of its power to link a person to a criminal incident. And unlike fingerprints, the probability that questioned evidence from a crime scene matches DNA from a known person can be calculated. In past decades, the investigation of serious crimes that led to a conviction typically did not use individualizing forensic biological evidence such as DNA. Thus, it is possible that some individuals convicted in serious person crimes (sexual assault and homicide) would have been eliminated by a forensic analysis more discriminating than what was available at the time. To estimate the rate of such possible wrongful convictions and to identify their predictors, the National Institute of Justice (NIJ) in the U.S. Department of Justice funded retrospective DNA testing of physical evidence in cases where there was a conviction of a sexual assault or homicide and physical evidence was retained.

Two states participated in this research. In Arizona, every eligible prisoner was informed about the program and was given the opportunity to request DNA testing of physical evidence. Testing was performed when physical evidence could be located and if a review of the case deemed that evidence to be probative in the conviction. The Arizona site thus provides a case study that can be used to qualitatively evaluate how often a voluntary program leads to detection of wrongful conviction. The results of the Arizona experiment are described in a separate report.

In Virginia, a cohort of 634 cases of sexual assault and/or homicide dating from 1973 to 1987 was discovered to have retained physical evidence. Since most state legislation that requires evidence storage was enacted in the post-DNA era, it is likely that many states have not preserved physical evidence for cases from the pre-DNA era. Therefore, the evidence in the Virginia cases provides a unique opportunity to determine how often DNA testing can be used to identify wrongful convictions. The results can be generalized (with caveats) because the physical evidence was retained for reasons unrelated to the case outcome, and the cases were assigned to the serologist who retained the evidence in a way that did not introduce bias.

Once cases were found to meet the NIJ eligibility requirements (retained physical evidence, conviction of a sexual assault and/or homicide), the evidence was sent to a private lab for DNA analysis. The goal of this DNA testing was to develop a profile from questioned evidence, generally from the crime scene, and compare it to profiles of known persons developed from the original evidence or stored in a database.[1] From these comparisons, a determination can be made whether

[1] Associative physical evidence is either questioned (Q) or reference (K). When evidence is questioned, its true source is unknown. For example, when a bloodstain is found at a crime scene, investigators do not know whose blood has been found. To make that determination, it must be compared to a reference sample. Reference samples are evidence collected directly from persons of interest (e.g., suspects, victims, and/or consensual partners). DNA profiles from questioned evidence are compared with DNA profiles from reference samples to determine if a suspect, victim, or other known person can be included or excluded as the source of that questioned evidence.

that evidence is indeterminate,[2] inculpatory, or exculpatory.[3] The Virginia cases, all of which occurred before DNA evidence testing was readily available, can therefore be used to answer a critical policy question: "What proportion of convicted offenders in serious person crimes with retained forensic evidence could be exonerated if that evidence were DNA tested?"

To answer this question, the Urban Institute (UI) conducted a retrospective study using observational data from the Virginia post-conviction DNA analyses to estimate the rate at which defendants are wrongly convicted and to identify case attributes associated with such wrongful convictions. Toward this end, the Virginia data, which were contained in files maintained by the Virginia Department of Forensic Science (DFS), were made available to UI researchers. All files contained information about the pre- and post-conviction forensic facts of the case, including results of the original forensic testing on the physical evidence, as well as results of the contemporary DNA analysis. Additionally, most files contained information about other basic case attributes, such as the charge and jurisdiction of the crime and demographic information about the convicted offender and other known suspects and victims. These data will serve two purposes.

- First, we will use these data to determine whether the results of Virginia's DNA testing would support exoneration of a convicted defendant, inculpate the defendant, or be insufficient[4] to change the outcome of the case. We note that it is critical to keep in mind that our data collection was largely limited to the DFS forensic files, and because of this, we must assume that the *forensic* evidence is sufficiently probative to make such a determination for each conviction. However, it is possible that other *nonforensic* facts of the case that are not available to us may lead to a different conclusion. For instance, DNA tests from a questioned stain on clothing recovered from a sexual assault case might eliminate the convicted offender as the source of the stain, which we would label as supportive of exoneration. However, if more information about the case was available, other facts of the case may prove the clothing was unrelated to the assault. In that case, what appears to be strong evidence in support of exoneration is actually not probative. Since our data collection was limited to data in the DFS forensic files, we might not be able to observe those additional facts.

---

[2] DNA testing results are indeterminate for four reasons: (1) questioned evidence from a crime scene could not be compared with a reference sample because there was no reference sample available for the convicted offender; (2) there were no DNA profiles obtained from any questioned evidence, only DNA obtained from a victim or offender reference sample; (3) technology applied to the DNA analysis of questioned evidence could not develop a profile because the quantity of DNA was below detectable levels; and (4) testing did not yield a DNA profile because no DNA was ever present in the biological evidence that was collected at the crime scene.

[3] As is discussed later in the report, a finding that a suspect is eliminated as the source of questioned evidence is not synonymous with exoneration because that evidence might not be probative (i.e., does not point to guilt or innocence). For example, a profile from questioned evidence found on the victim may have come from the victim and not the suspect, which still does not address the suspect's guilt or innocence. Even when questioned evidence includes the convicted offender, it is a necessary but not sufficient condition for exoneration. Other facts of the case (statements, eyewitnesses, etc.) must also be considered before a convicted offender can be exonerated. For instance, finding a DNA profile matching the suspect at a crime scene is not sufficient to conclude guilt if the suspect had a legitimate reason to be there at some other time.

[4] DNA testing would be insufficient to change the outcome of a case if (1) results of testing were indeterminate or (2) results were exculpatory but other known case characteristics make this result not relevant.

- Second, we will use these data to identify associations between case characteristics and the likelihood that DNA testing would produce determinate results and support exoneration of a convicted defendant. These findings can be used by states to prioritize closed cases for post-conviction DNA analysis. If those attributes include factors that exist today, policy recommendations can be made to avoid new wrongful convictions.

What this report can and cannot say about wrongful conviction

The data available for this study likely provide the best opportunity to date to understand the rate of wrongful conviction and the correlates of wrongful conviction. As described further later in the report, the data developed by the Virginia DFS appear to be from an unbiased sample of homicides and sexual assaults where an offender was convicted and physical evidence was retained over a period of about 15 years.[5] Though these cases were assigned to a single forensic examiner, these crimes, investigations, and prosecutions occurred in counties throughout the state of Virginia. Interviews with DFS supervisors found that there were no differences in caseload across forensic examiners during this period. Thus, we believe that our data set includes cases that are equivalent to other serious person crimes in the state of Virginia from 1973 to 1987.

However, there are serious limitations to the data set as presently constituted. First, the DFS files did not always contain sufficient information about the *context* of the physical evidence and are missing many nonforensic facts that may be critical to ultimate determination of the probative value of DNA testing results. In fact, as a pilot test, we visited three Virginia county courthouses and found that sufficient, nonforensic data still exist in public court records to allow for more precise designation of case outcomes. However, for technical reasons the research contract could not be extended to allow visits to the 94 counties with a convicted offender in this data set.

The second limitation of this data set is that in two-thirds of the convictions[6] the DNA analysis did not produce a DNA profile or no forensic determinations about wrongful conviction could be made.[7] If the likelihood that a case has determinate results is not related to the probability of wrongful conviction, then we could generalize results from convictions with determinate findings to convictions with indeterminate findings. However, we found that convictions for crimes involving any sexual assault were more likely to yield determinate results when compared to convictions for nonsexual assault homicide, simply because of the presence of a victim or suspect physical evidence recovery kit (PERK), which often yielded a DNA profile. Thus, we cannot interpolate from sexual assault convictions with determinate results to nonsexual assault homicide convictions with indeterminate results. These two limitations have particularly important impacts on the way in which we estimate the rate of wrongful conviction.

Of the cases originally reviewed (more than 534,000), approximately 3,000 had retained physical evidence; in 2,100 of those cases a suspect was identified; and 740 cases had at least one suspect convicted of a felony. Of those, 634 cases with 715 convictions (62 cases had multiple suspects) were NIJ eligible based on crime type (homicide, sexual assault) and a conviction. The relationship between case and number of convictions is illustrated in Table 1.

[5] The offense dates in these cases occurred from 1973 to 1987; DNA testing was conducted from 2009 to 2011.
[6] Convictions were obtained by guilty plea, jury trial and judge trial; however, DFS data were incomplete and thus the type of disposition is missing for many cases.
[7] As is discussed later, only 8 percent of convictions for nonsexual assault homicide produced a determinate finding. More than half (54 percent) of sexual assault cases, including those ending in homicide, resulted in a determinate finding.

Table 1. Individual Cases and Individual Convictions

Number of Convictions in a Single Case	Number of Cases	Number of Convictions
1	572	572
2	48	96
3	10	30
4	3	12
5	1	5
Total	634	715

DNA testing produced a determinate outcome for 230 of these cases, in which there were 250 convicted offenders. In 56 of those convictions the convicted offender was eliminated as the source of DNA evidence, and for 38 convictions that elimination supported exoneration.

Thus, we find that in Virginia cases resulting in a convicted offender between 1973 and 1987 where evidence was retained in an unbiased sample of 715 **homicides and sexual assault** convictions—

- The convicted offender is eliminated as a contributor for a probative evidence item in 8 percent (n=56) of convictions.[8]

- The convicted offender is eliminated as a contributor for a probative evidence item, and that **elimination is supportive of exoneration,** in 5 percent (n=38) of convictions.

For nonsexual assault homicide cases, a determinate finding about a convicted offender being a source of a DNA profile was reached in only 23 out of 293 convictions (8 percent), making it too rare to make declarative statements about the likelihood of potential wrongful conviction in those homicide convictions.

We find that DNA testing of items in these cases leads to a determinate conclusion in more than half of the sexual assault convictions (including homicides with a sexual assault). Thus, we focus much of our analysis on the sexual assault offenses. We find that in convictions in Virginia between 1973 and 1987 where evidence was retained in a sample of 422 convictions for **sexual assault**—

- The convicted offender was eliminated as the source of questioned evidence in 40 out of 422 convictions (9 percent).[9]

- The convicted offender was eliminated as the source of questioned evidence in 33 out of 422 convictions (8 percent) **and that elimination was supportive of exoneration**.

- The convicted offender was eliminated as the source of questioned evidence in 40 out of 227 convictions (18 percent) where a determination could be made from the DNA analysis.[10]

[8] (exculpatory but insufficient n=18) + (exculpatory supporting exoneration n=38) = 56.
[9] Where sexual assault = yes, (exculpatory but insufficient n=7) + (exculpatory supporting exoneration n=33) = 40.
[10] (Any sexual assault n=422) – (indeterminate sexual assaults n=195) = 227.

- The convicted offender was eliminated as the source of questioned evidence in 33 out of 227 convictions (15 percent) where a determination could be made from the DNA analysis, **and that elimination was supportive of exoneration**.

The two most important numbers in the bullets above show the rate at which convicted offenders were eliminated as the source of questioned evidence and that elimination was supportive of exoneration. This occurs for 8 percent of all sexual assault convictions in the sample and for 15 percent of all sexual assault convictions where a determinate finding was made. We note again that additional facts about the case not included in the forensic file may ultimately include the convicted offender. However, given that these are sexual assault cases where the profile was determined to be male and excluded the convicted offender, we anticipate this will be relatively rare.

Table 2. Outcome of DNA Testing Results, by Sexual Assault Status

Outcome		Sexual Assault: No	Sexual Assault: Yes	Total
Indeterminate	Count	270	195	465
	% of Column	92%	46%	65%
Inculpatory	Count	7	187	194
	% of Column	2%	44%	27%
Exculpatory but insufficient	Count	11	7	18
	% of Column	4%	2%	3%
Exculpatory supporting exoneration	Count	5	33	38
	% of Column	2%	8%	5%
Total	Count	293	422	715
	% of Column	100%	100%	100%

From our data, there are several ways to calculate an estimated rate of wrongful conviction, and all are unsatisfactory. The first option is to divide the number of exculpatory outcomes by the total number of cases considered (over 534,000 case files were originally reviewed). We did not use this approach given that the vast majority of cases were not subjected to DNA testing because there was no conviction and no physical evidence retained (and we are not attempting to generalize findings in this study to nonfelony convictions or to cases in which no physical evidence was collected or retained).[11]

Given the potential inaccuracy of an estimate of any rate of wrongful conviction, we provide two statistics as an alternative, both based on the actual numbers observed in this data:

[11] Additionally, it would be incorrect to calculate a rate when the units in the numerator (convictions) are different than the denominator (cases). A single case could result in multiple convictions.

1) The rate at which convictions for serious person crimes and retained evidence yielded a DNA profile and the convicted offender was eliminated as the source (56/715 or 7.8 percent); and

2) The rate at which convictions for serious person crimes and retained evidence yielded a DNA profile and the convicted offender was eliminated, and that elimination appears to be probative evidence that supports exoneration (38/715 or 5.3 percent).

Finally, we note that despite our concerns about calculating an estimated rate of wrongful conviction solely from the 227 convictions for sexual assault with determinate results, we nevertheless conduct several analyses to look at the association between the case attributes of these 227 convictions and whether the DNA analysis was inculpatory or exculpatory. While we have the same concerns about whether unobserved heterogeneity may lead to spurious conclusions about these relationships, we believe these findings are an important starting point for the field to investigate old cases for wrongful conviction and to prevent future wrongful conviction. We do not make any causal claims about these relationships: Rather, we see them as clues in the hunt for innocence.

What is wrongful conviction?

Conviction may be classified as wrongful for one of two reasons (1) the person convicted is factually innocent of the charges, or (2) there were procedural errors that violated the convicted person's rights. In this study, since DNA evidence is the tool used to detect wrongful convictions, we are solely concerned with those where factual innocence is the issue. Post-conviction DNA testing cannot be used to detect erroneous convictions due to reversible procedural errors.

A review of the wrongful conviction literature (Gould and Leo 2010) finds that several studies put the upper bound rate of wrongful conviction between 3 percent and 5 percent. The most conservative estimate was proffered by Scalia (*Kansas v. March*, 278 Kan. 520, 2006) and Marquis (2006), who took the 340 known wrongful felony convictions from a previous study (Gross 2005), multiplied by a factor of 10 and divided by all felony convictions from the same time frame (Gould and Leo 2010). The resulting rate, 0.027 percent, is criticized as much too conservative given that the numerator only represents detected wrongful convictions where DNA was used to evaluate culpability, 95 percent of which were sexual assaults or murders. The denominator, all felony convictions, has a different distribution of crime types that included a much smaller percentage of rapes and murders.

The data set in our study is better suited to determine rates of wrongful convictions than previous works. All cases in this study were convictions for serious person crimes, from a single time frame, where biological evidence was collected and tested in the original investigation. The post-conviction DNA testing identified not just likely wrongful convictions but also rightful ones. This provided several denominator choices that more closely resemble the convictions with exculpatory results in convicted offender, victim, and crime characteristics. One limitation to this data set is that it remains unknown how many of the convictions with exculpatory results of DNA testing are actually wrongful and will result in exoneration. The media and the Innocence Project have reported on several exonerations that are due to Virginia's post-conviction DNA testing, which we have reported on in the Case Studies section when such individuals were located in this study's data set; however, the current status of each conviction with an exculpatory finding was not available to UI researchers through the DFS case files or via other data sources.

What has previous research determined contributes to wrongful convictions?

Until this study, previous research on wrongful convictions has been based on data known only for cases in which the convicted offender (or others on his/her behalf) actively pursued exoneration. Given this caveat, there is a substantial body of literature that indicates certain attributes of the victim, offender, and crime may be associated with the likelihood that an individual is wrongly convicted.

Garrett (2008) found that minorities were overrepresented among exonerated offenders, given the rate at which minorities are typically convicted of murder and rape. Conners et al. (1996) reported that most DNA exonerations occurred in cases beginning in the mid- to late 1980s, a period when forensic DNA technology was not readily available. They also connected actual-innocence cases with short jury deliberations (the majority of which lasted less than a day) and with prior police knowledge of the defendant. Garrett (2008) suggested that codefendants may play a part in wrongful conviction; for example, a defendant may only be identified through false testimony of a codefendant, who may have been offered a reduced sentence for cooperation with the prosecution.

Eyewitness Identification and Informants

Most studies on actual innocence have found that false eyewitness testimony and faulty forensic evidence were the leading causes of wrongful convictions (Conners et al. 1996; Garrett 2008, Gross et al. 2005; Innocence Project web site). In the Garrett (2008) study, false eyewitness testimony contributed to a wrongful conviction in 79 percent of his sample, while faulty forensic evidence was present in 55 percent of wrongful convictions (a defendant could be convicted based on more than one type of evidence, so these percentages do not sum to 100 percent). In regard to witness misidentification, Garrett's police records indicated many instances where an eyewitness hesitated on the identification, did not initially correctly identify the defendant, or indicated less than 100 percent certainty when identifying the suspect to police. Furthermore, Conners and colleagues (1996) indicated that in murder cases, where no victim eyewitness is possible, wrongful convictions may be made by witness misidentification placing the defendant near the scene of the crime or with the victim. Kreimer and Rudovsky's (2002) study on post-conviction DNA testing found that jailhouse informants' testimony has been well-documented as particularly unreliable

Forensic Evidence

Peterson and colleagues (1987) found that forensic evidence had an effect on conviction (but not necessarily wrongful) in two independent ways. There was an initial effect of a case having any sort of forensic evidence, and the additional effect of the forensic evidence linking the defendant with the crime. Peterson and colleagues also found that when a laboratory had nonassociative forensic results, the conviction rate was 59 percent, while if the laboratory report yielded results that associated the defendant with the crime,[12] the conviction rate was 95 percent.

Garrett (2008) reported that in wrongful convictions, some types of forensic evidence were particularly unreliable. Specifically, bite mark and hair comparisons were particularly problematic because their associations with a suspect are unquantifiable. Forensic evidence may be associated with a wrongful conviction in several ways. First, the results of a forensic analysis may be unreliable or even false if an examiner has purposefully altered data to produce a desired result. Second, forensic evidence may rightfully create a link to the wrong person (i.e., the true perpetrator and a person wrongfully convicted may have the same blood type). Or finally, the significance of links created by forensic evidence could be overstated by the expert, not adequately challenged by defense counsel, or mischaracterized in closing statements by the prosecution.

Confessions

Wrongful convictions based on false confessions make up a small proportion of total exonerations. However, of those who falsely confess, 35 percent have a diagnosed mental illness and 39 percent are juveniles (Garret 2008). Further, differences in false confessions across types of charges indicate that a false confession may be more likely for a murder than for a rape, and thus the interaction between the type of charge and whether or not there was a confession could be particularly important. Garrett (2008) shows that within his sample, only 6 percent of rape exonerees had a false confession, whereas 41 percent of rape-homicide exonerees had a false confession.

[12] In other words, the suspect could not be eliminated as the source of some physical evidence.

How does post-conviction DNA testing detect wrongful convictions?

The DNA molecule stores the genetic code for the functions of the human body and is present in almost every cell. Each person's DNA sequence is unique[13]; however, the processes used by labs to analyze DNA for criminal justice purposes do not typically reveal the DNA sequence itself. Instead, the information developed, shared with law enforcement ,and possibly uploaded to a database is called the DNA profile. When a full DNA profile is developed, there is little doubt about the identity of an individual. The profile is a series of numbers, each one of which represents the number of repeated patterns of DNA at a particular location on the DNA molecule. The profiles, produced from forensic evidence, are compared to profiles produced from known persons or profiles from other crime scene evidence in order to make associations. The high specificity of these associations comes from the frequency statistics associated with each number (or allele) in the profile.

The use of DNA evidence as an investigative tool has its roots in the pioneering work of Alec Jeffreys in 1985 (Jeffreys, Wilson, and Thein 1985; Jobling and Gill 2004). The first DNA-based criminal investigation, in 1986 in Leicestershire, England, used Jeffreys's restriction fragment length polymorphism (RFLP) technique (Friedman 1999). While RFLP-based methods were effective, they were slow and required large amounts of intact DNA (Friedman 1999). Due to these limitations and technical advances in the 1990s, RFLP processing was gradually displaced by superior methods based on the polymerase chain reaction (PCR) (Friedman 1999). PCR-based methods produce multiple copies of the DNA pieces for analysis. A PCR-based method that analyzes polymorphic regions of DNA called short tandem repeats (STRs) is now the preferred method of DNA identification (Wise 2004).

Forensic STR processing of DNA uses predefined, specific locations on the human genome that are noncoding and therefore do not influence a person's physical or biological traits. Therefore, data produced through forensic DNA processing do not reveal any expressed genetic information or physical characteristics of a person.[14] They merely act as an identifying mechanism that forensic scientists use to determine if there is an association between the evidence sample and a particular person. Once these associations are made,[15] they are used by law enforcement agencies to aid investigations and prosecutions. The impact of the DNA association on any criminal investigation, and in any investigation of a wrongful conviction, is dependent on the probative value of the evidence and the context of the investigation.

Because sex offenders nearly always leave biological evidence behind, DNA analysis can be an especially powerful tool for the criminal investigation and prosecution of sexual assault cases (Weedn and Hicks 1998). The effectiveness of DNA in those cases has led to efforts to expand DNA evidence collection and processing to other types of crime (Roman et al. 2009).

DNA testing was not available at the time the crimes in our data set occurred. A 1983 survey of more than 300 crime labs in the United States (Peterson et al. 1985) shows that 75 percent of labs analyzed hair, semen, blood, and other forensic evidence and 90 percent performed drug

[13] With the exception of identical twins and other multiples.

[14] The only characteristic that may be revealed is gender.

[15] And quantified through the use of population statistics to generate the random match probability (RMP).The RMP is defined as the probability that the DNA profile of a person randomly chosen from the population is the same as the profile developed from questioned evidence (http://www.dna.gov/glossary/#E).

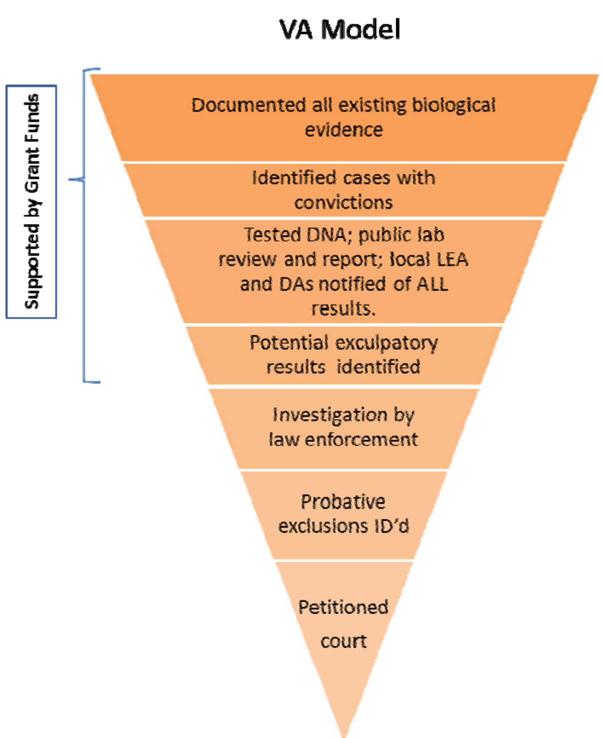
examinations. A similar survey undertaken in 2002 illustrates the dramatic transformation of crime labs since the 1990s (Hickman and Peterson 2004; Peterson and Hickman 2005). By year-end 2002, a total of 351 publically funded crime laboratories operated in the United States (Peterson and Hickman 2005). Approximately 61,000 requests (2 percent of new requests for forensic analysis) were in the area of DNA analysis.

The Virginia model of post-conviction DNA testing relief

In traditional models of post-conviction DNA testing, an advocacy group or government agency reacts to the claim of wrongful conviction made by the person convicted or others on their behalf. Almost all relief actions (e.g., investigations, DNA testing) occur after this petition is made. As a result, almost all cases of known wrongful conviction due to actual innocence are detected because a person is actively making that claim. Any innocent persons who do not outwardly claim it remain undetected. In the traditional model, DNA testing is performed near the end of a post-conviction relief review, while in Virginia, for the convictions in this study, it was performed at the beginning.

The Virginia (VA) model of post-conviction DNA testing, shown in figure 1, is unique. Rather than start with claims of actual innocence from living convicted offenders, the state received funding to test all existing physical evidence that might contain DNA for serious person crimes that resulted in conviction. The claims of actual innocence (or admittance of actual guilt) therefore did not influence the decision to conduct DNA testing. This "test-them-all" approach to post-conviction DNA testing has never been replicated by any other state. However, this novel model emerged from activities associated with the traditional approach.

Figure 1. The VA Model of Post-Conviction DNA Testing



In 2001, VA passed a law allowing persons convicted of a crime to have evidence that was newly discovered or previously untested for DNA, tested. Soon thereafter, the Mid-Atlantic Innocence Project began contacting the VA Department of Forensic Science about prisoner petitions for post-conviction relief. The first convicted person with such a petition (who was later pardoned by VA's governor) led to DFS's discovery of the retained physical evidence examined in this study. Although most of the case evidence from the time of that first case (1982) had not been retained, his case file included clippings of the physical evidence that the serologist in his case (Mary Jane Burton) had included in her files.[16] Upon further review, DFS discovered that this practice was repeated in hundreds of Burton's case files,[17] and these files represent the cases included in this study. Clippings in two other cases were tested, leading to three additional exonerations, but these cases are not included in our data set.

Given this finding, in 2005, the governor ordered testing of all eligible convictions to see if they could develop any additional DNA profiles and whether they led to exoneration. VA DFS looked for cases that had evidence retained. Among the cases reviewed, an additional two exonerations were made. At this point the governor ordered the review of all convictions where DNA may exist but had not been tested.

VA applied for and was granted funding from NIJ for these activities. Case files were stored in paper from across the state's four regional labs. All cases were from 1973 to 1987, and all 534,000+ were brought to the Central Lab for review. DFS then used a number of screening criteria to wade through the 534,000 cases. First, the case had to have physical evidence retained that could be tested (the clippings mentioned above). This brought the number from 534,000 down to around 3,000 cases. Next, there had to be a known suspect in the case (which reduced the number of eligible cases 3,000 to 2,100) and there had to be a felony conviction (reducing the number of eligible cases dropped from 2,100 to 740). Finally, NIJ required that the felony conviction be for a sexual assault, homicide, or non-negligent manslaughter, reducing the number of cases to the final sample of 634.

To prevent additional workload pressure on the VA DFS lab, Virginia outsourced all post-conviction DNA testing to a private laboratory. After the private lab's analysis, the DFS lab personnel reviewed the testing results and issued the final lab report (a certificate of analysis). The laboratory processing developed DNA profiles from STRs. When necessary, differential extractions were performed on the evidence prior to amplification. This type of extraction attempts to separate sperm cells from nonsperm cells (like those shed by skin). During this procedure, the two extract fractions are analyzed separately, with any male DNA more likely present in the sperm fraction. This procedure is more laborious than traditional extractions but is generally more effective on evidence items with a high likelihood of male/female mixtures, like those collected during a sexual assault examination.

As noted above, NIJ required that grant funds be used only to test evidence from sexual assaults, homicides, and cases of non-negligent manslaughter. Ultimately, 634 such cases, with 715 persons convicted for those crimes, matched these criteria. VA DFS did not contact living victims.

---

[16] It is important to note that these clippings and all of the swabs and swatches tested in this project were already subjected to serological testing in the 1970s and 1980s. These were not whole items with undisturbed stains. It is likely that the action of serology testing had already removed some of the existing DNA.

[17] While most of the samples were from Burton's cases, a few were from serologists she had trained.

It did, however, attempt to contact the convicted persons whose cases were tested, by certified letters with postage-paid return postcards enclosed. Among the 715 persons convicted, some were still incarcerated and some were deceased.

Virginia in the 1970s and 1980s

The criminal convictions analyzed in this report occurred in Virginia from the early 1970s through the mid-1980s (the mean and median offense year was 1978). To provide historical context for this analysis, in this section we present a sociodemographic profile of the state during that time. We base this description largely on county-level data in Virginia's County Statistics File I (1984), which we obtained from the Interuniversity Consortium for Political and Social Research (ICPSR). As discussed in the Data section below, these county data provide a snapshot of VA counties between 1977 and 1981 (USDOC Exports 1984). The data include information provided by the U.S. Census, VA Department of State Police, and other local and federal government sources.

In 1978, Virginia had a population of 5.3 million, ranking as the 14th most populous state in the U.S., with a population density of 135 people per square mile (for comparison, Virginia today has an estimated population of 8.2 million and is ranked 12th largest in the U.S.). Average annual per capita income in 1978 was just over $7,500, with a median annual household income of $17,475. Virginia's unemployment rate was relatively low, at 5 percent (the U.S. average at the time was 7 percent), though the poverty level in Virginia was more than twice that (11 percent). One-third (34 percent) of Virginians lived in rural areas (with less than 2,500 residents), and about the same share (32 percent) rented rather than owned. Overall, just over half of Virginians (52 percent) said they had lived in a different housing unit five years prior.

One in five Virginians were black/African American and the rest were white/Caucasian (only 1 percent said they were Hispanic or of Spanish origin). Most (62 percent) had a high school diploma, though more than half (52 percent) of eligible voters failed to vote in the 1980 presidential election. As was true elsewhere in the U.S., most households (89 percent) were headed by males, and only 6 percent were headed by single females with children. Fourteen percent of residents of the state were between age 15 and 21, and 15 percent were unmarried males over the age of 14.

With respect to crime and safety, in 1978 in Virginia, there were 286 violent crimes per 100,000 residents, which was substantially below the national average of about 500 per 100,000. Today, Virginia's violent crime rate (210 per 100,000) remains roughly half the national average of 400. However, Virginia's homicide rate (8.8 per 100,000) was about the same as the national average (9), which is still true today, although Virginia's current rate (4.6) and the nation's current rate (4.8) are almost half of what they were 34 years ago. In Virginia in 1978, there were 23 sexual assaults per 100,000 residents, which was well below the national average of 31. In 2010, reported sexual assaults had declined only slightly in both Virginia (to 19) and nationally (27.5). The average number of police officers per 1,000 persons was 1.5, and local Virginia governments spent approximately 5 percent of their revenue directly on police protection.

In the 1970s (and today), virtually all Virginia counties elected rather than appointed their local sheriff and prosecuting attorney. Judges, however, were uniquely appointed by the Virginia state legislature. From the 1960s through the 1990s, Democrats controlled the Virginia state legislature and were thus responsible for appointing all judges during that time. Since 2000, Virginia's legislature has generally (though not exclusively) been controlled by Republicans, although there has been a Democratic governor eight of the last 12 years.

In 1978, Virginia was comprised of 96 counties and 40 independent cities (compared to 95 and 39 today, respectively). The latter group was and is largely unique to Virginia and represents cities whose governments function independently of the counties in which they reside or which surround them; thus, they also have independently operating courthouses.

Data

The physical evidence from the criminal convictions described in this report were tested by Virginia DFS forensic scientist Mary Jane Burton, who worked as a forensic serologist for the state of Virginia from 1973 to 1987, and processed biological evidence in serious criminal cases.[18] As part of her testing protocol, she attached cotton swab heads and textile clippings to the worksheets in her hard-copy case files. Her coworkers report that she would use these clippings while testifying in court to show the jury the exact piece of evidence that underwent serological testing. These samples, which predated the use of DNA testing for criminal cases, were discovered in 2001. Thus, physical evidence in Burton's case files (and in case files of serologists whom she had trained) was retained, while all other physical evidence from that period was returned to the originating jurisdiction and its disposition is unknown.

All of the items tested in this study had previously been subjected to serology testing as it was performed in the pre-DNA era. This included screening tests for blood and other physiological fluids, species determination, ABO blood group typing, and—if sufficient material was available—typing of other antigen, protein, or enzyme groups. However, the majority of the items tested were subjected to screening and ABO typing alone. When successful, these tests characterized a biological sample as type A (shared by 41 percent of the population) B (10 percent), AB (4 percent), or O (45 percent).[19] Even when additional discrimination was obtained by typing other systems (enzymes, proteins, etc.), the specificity of these tests, and therefore the links among suspect, victims, and crime scenes, were much weaker than what is possible with modern DNA testing.

Case Selection

In 2008, the NIJ awarded the Virginia DFS funds to conduct DNA testing on the biological evidence that Burton and others had saved. NIJ required that all cases enrolled in this study have resulted in a conviction for murder, sexual assault, or non-negligent manslaughter. Ultimately, 634 cases resulting in 715 convictions were eligible for this study.

Because cases were identified in this way, these 634 cases should represent an unbiased sample of serious person crimes resulting in at least one conviction in Virginia from 1973 to 1987. Our interviews indicate that cases were assigned to forensic serologists at random. More specifically, cases were distributed among all trained examiners rather equally, and no one examiner was routinely assigned the most difficult (or the easiest) cases.

---

[18] Some of the serology evidence in these cases was tested by other analysts that she had trained. However the vast majority of evidence was tested by Burton.

[19] DeForest, Gaensslen, and Lee (1983).

Data Collection

For the 634 criminal cases (and 715 convictions) eligible for this NIJ study, UI researchers collected three types of data from three separate sources:

1) Information on the physical evidence collected, submitted, and tested during the original investigation and the post-conviction DNA testing results (collected from DFS files);

2) Information on the original investigation, case processing, and disposition, including suspect and victim demographics (collected primarily from DFS but supplemented by visits to three Virginia county courthouses—Alexandria, Arlington, and Fairfax); and

3) County-level sociodemographic and crime data from the 1970s and 1980s, collected from the County Statistics File I, as downloaded from the ICPSR web site.

Coding Schema

From March 2009 to August 2011, teams of four to six UI researchers conducted 10 two-day site visits to the VA DFS laboratory in Richmond to review eligible cases after post-conviction DNA testing had been completed. When test results were delivered to DFS but prior to UI's visits, DFS staff designated cases as "Red" or "Green" depending on the results of the DNA analysis:

- Red cases were those containing exculpatory DNA testing results, meaning that at least one convicted offender was eliminated as a contributor of DNA found on questioned evidence.

- Green cases were those containing either inculpatory DNA testing results, meaning a convicted offender could not be eliminated as a contributor of DNA found on questioned evidence, or indeterminate DNA testing results, for all convicted offenders. UI deemed the DNA testing results "indeterminate" for one of two reasons:

    - A DNA profile was developed but no conclusion could be drawn because there were no convicted offender or victim reference samples to compare to questioned evidence; or

    - No DNA profiles of value were developed from any questioned evidence.

Given the elevated value of Red-designated cases, UI researchers devised a coding scheme that involved recording post-conviction DNA testing results in Red cases at the sample level, meaning separate data entries were made describing each sample of forensic evidence submitted. DNA testing results in Green cases, alternatively, were coded at the case level, unless UI researchers determined that a Green case in fact had potentially exculpatory evidence (in which case it was coded at the sample level).

Ultimately, UI researchers established a more detailed method of identifying the four possible outcomes of post-conviction DNA testing (indeterminate, inculpatory, exculpatory but insufficient for exoneration, and exculpatory supportive of exoneration), as illustrated in Figure 2. Notably, UI's method was conducted at the convicted-offender level, while DFS's designations were conducted at the crime/case level.

Figure 2. Coding DNA Testing Outcomes at the Convicted Offender Level (n=715)

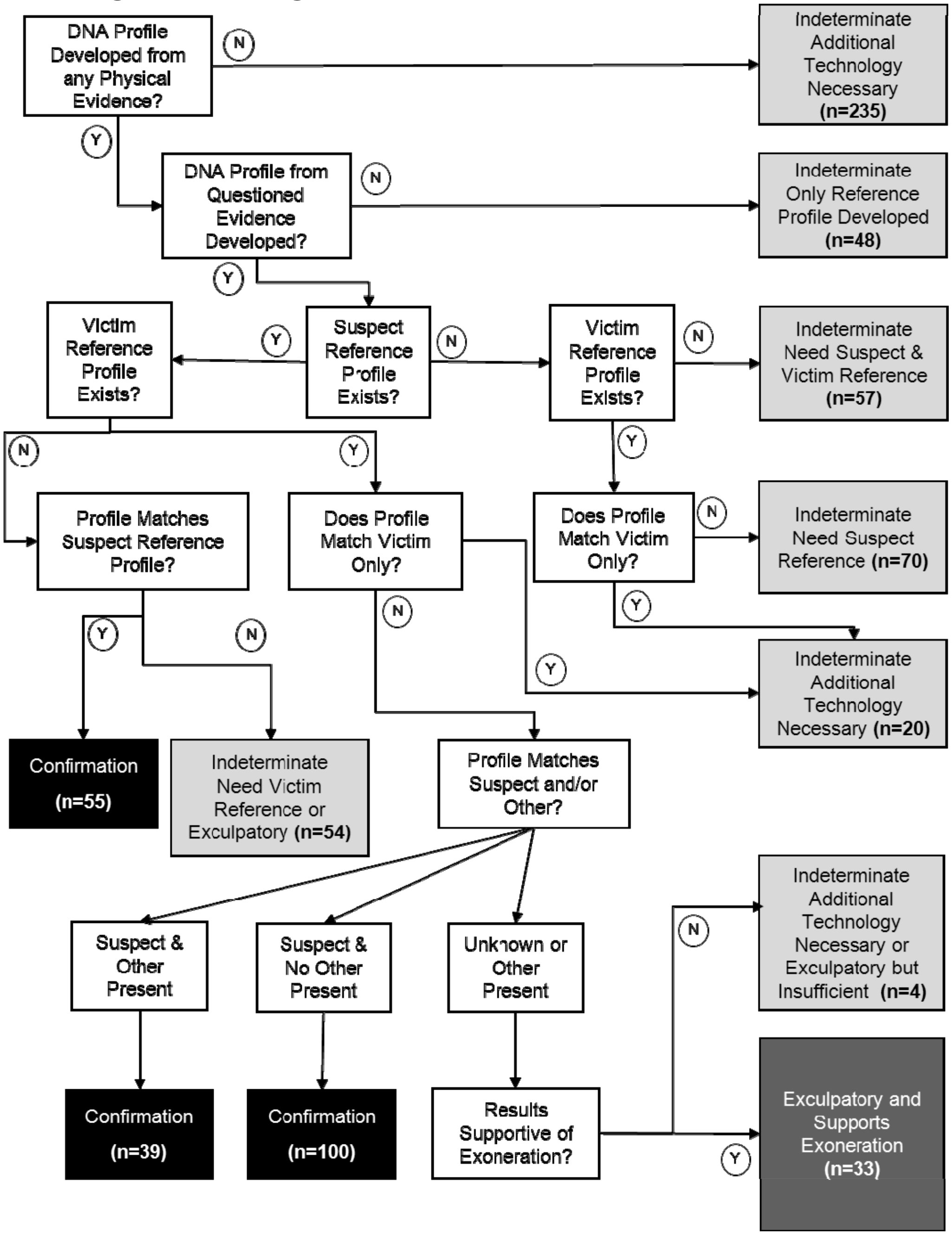


Table 3 compares the original DFS case designations of Red and Green with the four outcomes specified by UI researchers at the convicted offender level. In general, there was a high correlation between DFS and UI case coding. The only sources of disparities had to do with cases of multiple convicted offenders (e.g., a Red case contained testing results that were exculpatory for one person but inculpatory of another), and cases designated as Red by DFS but that lacked a victim reference sample needed to eliminate the convicted offender (in which case, UI designated the outcome as indeterminate).

Table 3. Comparison of UI and VA DFS Case Designations

	Percent of Outcome Type		
Outcome of post-conviction review (convicted offender-level)	Green Case	Red Case	Total
Indeterminate	96%	4%	100%
Inculpatory	94%	6%	100%
Exculpatory but insufficient	17%	83%	100%
Exculpatory supporting exoneration	0%	100%	100%
Total	88%	12%	100%

Quality Control

UI coding staff was trained on the proper use of the coding instruments and on the types of forensic analyses conducted at the time of the original investigation. The latter ensured that UI staff would correctly identify the forensic tests performed, both more common (e.g., ABO blood group typing) and less common (e.g., isoenzyme typing). Additionally, VA DFS forensic biology staff was available to answer any UI coder questions that arose concerning the original testing performed or the results of the post-conviction DNA analysis.

A number of steps were taken to ensure the quality of the data coding, since none of the forensic data were available electronically. After cases were coded, UI researchers conducted three types of quality control reviews: (1) a complete review of all cases that were coded during the first two site visits (after which the coding database was revised); (2) a complete review of cases that were randomly selected by DFS[20]; and (3) a partial review (during the final site visit) of cases that were missing data for key forensic variables. All quality control reviews were conducted on-site with all DFS case file information available and by someone other than the original coder. Additionally, whenever DFS initiated further DNA testing and/or DNA testing results changed, that case was recoded. During the data-cleaning process, automated quality checks were performed to identify any variables that were in conflict with one another. Finally, at the end of the project, DFS staff reviewed all cases that UI coded as supporting exoneration.

Court Data Collection

After DFS data collection was completed in August 2011, a review of the data confirmed that the complete data were generally limited to basic case information and data on forensic test results. Data on important nonforensic case characteristics (e.g., type of counsel, trial or plea, sentence) were not present in enough cases to allow statistical tests of association between those variables and sample outcome designation. UI researchers undertook a pilot review of case data available from public records held at Virginia courthouses. Unfortunately, court files from the 1970s and 1980s are not held in a centralized location; rather, each court file is held in one of 120 circuit courts in the jurisdiction where the case was originally prosecuted. There are no electronic records for these cases.

Prior to launching a planned statewide data collection, UI conducted a pilot study to determine the data available at three local circuit courts—the City of Alexandria, Arlington County, and Fairfax County. The three-court pilot study revealed that the court records included substantial case characteristics that were not widely available in the DFS case files. However, for contractual

[20] When preparing the files for UI researchers to code, DFS often included additional cases that had already been coded by UI. We took this as a "random" selection of cases to recode as a quality control.

reasons, UI's evaluation could not be extended to match delays in DNA analysis, and thus data collection was halted before the rest of the court visits could be completed. While some DFS case files yielded information on conviction offense, sentence length and type, and method of conviction (i.e., pled guilty vs. convicted by jury trial), the majority of the legal variables' level of missingness was too high for any of these variables to be used in our final quantitative analyses.

County Data Collection

To supplement the data collected from the DFS files and three-court pilot, we downloaded the County Statistics File for Virginia from ICPSR. The file includes data for Virginia counties (and independent cities) published in the 1983 *County and City Data Book* and the 1982 *State and Metropolitan Area Data Book*, as well as additional previously unpublished statistics (USDOC Exports 1984). The purpose of collecting these data was to identify any jurisdiction-specific variables that could potentially affect the case investigation and final disposition. The dates for each county variable ranged from 1977 to 1981, which is close to our average year of the offense date for all cases included in the data set (1978).

Data Limitations

There are three important limitations to this data set, as there would be in any quantitative collections of this sort: generalizability, omitted variables, and missingness. We discuss these limitations and our attempts to address them below.

Generalizability

The generalizability of this data set is limited by the age of the convictions (1973 to 1987) and the randomness of the sample. Although we have controlled for the age of each case in the final statistical models, this accounts for differences within the date range but does not make the data set comparable to the present year. To explain the ramifications of this limitation, we previously presented a comparison of Virginia to other U.S. states in the 1970s/80s and to present-day Virginia. We note that although much has changed in the past few decades and Virginia's violent crime rates are currently half of what they were then, the relative rate of serious person crimes in Virginia compared to the national average has remained largely the same. That fact alone, however, does not allow us to generalize results from this analysis to current convictions, especially given the increased use and awareness by offenders and police of the investigatory value of DNA evidence.

With regard to the randomness of this sample as compared to other serious person convictions involving physical evidence at the time, interviews with DFS supervisors gave every indication that criminal cases at the time were assigned at random to DFS forensic serologists. No single examiner was routinely assigned cases based on the cases' attributes (e.g., the difficulty or timeliness of the case). As a result, there is no reason to believe that the assignment of cases to examiners introduced any bias, and therefore we view this sample of Burton's cases as equivalent to other serious person crimes with biological evidence in the 1970s/80s that were assigned to other examiners. However, as discussed at length later in the report, the sexual assaults in this sample may over represent stranger offenses (i.e., the victim did not know the suspect prior to the sexual assault).

Omitted Variables

UI researchers visited three of the approximately 94 VA courthouses present in the data set. The most critical pieces of information housed at VA courthouses, which are omitted from this data set because of their missingness in 75 to 100 percent of the convictions, are as follows: method of conviction (jury/bench trial or guilty plea), type of defense attorney (court-appointed or retained), whether the offender confessed or gave incriminating statements, victim and eyewitness identification, offender's prior record and mental health problems, detailed description of the criminal event, and notice of appeals and results from those appeals. We expect that at least some of these variables have statistical relevance to the models predicting exculpatory evidence. Their absence has two possible effects: first, it decreases our ability to explain why potential wrongful convictions occur, and second, it leaves us uncertain as to whether the explanatory power of other variables that we were able to test was artificially deflated (or inflated) due to correlations with omitted but relevant variables. Beyond conducting additional visits to VA courthouses to collect these missing data, we can do nothing statistically to control for omitted variable bias—as is the case in most quantitative analyses.

Missingness

For the DFS data, we approached data missingness challenges from a different perspective. Because we were relying on 30- to 40-year old case files that were preserved primarily by a single forensic serologist, we acknowledge that we might not have been able to obtain all information on forensic testing performed during the original investigation case. However, given the repeated mention of several different types of forensic tests in the case files, it seemed likely that the absence of a test's mention meant that it was not performed in that case, rather than simply not discussed in the case files. Therefore, for example, when there was no mention of microscopic hair analysis in a case file, we coded that case as 0="no hair analysis done" rather than "missing" (unknown if hair analysis was done). We repeated this same logic, with the same degree of confidence, with regard to certain case characteristics included in the DFS case files. Specifically, if the detailed crime descriptions made absolutely no reference to a sexual assault (and the types of forensic tests performed on such cases supported this classification), then we coded a case as though no sexual assault had occurred. Similarly, if the crime description was detailed enough to discuss the offender, victim, and offense but did not mention any presence of a relationship between the offender and victim, then the offender was assumed to be a "stranger" (unknown to the victim prior to the day of the crime).

With regard to these and other variables, there remained as much as 27 percent missing values for cases included in statistical analyses. There is, to our knowledge, no reasonable basis for classifying these data as anything but "missing completely at random"; therefore, we used a complete case analysis (listwise deletion) approach to estimation of final predictive models. When missingness is completely random, removal of cases that have missing values from final models will still lead to unbiased estimators (Allison 2001).[21]

[21] In evaluating this approach, we compared case information for suspects whose crimes were included in the final models with those whose crimes dropped out due to missingness on at least one variable, and found no significant differences in offense type, age of the case, number of suspects reported to the forensic lab, number of victims, whether the offense involved a firearm, number of different types of preconviction forensic tests performed, and number of preconviction forensic tests that included the convicted offender.

Measures

In this section, we describe the measures created from data collected for this project, which are divided into five categories: post-conviction DNA testing variables, preconviction forensic testing variables, case characteristics, suspect and victim demographics, and characteristics of the Virginia counties in which the convictions occurred.

Post-Conviction DNA Testing Variables

These variables document the results of the post-conviction DNA testing and were derived by UI researchers from the certificates of analysis that DFS completed after reviewing testing results from the private laboratory. The variables included herein are as follows:

- *Red case (versus Green):* As described in the Data section, DFS designated Red cases as those for which DNA testing results included exculpatory evidence in favor of at least one convicted offenders . UI researchers coded each conviction stemming from these cases as either 1=Red or 0=Green for this measure.
- *DNA testing yielded a DNA profile*: This measure was coded as 1=yes if post-conviction DNA testing resulted in at least one DNA profile, which was a necessary but not sufficient condition for making conclusions about a convicted offender's probable involvement in an offense. All determinate results depended on development of a DNA profile, but many indeterminate results also had a profile developed. If no profile of value was developed, this measure was coded as 0=no.
- *Textile item developed DNA profile*: This measure was one of five general categories designated by UI to capture most of the types of physical evidence that were analyzed. This specific variable indicates whether a DNA profile was developed from a textile item, which included the suspect or victim's clothing (excluding panties, which were coded separately below), bedspreads, furniture fabric, and stains from different textile materials.
- *Vaginal swab developed DNA profile*: This measure indicates that a DNA profile was developed from vaginal and/or thigh/vulva swabs, which were typically collected as part of the victim physical evidence recovery kit (PERK), but which were sometimes collected from victims separately from a full PERK.
- *Anal swab developed DNA profile*: This measure includes DNA profiles developed from anal swabs that were collected from either the victim or suspect, including those obtained from a PERK.
- *Oral swab developed DNA profile*: This measure includes oral swabs collected from either the victim or suspect, including those obtained from a PERK.
- *Panties developed DNA profile*: This item is coded separately from textiles above and specifically refers to DNA profiles developed from panties or underwear collected from the crime scene, including those obtained from a victim PERK, as well as those items collected from the victim or suspect at a later date.
- *Reference sample developed DNA profile*: Reference samples were collected from the victim and/or suspect separately from a PERK and were used to develop a reference profile (an "alternate known" profile) for either the victim or the suspect.

Preconviction Forensic Testing Variables

These variables were designed to capture any information about the forensic tests that were conducted to aid the original investigation and whether results of these tests implicated the convicted offender in his/her original case. The variables were split into two categories: items collected (the amount and types of forensic evidence collected at the crime scene[22] and from the suspects/victims for comparison purposes[23]) and forensic tests conducted. To summarize this information for final analyses, UI created the following variables:

- *Number of different types of forensic tests done*: This measure produces a count of the number of different types of forensic tests that were done (not the total number of tests that were done—e.g., if multiple microscopic hair comparisons were done, this would only count as one type of forensic test); values can range from 0 to 6, based on the test types described below.
- *Number of different types of forensic tests done that included convicted offender*: This measure produces a count of the number of different types of forensic tests that created a link to the suspect. For example, if a suspect's fingerprints matched[24] those found at the scene, and his ABO blood type was included in that found at the scene, this variable would equate to two different types of matching tests.
- *Percent of different types of forensic tests done that included convicted offender*: This measure is derived from the previous two variables and is calculated as the number of forensic test types that included the suspect divided by the number of tests done.
- *Strength of forensic tests that included a convicted offender*: This measure was created to rank the strength of suspect inclusion based on forensic testing. If no tests included the convicted offender, this measure was coded as 0. Otherwise, the measure represents the average score across values assigned as follows, from strongest to weakest type of inclusionary forensic evidence: fingerprint comparison (=3), microscopic hair comparison (=3), ballistics analysis (=3), ABO blood group typing (=1), enzyme typing (=1), and racial origin of hair analysis (=1). The average score could have mathematically ranged from 0 to 3 but in the data ranged from 0 to 1.75.
- *Fingerprint comparison done in case*: This variable measures whether fingerprints collected at the scene were compared to latent prints obtained from a suspect or victim.
- *Fingerprint comparison included convicted offender*: If a fingerprint comparison matched latent prints from a convicted offender, this variable is coded as 1=yes; otherwise 0=no.
- *Microscopic hair comparison done in case*: This variable measures whether a microscopic hair comparison, a more sophisticated test than the racial origin of hair, was done in the case.
- *Microscopic hair comparison included convicted offender*: If a microscopic hair comparison was done and included the convicted person's hair, this variable is coded as 1=yes; otherwise 0=no.
- *Ballistics analysis done in case*: This measures whether firearms or bullets were analyzed and/or compared to a weapon obtained from the person convicted.[25]

---

[22] This includes all questioned evidence, including intimate swabs from sexual assault forensic exams.
[23] This includes all known evidence (i.e., reference samples), collected to be compared with collected questioned evidence.
[24] The term "match" as it is used in this report indicates any result where the convicted offender cannot be eliminated as the source of physical evidence.
[25] This does not include reconstruction through trajectory analysis or distance determination analysis.

- *Ballistics analysis included convicted offender*: If a ballistics analysis on firearms or bullets from the crime scene was conducted and linked to a weapon belonging to the convicted offender, this variable is coded as 1=yes; and otherwise 0=no.
- *ABO blood group typing done in case*: This variable measures whether ABO blood group typing was conducted to determine the blood type of biological material left at the scene.
- *ABO blood group typing included convicted offender*: If ABO blood group typing was conducted on questioned evidence from the crime scene and the blood type included that of the person convicted, this variable is coded as 1=yes; and otherwise 0=no.
- *Enzyme typing done in case*: This variable measures whether testing was done to determine the type of blood enzymes left at the crime scene This includes all non-ABO typing systems including other antigen markers, protein markers (Hb, Hp), and actual enzyme markers (such as PGM, ESD, EAP). In the pre-DNA era, the more types used to link questioned and known items, the higher the likelihood that they came from the same source.
- *Enzyme typing included convicted offender*: Coded as 1=yes if enzyme typing was done and included the convicted offender's blood enzyme type; 0=no otherwise.
- *Racial origin of hair analysis done in case*: This variable indicates whether hair collected at the crime scene or from the victim/suspect was analyzed (subjectively) to place it into one of three anthropomorphic racial categories.
- *Racial origin of hair included convicted offenders*: This variable indicates whether racial origin of hair analysis, as described above, implicated the person convicted (1=yes; 0=no).

Case Characteristics

Information about characteristics of the convicted offender's criminal case and conviction was recorded in the following measures, which were coded as 1=yes or 0=no, unless otherwise stated:

- *Murder is most serious offense*
- *Sexual assault is most serious offense*
- *Firearm was involved in the crime*: This was assumed to be "no" unless firearms or ballistics evidence was specifically mentioned in the crime description or lab report.
- *Length of case in months*: This measured the time from offense to conviction. If offense date was missing, then the date of forensic evidence submission was used, and if conviction date was missing, then sentencing date was used.
- *Age of case in years (time from offense to Jan. 1, 2012)*
- *Location of offense: Victim's home/apartment*
- *Location of offense: Indoors (inside a home, apartment, or building)*
- *Location of offense: Vehicle (either the convicted offender's or victim's)*
- *Location of offense: Private location (no public access)*: This particularly included the victim's home or vehicle, or the *convicted offender's* home or vehicle.
- *Person convicted was stranger (not known prior to day of crime)*
- *Person convicted was relative or (ex)intimate partner of victim(s)*
- *Number of suspects ever reported to forensic lab (regardless of conviction)*: This measured the number of suspects reported by police to DFS in the 1970s/80s at the time of original evidence submissions.
- *Number of suspects convicted for this crime*

- *Percent of known suspects who were not convicted for this crime*
- *Number of victims*

Convicted Offender/Victim Demographics

Basic demographic information about the convicted offender and victim (e.g., age, gender, race) was also recorded in the DFS files. We used this information to create a large number of variables, many of them interactions of convicted offender/victim demographics, which we tested as potential predictors of exculpatory DNA testing results (they were also tested in models predicting determinate testing results).

- *Convicted offender age*
- *Convicted offender under 18*
- *Convicted offender gender is male*
- *Convicted offender race is black/African-American*
- *Convicted offender race is white/Caucasian*
- *Average victim age*
- *Oldest victim age*
- *Youngest victim age*
- *Any victim under 18*
- *Any victim 65 or older*
- *Any female victim(s)*
- *All female victim(s)*
- *All female and/or juvenile (<18) victim(s)*
- *All juvenile (<18) victim(s)*
- *All female and/or juvenile (<18) and/or elderly (65+) victim(s)*
- *Male convicted offender, all female victim(s)*
- *Male convicted offender, all female and/or juvenile (<18) victim(s)*
- *Male convicted offender, all female and/or juvenile (<18) and/or elderly (65+) victim(s)*
- *Convicted offender is black/African-American male stranger to victim(s)*
- *All victims are black/African-American*
- *Any victim is black/African-American*
- *All victims are white/Caucasian*
- *Any victim is white/Caucasian*
- *Any victim is white/Caucasian female*
- *Black male convicted offender, any white female victim*
- *Black convicted offender, any white victim*
- *Convicted offender and at least one victim are different races*

Conviction County Characteristics (Virginia)

Characteristics of the county (or independent city) in which convictions took place were recorded based on 1970s/80s information derived from the VA County Statistics File. Notably, the data set includes convictions from 94 (69 percent) of the 137 counties and independent cities in VA during that time. The county variables can be grouped into the following four categories:

1. *Crime-related variables*, which include the number of offenses, violent crimes, murders, sexual assaults, aggravated assaults, burglaries, property crimes, motor vehicle thefts, and larceny thefts known to police per 1,000 persons; and the number of police officers per 1,000 persons.
2. *Socioeconomic variables*, which include the percentage of persons 25 and older with no high school diploma; percentage of persons 18 and older who did not vote in presidential election; percentage of female-headed households with children; percentage of renter-occupied housing units; percentage of vacant housing units; percent unemployed persons; median household income; per capita personal income; percentage living below poverty level; percentage black/African-American living below poverty level; and percentage receiving Aid to Families with Dependent Children.
3. *Demographic variables*, which include the number of persons per square mile; percentage African American/black; percentage Hispanic/Spanish-origin; percentage unmarried males 15 and older; percentage youth; percentage persons living in different house five years ago; and percentage rural population.
4. *Local government variables*, which include local government revenue per 1,000 persons; local government expenditure on police protection per 1,000 persons; and percentage of local government revenue spent on police protection.

Additionally, the following variables were used to develop an economic deprivation scale (standardized, alpha=.796): lack of high school diploma, unemployed adults, percentage living below the federal poverty level, and percentage on public assistance.

Methodology

Our methodology sought to address the two primary objectives of this evaluation. First, using the data collected from the DFS forensic files, we determined whether the results of Virginia's DNA testing would support exoneration of a convicted defender, inculpate the defendant, or be insufficient to change the outcome of the case (acknowledging that the nonforensic facts of the case might affect final classification). Second, we used the same data to identify associations between case characteristics and the likelihood that DNA testing would produce determinate results and support exoneration of a convicted defendant. This section discusses the analytic plan that we used to address both objectives.

The analytic plan was developed iteratively. First, we calculated univariate analyses and reported descriptive statistics. These statistics include means and proportions (percentages) of the entire sample and means and proportions of each of the four groups (the one indeterminate group and the three determinate groups: inculpatory, exculpatory but insufficient for exoneration, and exculpatory and supporting exoneration). We also evaluated the significance of differences across all five groups based on the F-statistic. Next, we estimated a series of logistic regressions to compare each group to the convictions with indeterminate results and to the convictions with inculpatory results, across all means and proportions, tested one at a time.

From these regressions we selected candidate variables for the final predictive models: a multivariable logit predicting determinate DNA testing results, and a multivariable logit predicting exculpatory evidence, given determinate results. Our selection of candidate variables included significant predictors of each outcome as well as variables that were theoretically related to outcomes. Next, we estimated a correlation matrix calculating covariance among the candidate independent variables.[26] When candidate independent variables were highly correlated (r>0.5), we selected the variable with the strongest theoretical relationship to the dependent variable, or the independent variable most highly correlated with the dependent variable and deleted the collinear variable(s). We then estimated each final model in a series of steps, progressively adding independent variables in blocks: first, preconviction forensic testing variables, then case characteristics, convicted offender/victim demographics, and county characteristics. Candidate variables that remained significant in at least one multivariate model or were included as theoretically relevant controls were kept in the final model.

Dropping Nonsexual Assault Homicide Convictions

Once the preliminary analyses comparing convictions with determinate results to those with indeterminate results were complete, it became apparent that few nonsexual assaults (only 8 percent) had determinate outcomes. Thus, we chose not to model correlates of determinate outcomes for nonsexual assault homicides. Unless otherwise noted, the analysis that follows considers only convictions for homicide with a sexual assault and sexual assault only.

Table 4. Outcome of DNA Testing Results by Sexual Assault Status

Outcome		Sexual Assault? No	Sexual Assault? Yes	Total
Indeterminate	Count	270	195	465
	% of Total	(38%)	(27%)	(65%)
Inculpatory	Count	7	187	194
	% of Total	(1%)	(26%)	(27%)
Exculpatory but insufficient	Count	11	7	18
	% of Total	(2%)	(1%)	(3%)
Exculpatory supporting exoneration	Count	5	33	38
	% of Total	(1%)	(5%)	(5%)
Total	Count	293[27]	422[28]	715
	% of Total	(41%)	(59%)	(100%)

Logistic Regressions

Next, we specified three sets of multivariable logistic regressions each of which was designed to identify covariation between case attributes and DNA testing outcomes in homicides with a sexual assault and in sexual assaults:

- The first set of regressions estimates the association between case characteristics (including preconviction forensic testing, convicted offender/victim demographics, and county attributes) and whether the DNA testing yielded a determinate outcome.

[26] Pearson's correlation coefficients are not reported here, but are available from the authors upon request.
[27] Nonsexual assault homicides.
[28] Includes 47 homicides where a sexual assault occurred and 375 nonhomicide sexual assaults.

- The second set of regressions, run on convictions with determinate outcomes only, estimates the association between the same such attributes and whether the evidence was potentially exculpatory,[29] as opposed to inculpatory.

- The third set of regressions, run on convictions with determinate outcomes only, estimates the association between the same attributes and whether the evidence was exculpatory and supported exoneration, as opposed to inculpatory.

Each of the regressions takes the general form of:

$$\text{Log}\,(Y/1\text{-}Y) = \alpha + \beta_{\text{FORENSIC}}X + \beta_{\text{CASE}}X + \beta_{\text{DEMO}}X + \beta_{\text{COUNTY}}X + \varepsilon \qquad (1)$$

where the log of the odds of each of the three dependent variables is regressed (iteratively) on four blocks of independent variables (preconviction forensic testing variables, case characteristics, convicted offender and victim demographics, and attributes of the county at the time of the offense). The final tables report the results of all four and note which model fits the data the best.

Multinomial/Sequential Logistic Regression/Propensity Score Analysis

We considered several alternative model specifications but ultimately chose the more straightforward models described above. One alternative approach would be to consider each of the four outcomes simultaneously using a multinomial regression, which is appropriate for categorical dependent variables. However, the four categories described here are not different levels of the same variable but rather different concepts. Since inculpatory testing results have a single value but exculpatory testing results have three possible values (where two are subsets of the third), it is more conceptually appropriate to consider separately whether the evidence was determinate and whether it was exculpatory.

Having made that decision, we considered whether to specify a sequential logistic regression that would predict associations between both stages of case processing. That approach appears appropriate when simply modeling whether evidence was determinate and whether it was exculpatory. However, while inculpatory and exculpatory test results are conceptually similar, the more interesting analysis, comparing probable exonerations to convictions with inculpatory outcomes, is quite different. Thus, rather than specifying different models for each of the dependent variables, we chose to use one consistent approach for ease of interpretation.

We note that the first of the three models described above tests for predictors of a determinate versus indeterminate outcome. These results could be used to generate a prediction of the likelihood of obtaining a determinate result, which could then be used to reweight the sample to resemble all convictions. This propensity score weighting approach requires that the first stage model contain predictors that are associated with a determinate/indeterminate finding, but are not related to the ultimate DNA testing outcome. However, we were unable to identify any variables that could achieve that objective. Given that the propensity score weight would be used effectively to generate a prediction about missing DNA testing *outcomes*, this propensity score model would have to be extraordinarily convincing. While such a model might have been plausibly specified if all data from the courthouses had been collected, in the absence of those data a convincing model

[29] This includes all exculpatory results: exculpatory but insufficient and exculpatory but supports exoneration.

could not be specified. That said, in the final model predicting exculpatory findings we include the independent variables from the model predicting determinate outcomes as statistical controls.

Clustering

In our sample, because there are 715 convicted suspects in 634 criminal cases in 94 counties, we were concerned about the potential effects of clustering on our results. That is, because the county is an important unit of analysis with respect to law enforcement policymaking and because county courthouses were the venue for case disposition, we could potentially misinterpret differences in outcome as being due to case attributes when the real causal mechanism is between-county differences. However, in our sample we have cases from 28 counties in which there was only a single criminal conviction. Given the distribution of the data, multilevel models would fail to converge, and models that account for clustered standard errors require at least two observations per cluster. As an exploratory approach, we deleted those 28 observations and repeated a select number of logistic regressions specifying clustered standard errors; however, we observed no consistently substantive change in outcomes and thus report only the logistic regressions that did not control for clustering.

Results

This section describes the prevalence and correlates of inculpatory and exculpatory DNA evidence in 634 criminal cases from Virginia between 1973 and 1987 that resulted in 715 convictions for which the most serious crime was murder (48 percent) or sexual assault (52 percent).

First, we describe how many convictions had retained physical evidence that yielded determinate DNA testing results (i.e., post-conviction testing yielded enough information to draw a conclusion about whether the convicted offender was the source of DNA developed from old evidence) and how many yielded indeterminate results.[30] This analysis is conducted for all 715 convictions.

Then, we separate convictions into those for sexual assaults and nonsexual assaults (where there were few determinate outcomes), and focus on the subset of 422 sexual assault convictions. Of these sexual assault convictions, 11 percent had murder as the most serious charge and 89 percent had sexual assault as the most serious charge. We compare convictions for sexual assault and indeterminate DNA testing outcomes to those for which testing yielded a determinate outcome (either inculpatory or exculpatory evidence) and use results from those comparisons to iteratively estimate a final predictive model of determinate DNA testing results in sexual assault convictions. We then use these final predictors as statistical controls in the subsequent stage. In this subsequent stage, we first conduct bivariate comparisons of convictions for sexual assault and exculpatory DNA evidence to those whose DNA evidence implicates the convicted suspect (inculpatory outcomes). Next, we use information from these comparisons to iteratively estimate a final predictive model of exculpatory DNA testing results in sexual assault convictions, while controlling for factors related to determinacy of such results. We then repeat that analysis comparing only convictions with exculpatory outcomes that are supportive of exoneration to those that are inculpatory and drop those exculpatory outcomes that do not support exoneration. Throughout this section, we examine

[30] The determinacy of DNA testing results relates to specific convicted persons rather than to criminal cases.

as possible predictors a number of crime, offender, victim, and county characteristics, as well as the forensic testing performed by DFS prior to the original conviction.

What proportion of convictions had determinate DNA testing results?

Thirty-five percent (n=250) of the 715 convictions for which physical evidence was examined yielded determinate DNA testing results, as shown in Table 5.[31]

Table 5. Outcome of All DNA Testing Results

Outcome	Indeterminate	Inculpatory	Exculpatory but insufficient	Exculpatory supporting exoneration	Total[32]
No results; additional technology needed	235 (33%)	-	-	-	235 (33%)
Need convicted offender reference sample	70 (10%)	-	-	-	70 (10%)
Need victim reference sample	35 (5%)	-	14 (2%)	5 (1%)	54 (8%)
No results of value; DNA profile matches victim only	20 (3%)	-	-	-	20 (3%)
Unknown DNA profile OR other DNA profile present	-	-	4 (1%)	-	4 (1%)
Need convicted offender and victim reference samples	57 (8%)	-	-	-	57 (8%)
DNA profile matches convicted offender reference sample; victim reference sample not present	-	55 (8%)	-	-	55 (8%)
Convicted offender's DNA profile and other DNA profile present	-	39 (6%)	-	-	39 (6%)
Convicted offender's DNA profile and NO other DNA profile present	-	100 (14%)	-	-	100 (14%)
Unknown DNA profile OR other DNA profile present; convicted offender eliminated	-	-	-	33 (5%)	33 (5%)
No results of value; only DNA profile developed from reference sample	48 (7%)	-	-	-	48 (7%)
Total	465 (65%)	194 (27%)	18 (3%)	38 (5%)	715 (100%)

Most determinate results are inculpatory (194 of 250 convictions with determinate results, or 78 percent) and are determined to be inculpatory because the profile developed from questioned evidence included—

[31] The outcomes shown in Table 5 repeat the outcomes described in figure 2.

[32] Percentages may not sum exactly due to rounding error.

- the convicted offender alone (100 out of 250 convictions with determinate results; 40 percent of all convictions with determinate results) when a victim reference was available;
- the convicted offender alone (22 percent of convictions with determinate results) when a victim reference was not available; or
- the convicted offender and another unknown source (16 percent of convictions with determinate results).

In the remaining 22 percent of convictions with determinate results, the convicted offender was eliminated as the source of the DNA. However, this alone *is not* equivalent to a wrongful conviction or exoneration, as is discussed further below. In 38 convictions (15 percent of convictions with determinate results), all of the available evidence supports exoneration.[33] Those include—

- Thirty-three convictions (13 percent of convictions with determinate results) where the convicted offender was eliminated because an unknown DNA profile was generated that did not match the convicted offender's reference standard, and/or there was a match to a known person who was not the convicted offender or the victim;[34]

- Five convictions (2 percent of convictions with determinate results) where the convicted offender was eliminated because a DNA profile was generated in a sexual assault with a male contributor (but no victim standard) who was not the convicted offender.

However, in an additional 18 convictions (7 percent of convictions with determinate results), the evidence was not sufficient to support exoneration without additional probative evidence. Those convictions include—

- Four convictions (2 percent of convictions with determinate results) where the convicted offender was eliminated because an unknown DNA profile was generated that did not match the convicted offender's reference standard, or there was a match to a known person who was not the convicted offender or the victim. However, in these convictions that elimination was not probative, and thus there is insufficient evidence from that finding alone to support exoneration. This includes convictions where, for example, the questioned evidence identified a known person who had provided an elimination sample and was known to have legitimate reason to be at the crime scene. Thus, the convicted offender's elimination in these cases was not sufficient to support exoneration.

- Fourteen convictions (6 percent of convictions with determinate results) where the convicted offender was eliminated as the source of a DNA profile. For example, a convicted offender was eliminated as the source of a DNA profile, but the gender of the actual source could not be determined. Thus, without a victim standard, it cannot be determined whether the elimination was probative, and thus there is insufficient evidence from the elimination alone to support exoneration.

---

[33] All of the information available to the research team supported exoneration. There may be other evidence that the research team did not have access to that does not support exoneration.

[34] The DNA match to a known offender is not necessarily a match to the "real" perpetrator, as it may be a match to elimination samples taken from a family member or someone else with a legitimate reason to be present at the crime scene, even if this association was made through a database hit.

With regard to the convictions with indeterminate DNA testing results (n=465), reasons for this indeterminacy were varied. DNA testing produced no results for 235 convictions. In other convictions, a profile was developed but a) there was no convicted offender reference sample[35] to which to compare the questioned (crime scene) evidence (n=70); b) there was no victim reference sample (n=35)[36]; or c) both a convicted offender and victim reference sample were missing (n=57). In some cases, the questioned evidence matched to only the victim (n=20). In 10 percent of convictions with indeterminate results (7 percent of all convictions), a reference sample existed, but no questioned evidence developed a profile that could be compared to a reference sample.

What factors distinguish convictions with determinate and indeterminate DNA testing results?

As noted in the Methodology section, the primary factor distinguishing convictions with determinate and indeterminate DNA testing results was whether or not a sexual assault had occurred. Very few nonsexual assault convictions (only 8 percent) had determinate DNA testing outcomes. On the other hand, 54 percent of sexual assault convictions resulted in a determinate outcome after post-conviction DNA testing was performed. **Therefore, unless otherwise noted, the analysis that follows considers only convictions that involved a sexual assault, including homicides with a sexual assault and rape cases.**

In the next sections, we identify factors that distinguished determinate sexual assault convictions from indeterminate sexual assault convictions, on a bivariate basis, with regard to the following types of variables:

- post-conviction DNA testing (Table 6),
- preconviction forensic testing (Table 7),
- case characteristics (Table 8),
- convicted offender/victim demographics (Table 9), and
- conviction county characteristics (Table 10).

Table 6 shows that for all sexual assault convictions, 54 percent resulted in a determinate outcome after post-conviction DNA testing was performed. In all of these cases, lab analysts developed DNA profiles from at least one piece of questioned evidence and were able to make meaningful comparisons to determine if the person originally convicted could be eliminated (or not) as the DNA contributor. Of the 195 (46 percent) indeterminate sexual assault convictions, 73 percent also had at least one profile developed from old evidence yet lacked sufficiently relevant profiles for determinate comparisons. Thus, even when physical evidence is preserved and DNA testing on it produces a profile, it is not always sufficient to draw conclusions from those profiles that aid investigations, either pre or post-conviction. For example, a convicted offender or victim reference sample may still be needed to compare DNA found on crime scene evidence, or only

---

[35] The convicted offender reference sample could come from the original case file or be obtained for purposes of post-conviction DNA testing—for samples that were obtained, the convicted person either voluntarily submitted a sample or the sample was obtained from the Virginia DNA databank.

[36] In 55 cases there was no reference sample. In 20 of the cases, the case was a sexual assault where the victim's gender was known and thus she could be excluded as a possible contributor of a male DNA profile. In 35 cases the case was not a sexual assault, or the victim and offender were of the same gender or the gender of the profile was unknown and thus the results are indeterminate.

reference profiles are developed.

Table 6. Bivariate Comparison of Determinate and Indeterminate Sexual Assault Convictions: Post-Conviction DNA Testing

	Proportion / Mean				
	Indeterminate (n=195) 46%	Determinate (n=227) 54%	Total (n=422) 100%	% missing	Significance of Difference
Post-Conviction DNA Testing Variables					
DNA testing yielded a DNA profile	73%	100%	87%	0%	N/A
Textile item developed DNA profile	22%	48%	36%	0%	.000
Vaginal swab developed DNA profile	29%	41%	36%	0%	.012
Anal swab developed DNA profile	3%	6%	5%	0%	.144
Oral swab developed DNA profile	10%	33%	23%	0%	.000
Panties item developed DNA profile	18%	45%	33%	0%	.000
Reference sample (from old case file) developed DNA profile	4%	12%	9%	0%	.017

By definition, determinate results were obtained when at least one profile from questioned evidence could be compared to convicted offender and victim reference profiles.[37] Of the item types listed in Table 6, reference profiles could have been obtained from known reference samples or from any female profile developed from an intimate swab (oral, vaginal, anal). Reference profiles from the latter category were usually referred to as "alternate known reference profiles" because while they did not come from a designated reference swab, it is very likely that the victim was the true source of that profile. With the exception of anal swabs, profiles developed from all of these sources are associated with determinate outcomes. Intimate swabs, as well as any nonreference sample source (textile and panties), may have also develop profiles foreign to the victim and comparable to convicted offender or other reference profiles. Thus, it is not surprising that sources of both reference and questioned profiles are associated with determinate results.

We can observe the relative usefulness of profiles from these evidence types by comparing the differences between the averages in each outcome. The yield of each evidence type—that is, the rate at which evidence items produce profiles and the rate that those profiles are used to make meaningful comparisons, is not quantified in this data set but is reflected in the differences of the averages in Table 6. Profiles from textiles, panties, and vaginal swabs were the most valuable, followed closely by profiles from oral swabs. Actual reference items from the old evidence were moderately useful in making determinate conclusions. Profiles from anal swabs were the least valuable in making any determination and the only profile source that was not associated with determinate outcomes.

[37] A victim reference profile is not necessary if the gender of the questioned profile contributor is known and it is different from the victim's gender. A female victim can be eliminated as the source of a questioned profile from a male contributor.

As shown in Table 7, there were a number of bivariate differences between sexual assault convictions with determinate and indeterminate DNA testing results, with regard to attributes of the original forensic testing performed. For convictions with determinate results, more types of forensic tests had been performed prior to conviction, more types of these tests had established a connection with the person convicted (i.e., the convicted offender could not be eliminated as the source of evidence), and these connections were relatively stronger for convictions with determinate results than for convictions with indeterminate results (based on a scaling of forensic testing that ranked, for example, microscopic hair analysis as strong and racial origin of hair analysis as weak). Of the variables that described specific forensic tests, determinate DNA testing outcomes were more likely in sexual assault convictions where the convicted offender was not eliminated as the source of biological evidence through ABO typing or through racial hair characterization.[38]

Table 7. Bivariate Comparison of Determinate and Indeterminate Sexual Assault Cases: Preconviction Forensic Testing

	Proportion / Mean				
	Indeterminate (n=195)	Determinate (n=227)	Total (n=422)	% missing	Significance of Difference
Preconviction Forensic Testing Variables					
Number of different types of forensic tests done	1.69	1.83	1.76	0%	.072
Number of different types of forensic tests done that included the convicted offender	.72	.93	.83	0%	.007
Percentage of different types of forensic tests that included the convicted offender	41%	50%	46%	0%	.028
Strength of forensic tests that included the convicted offender (0=none, 1=weak, 3=strong)	.20	.24	.22	0%	.064
Fingerprint comparison done in case	12%	10%	11%	0%	.585
Fingerprint comparison included the convicted offender	1%	1%	1%	0%	.657
Microscopic hair comparison done in case	3%	2%	2%	0%	.808
Microscopic hair comparison included convicted offender	1%	0.4%	0.5%	0%	.914
Ballistics analysis done in case	7%	6%	6%	0%	.835
Ballistics analysis included convicted offender	3%	0.4%	1%	0%	.105
ABO blood group typing done in case	97%	97%	97%	0%	.789
ABO blood group typing included convicted offender	37%	49%	44%	0%	.011
Enzyme typing done in case	12%	15%	14%	0%	.359
Enzyme typing included convicted offender	5%	5%	5%	0%	.912
Racial origin of hair analysis done in case	38%	52%	46%	0%	.007
Racial origin of hair included convicted offender	27%	37%	32%	0%	.030
Racial origin of hair was only forensic test that included convicted offender	15%	16%	16%	0%	.687

[38] Racial origin of hair uses the gross characteristics of hair to place it in one of three anthropomorphic categories. This determination is not absolute and is a much less specific hair comparison than that performed by the comparison of microscopic characteristics (DeForest, Gaensslen, and Lee 1983).

In Table 8, we find several statistically significant case characteristics that were associated with whether post-conviction DNA testing results were determinate (or not). Crimes that were somewhat more recently committed (32 instead of 34 years ago), that were committed inside the victim's residence, and that involved conviction of a suspect who was a stranger to the victim were all associated with a higher likelihood of determinate DNA testing findings. Several other case attributes were not statistically significant, but were highly correlated with a determinate finding, including a crime committed in a private location, and with more victims. Notably, having an additional known suspect who was identified but not convicted was neither statistically nor substantively associated with the likelihood of determinate DNA testing outcomes.

Table 8. Bivariate Comparison of Determinate and Indeterminate Sexual Assault Convictions: Case Characteristics

	Proportion / Mean				
	Indeterminate (n=195)	Determinate (n=227)	Total (n=422)	% missing	Significance of Difference
Case Characteristics					
Murder is most serious offense	13%	10%	11%	0%	.310
Rape is most serious offense	87%	90%	89%	0%	.310
Firearm was involved in the crime (assumed no unless mentioned)	7%	6%	6%	0%	.835
Length of case in months (time from offense to conviction/sentencing)	7.66	8.41	8.06	23%	.446
Age of case in years (time from offense to Jan. 1, 2012)	33.75	32.38	33.01	0%	.000
Location of offense: Victim's home/apartment	32%	49%	41%	27%	.002
Location of offense: Indoors (inside home/apartment/building)	57%	63%	60%	27%	.237
Location of offense: Vehicle (convicted offender's or victim's)	24%	20%	22%	27%	.468
Location of offense: Private location (no public access)	63%	71%	67%	27%	.151
Convicted offender was stranger (not known prior to day of crime)	83%	92%	88%	24%	.012
Convicted offender was relative or (ex)intimate partner of victim(s)	6%	3%	4%	25%	.237
Number of suspects ever reported to forensic lab (regardless of conviction)	1.38	1.47	1.43	0%	.329
Number of suspects convicted for this crime	1.16	1.20	1.18	0%	.403
Percentage of known suspects who were not convicted for this crime	7%	8%	8%	0%	.489
Number of victims	1.05	1.10	1.08	0%	.149

With regard to demographics of the convicted offenders and victims involved, we found few differences between cases where a determinate finding could be made and cases where it could not (Table 9). The only significant difference in these convictions was that the convicted offender tended to be slightly older in convictions with indeterminate results. When the convicted offender was black/African American and a stranger to the victim, the conviction was more likely to have a determinate DNA testing outcome, although this association was not significant and data were missing in more than a quarter of convictions.

Table 9. Bivariate Comparison of Determinate and Indeterminate Sexual Assault Convictions: Convicted Offender/Victim Demographics

	Proportion / Mean				
	Indeterminate (n=195)	Determinate (n=227)	Total (n=422)	% Missing	Significance
Convicted Offender/Victim Demographics					
Convicted offender age	25.98	24.62	25.25	7%	.053
Convicted offender under 18	7%	3%	5%	6%	.054
Convicted offender gender is male	99%	100%	100%	5%	.890
Convicted offender race is black/African American	56%	61%	59%	6%	.323
Convicted offender race is white/Caucasian	43%	39%	41%	6%	.381
Average victim age	25.88	25.55	25.70	11%	.833
Oldest victim age	25.91	25.94	25.93	11%	.988
Youngest victim age	25.84	25.20	25.49	11%	.683
Any victim under 18	30%	24%	27%	11%	.176
Any victim 65 or older	4%	4%	4%	11%	.870
Any female victim(s)	95%	94%	95%	9%	.525
All female victim(s)	94%	92%	93%	9%	.542
All female and/or juvenile (<18) victim(s)	96%	97%	97%	11%	.756
All juvenile (<18) victim(s)	29%	23%	26%	11%	.149
All female and/or juvenile (<18) and/or elderly (65+) victim(s)	98%	97%	97%	11%	.719
Male suspect, all female victim(s)	93%	92%	93%	11%	.745
Male suspect, all female and/or juvenile (<18) victim(s)	96%	98%	97%	14%	.506
Male suspect, all female and/or juvenile (<18) and/or elderly (65+) victim(s)	98%	98%	98%	14%	.991
Convicted offender is black/African-American male stranger to victim(s)	48%	55%	52%	28%	.211
All victims are black/African American	26%	28%	27%	9%	.750
Any victim is black/African American	27%	28%	27%	9%	.949
All victims are white/Caucasian	73%	72%	72%	9%	.867
Any victim is white/Caucasian	74%	72%	73%	9%	.750
Any victim is white/Caucasian female	71%	69%	70%	9%	.618
Black male convicted offender, any white female victim	30%	33%	32%	12%	.567
Black convicted offender, any white victim	32%	34%	33%	12%	.627
Convicted offender and at least one victim are different races	33%	36%	35%	12%	.534

Table 10 compares sexual assault convictions with determinate and indeterminate DNA testing results across a number of characteristics regarding the counties in which the convictions occurred. Few statistically significant associations emerged from this comparison. The counties with convictions that had determinate outcomes were slightly poorer than those with indeterminate outcomes, as shown by marginally significant differences (p<0.10) on an economic deprivation scale and with regard to the number of persons living in poverty, household and per capita income, and unemployment. We found no associations between determinate outcomes and the county-level indicators.

Table 10. Bivariate Comparison of Determinate and Indeterminate Sexual Assault Convictions: Conviction County Characteristics

	Proportion / Mean				
	Indeterminate (n=195)	Determinate (n=227)	Total (n=422)	% missing	Significance of Difference
Conviction County Characteristics (Virginia)					
Number of offenses known to police per 1,000 persons (1978)	52.78	52.81	52.80	0%	.990
Number of violent crimes (murder, rape, robbery, aggravated assault) known to police per 1,000 persons (1981)	5.08	5.34	5.22	0%	.454
Number of murders and rapes known to police per 1,000 persons (1981)	.52	.53	.53	0%	.600
Number of police officers per 1,000 persons (1977)	1.83	1.90	1.87	0%	.227
Percentage 25 and older with no high school diploma (1980)	35%	36%	36%	0%	.190
Percentage 18 and older who did not vote in presidential election (1980)	52%	54%	53%	0%	.077
Local government revenue per 1,000 persons (1977)	.72	.70	.71	0%	.399
Local government expenditure on police protection per 1,000 persons (1977)	.04	.03	.04	0%	.431
Percentage local government revenue spent on police protection (1977)	5%	5%	5%	0%	.749
Percentage female-headed households with children (1980)	7%	8%	7%	0%	.147
Percentage female-headed households (1980)	12%	13%	13%	0%	.233
Percentage vacant housing units (1980)	6%	7%	6%	0%	.212
Percentage unemployed persons (1980)	6%	6%	6%	0%	.095
Median household income (1979)	$17,379	$16,589	$16,954	0%	.061
Per capita personal income (1978)	$8,274	$7,844	$ 8,042	0%	.052
Percentage black/African American (1980)	27%	28%	27%	0%	.693
Percentage Hispanic/Spanish-origin population (1980)	2%	2%	2%	0%	.210
Percentage youth 15 to 21 (1980)	14%	14%	14%	0%	.321
Percentage living below poverty level (1979)	12%	13%	13%	0%	.107

Percentage black/African-American persons living below poverty level (1979)	7%	7%	7%	0%	.269
Percentage receiving Aid to Families with Dependent Children (1980)	4%	5%	4%	0%	.231
Economic deprivation scale (standardized, alpha=.796)	-.15	.003	-.07	0%	.104

What model predicts whether DNA testing results on a case will lead to determinate or indeterminate conclusions about conviction?

Based on the significant associations observed in the previous bivariate comparisons, we estimated a model predicting whether DNA testing results on sexual assault convictions would lead to determinate or indeterminate conclusions. Table 11 presents the four iterations of this model, which conclude in the final and fifth iteration that contains only the predictors found to be significant in at least one prior iteration. Table 12 provides details on the final predictive model's results. As shown in Table 11, the first model included only preconviction forensic testing variables, the second added case characteristics, the third added convicted offender/victim demographics, and the fourth added county conviction characteristics.

Table 11. Multivariate Logit Model Predicting Determinate DNA Testing Results

	(1)	(2)	(3)	(4)	Final Model
Model N	422	309	294	294	294
Akaike information criterion (AIC) corrected[a]	574.44	405.12	382.69	385.11	380.73
Nagelkerke R-square	0.044	0.132	0.155	0.162	0.154
Preconviction Forensic Testing Variables	Beta	Beta	Beta	Beta	Beta
Number of different types of forensic tests done that included convicted offender	-0.181	-0.066	-0.121	-0.126	
ABO blood group typing included convicted offender	0.719*	0.613	0.753†	0.727	0.613*
Racial origin of hair analysis done in case	0.652*	0.410	0.476	0.469	0.390
Case Characteristics					
Age of case in years (time from offense to Jan. 1, 2012)		-0.10**	-0.115**	-0.101*	-0.116**
Location of offense: Victim's home/apartment[b]		0.711**	0.637*	0.641*	0.633*
Convicted offender was stranger (not known prior to day of crime)[b]		0.684†	0.564	0.498	0.584
Convicted Offender/Victim Demographics					
Convicted offender age			-0.034†	-0.037†	-0.034†
Conviction County Characteristics (Virginia)					
Percentage 18 and older who did not vote in presidential election (1980)				2.216	
Per capita personal income (1978)				0.000	
Constant	-0.302†	2.386†	3.698*	2.439	3.706*

Notes: [a] K. P. Burnham and D. R. Anderson, 2002, *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd ed. Springer-Verlag.
[b] Missing values for 24 percent to 27 percent of convictions. Significance levels defined as † p<.10, * p<.05, ** p<.01, *** p<.001.

Although we conducted and present results from these analyses in iterative models, it is the final predictive model (shown in the last column of Table 11 and in Table 12) whose results we focus on when interpreting what conclusions can be made. All else equal, the most significant predictors of whether DNA testing of evidence from a sexual assault conviction (in Virginia in the 1970s/80s) yielded determinate conclusions about wrongful conviction were as follows: in cases where ABO blood group typing was performed and included the convicted offender, DNA testing was more likely to lead to determinate results than in cases where this forensic test was not performed. In addition, sexual assaults that occurred within the victim's own residence were more likely to yield conclusive DNA testing results than sexual assaults that occurred elsewhere. Older cases and those involving older convicted offenders (at the time of the offense) were less likely to yield conclusive DNA testing results. Notably, despite their significant bivariate associations with determinate DNA outcomes, variables measuring the number of preconviction forensic tests that included the convicted offender and county of conviction characteristics were not significant in the final multivariate model predicting the likelihood of determinate DNA testing results.

Table 12. Final Multivariate Logit Model Predicting Determinate DNA Testing Results

	Beta	SE	Exp(B)
Model N	294		
Akaike information criterion (AIC) corrected[a]	380.73		
Nagelkerke R-square	0.154		
ABO blood group typing included convicted offender	0.613*	0.254	1.846
Racial origin of hair analysis done in case	0.390	0.251	1.477
Age of case in years (time from offense to Jan. 1, 2012)	-0.116**	0.039	0.891
Location of offense: Victim's home/apartment[b]	0.633*	0.259	1.884
Convicted offender was stranger (not known prior to day of crime)[b]	0.584	0.392	1.794
Convicted offender age	-0.034†	0.019	0.966
Constant	3.706*	1.444	

Notes: [a] K. P. Burnham and D. R. Anderson, 2002, *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd ed. Springer-Verlag.
[b] Missing values for 24 percent to 27 percent of convictions. Significance levels defined as † p<.10, * p<.05, ** p<.01, *** p<.001.

Using results from the final model presented in Table 12, we calculated the predicted probability that each sexual assault in the final model would yield determinate DNA testing results. Based on these calculations, we note the following conclusions: The predicted probability that DNA testing of a sexual assault conviction in this sample would yield determinate results ranging from .14 to .87, with a mean of .55. Controlling for all other known factors, this predicted probability was—

- .65 for convictions where ABO blood group typing included the convicted offender, compared to .46 for convictions where it did not (difference of .19);
- .61 for convictions where racial origin of hair analysis was done in the case, compared to .50 for convictions where it was not (difference of .11);
- .71 for convictions in cases that were 24 to 29 years old, compared to .60 for cases that were 30 to 34 years old, and .45 for cases that were 35 to 39 years old (difference ranging from .11 to .26);
- .64 for convictions where the offense occurred in the victim's home, compared to .49 for convictions where it occurred elsewhere (difference of .15);

- .57 for convictions when the convicted offender was a stranger, compared to .39 for convictions when the convicted offender was known to the victim (however, this difference was not statistically significant when controlling for other factors in the final predictive model);
- .60 for convictions where the convicted person was 14 to 20 years old, .56 where he was 21 to 29 years old, and .46 where he was 30 years or older (difference ranging from .04 to .14).

From these predicted probabilities, it appears that four factors stand out as the most substantively meaningful predictors of determinate DNA testing outcomes among sexual assault convictions in this data set: the age of the case, whether preconviction ABO typing included the convicted offender, location of the offense, and age of the convicted offender. More recent cases, cases where ABO typing included the convicted person, offenses that occurred inside the victim's home, and younger convicted persons were all associated with significantly and substantially higher probabilities of determinate post-conviction DNA testing results.

Table 11 describes the results of the final model which includes any predictor found to be significant ($p<0.10$) in any prior stage (column 5 of Table 11). All of the predictors are significant in the same direction as described above, except for stranger crimes, which are positively correlated with convictions with determinate results, although the relationship is not statistically significant. Overall, having characterized hair by race increases the odds that there will be a determinate finding from the new DNA analysis by about 60 percent. Each additional year in age of the case reduces the odds of a determinate test by about 10 percent. A crime occurring in the victim's home more than doubles the odds of a determinate finding, and each additional year in age of the convicted offender reduces the odds of a determinant finding by about 4 percent.

What factors distinguish inculpatory sexual assault convictions from all convictions with exculpatory evidence (either currently insufficient or supportive of exoneration)?

Next, we focus on the sexual assault convictions that resulted in determinate DNA testing results (n=227) and identification of the factors associated with exculpatory evidence, indicative of a potential wrongful conviction. Toward this end, we begin with bivariate comparisons, similar to those in the previous section but this time comparing sexual assault convictions with exculpatory results to convictions with inculpatory results. We again examine factors grouped into the following categories:

- post-conviction DNA testing variables (Table 13),
- preconviction forensic testing variables (Table 14),
- case characteristics (Table 15),
- convicted offender/victim demographics (Table 16), and
- county of conviction characteristics (Table 17).

As shown in Table 13, sexual assault convictions with exculpatory DNA testing results were significantly associated with three post-conviction DNA testing factors: DNA profiles developed from oral swabs, anal swabs, and reference samples. As noted in previous sections, reference sample evidence was required for certain determinate conclusions to be reached, so it is not surprising that a higher number of convictions with exculpatory results (38 percent) than inculpatory results (6 percent) depended on reference sample DNA profiles. Additionally, it was frequently observed during UI's coding of the DFS files that DNA profiles developed from oral swabs were used as alternate known references for victims and suspects. However, this fact alone does not explain why oral profile sources were more strongly associated with exculpatory outcomes. There were no statistically significant differences between inculpatory and exculpatory sexual assault convictions with regard to other post-conviction DNA testing variables, including whether DNA profiles were developed from textile items, vaginal swabs, or the victims' underwear.

Table 13. Bivariate Comparison of Exculpatory and Inculpatory Sexual Assault Convictions: Post-Conviction DNA Testing Variables

	Proportion / Mean			
	Inculpatory (n=187)	Exculpatory (n=40)	Total (n=227)	Significance of Difference
Post-Conviction DNA Testing Variables				
Red case (not Green), designation by DFS	6%	95%	22%	.000
DNA testing yielded a DNA profile	100%	100%	100%	N/A
Textile item developed DNA profile	47%	53%	48%	.493
Vaginal swab developed DNA profile	43%	33%	41%	.232
Anal swab developed DNA profile	5%	13%	6%	.077
Oral swab developed DNA profile	23%	83%	33%	.000
Panties item developed DNA profile	44%	50%	45%	.518
Reference sample (from old case file) developed DNA profile	6%	38%	12%	.000

With regard to the original, preconviction forensic testing variables (Table 14), one attribute was associated with inculpatory DNA testing results, while four seemingly separate but related attributes were associated with exculpatory results. Specifically, convictions with inculpatory results were more likely to have had enzyme typing performed on the original biological evidence (18 percent), compared to those with exculpatory results (5 percent). Enzyme typing, especially when combined with ABO typing results, increased the specificity of overall forensic serological testing.

With regard to bivariate predictors of exculpatory DNA testing results, the only preconviction forensic testing variable that was associated with exculpatory DNA results was racial origin of hair analysis, even when it included the convicted offender, and when it was the only forensic test that included the convicted offender. Previous publications have warned that "determinations of racial origin must be approached with a good deal of caution" (DeForest, Gaensslen, and Lee 1983). For the cases in this study, we cannot know if the conclusions reached regarding this work were accurate or not.[39] Since this type of work links hair to one of three broad classes, not to a specific individual, it is possible to have correct racial origin determinations in an actual wrongful conviction.

Notably, none of the other preconviction forensic testing variables was significantly associated with exculpatory DNA testing results, including whether a fingerprint comparison was done in the original case and/or included the convicted offender, whether ABO blood group typing

[39] This is true for all preconviction forensic testing conducted on the cases in this study.

was done and/or included the convicted offender, and whether microscopic hair analysis or ballistics analysis were done (though they rarely were and virtually never included the convicted offender).[40]

Table 14. Bivariate Comparison of Exculpatory and Inculpatory Sexual Assault Convictions: Preconviction Forensic Testing Variables

	Proportion / Mean			
	Inculpatory (n=187)	Exculpatory (n=40)	Total (n=227)	Significance of Difference
Preconviction Forensic Testing Variables				
Number of different types of forensic tests done	1.81	1.93	1.83	.378
Number of different types of forensic tests done that included convicted offender	.90	1.05	.93	.279
Percentage of different types of forensic tests that included convicted offender	49%	53%	50%	.574
Strength of forensic tests that included convicted offender (0=none, 1=weak, 3=strong)	.24	.26	.24	.487
Fingerprint comparison done in case	12%	3%	10%	.112
Fingerprint comparison included convicted offender	1%	0%	1%	N/A
Microscopic hair comparison done in case	2%	3%	2%	.888
Microscopic hair comparison included convicted offender	1%	0%	0.4%	N/A
Ballistics analysis done in case	5%	10%	6%	.275
Ballistics analysis included convicted offender	1%	0%	0.4%	N/A
ABO blood group typing done in case	97%	98%	97%	.950
ABO blood group typing included convicted offender	50%	48%	49%	.798
Enzyme typing done in case	18%	5%	15%	.061
Enzyme typing included convicted offender	5%	5%	5%	.960
Racial origin of hair analysis done in case	47%	75%	52%	.002
Racial origin of hair included convicted offender	33%	53%	37%	.023
Racial origin of hair was only forensic test that included convicted offender	13%	30%	16%	.012

In Table 15, we examine bivariate associations between case characteristics of these sexual assault convictions and the likelihood of exculpatory DNA testing results. These comparisons revealed four significant differences and one difference that approached significance. Specifically, cases that were about two years more recent (31 instead of 33 years old, on average) were more likely to yield exculpatory DNA testing results. Previously, we also found that more recent cases had a higher probability of yielding determinate DNA testing results (either exculpatory or inculpatory). In this specific data set, this seemingly trivial difference in case age may be capturing the distinction between offenses that occurred in the very late 1970s and those that occurred in 1980 and beyond. If so, it is possible that evidence from the post-1980 era was less degraded than older cases, thereby

[40] Generally, results of ABO blood typing place an item into one of four categories (A, B, AB, or O), which exist at different frequencies in the population. One may expect that wrongful convictions would be more likely if the convicted offender was linked through a type held by a large portion of the population, such as A at 45 percent, as opposed to AB at 4 percent. However, this could not be observed in our analysis.

increasing the likelihood that such evidence would develop useful profiles, 31 or fewer years later, to detect possible wrongful convictions.

Three other significant differences between inculpatory and exculpatory sexual assault convictions have to do with the number of suspects known and convicted for the crime. Not surprisingly, the more suspects known to police at the time of the original forensic testing, and the more suspects ultimately convicted for the crime, the more likely it was that post-conviction DNA testing would yield exculpatory results. The last notable difference, which approached significance at p=.071, was that when the offense occurred indoors rather than outdoors, post-conviction DNA testing was more likely to yield an exculpatory (79 percent) than inculpatory (60 percent) result.

With regard to a number of other case characteristics, there were no significant differences between sexual assault convictions with inculpatory or exculpatory results. These characteristics included the most serious offense type (murder or rape), firearm involvement, length of the case from offense to conviction, whether the offense occurred in a vehicle,[41] whether the convicted offender was a stranger versus known acquaintance or intimate/relative, and the number of victims.

[41] Occurring in the victim's home/apartment or private location, although not achieving significance, was correlated with occurring indoors, which as noted previously was significantly associated with exculpatory DNA evidence.

Table 15. Bivariate Comparison of Sexual Assault Convictions with Exculpatory and Inculpatory Results: Case Characteristics

	Proportion / Mean			
	Inculpatory (n=187)	Exculpatory (n=40)	Total (n=227)	Significance of Difference
Case Characteristics				
Murder is most serious offense	9%	13%	10%	.510
Rape is most serious offense	91%	88%	90%	.510
Firearm was involved in the crime (assumed no unless mentioned)	5%	10%	6%	.275
Length of case in months (time from offense to conviction/sentencing)	7.96	10.57	8.41	.231
Age of case in years (time from offense to Jan. 1, 2012)	32.70	30.89	32.38	.004
Location of offense: Victim's home/apartment	47%	61%	49%	.183
Location of offense: Indoors (inside home/apartment/building)	60%	79%	63%	.071
Location of offense: Vehicle (convicted offender's or victim's)	21%	18%	20%	.708
Location of offense: Private location (no public access)	69%	82%	71%	.155
Convicted offender was stranger (not known prior to day of crime)	93%	87%	92%	.270
Convicted offender was relative or (ex)intimate partner of victim(s)	2%	7%	3%	.196
Number of suspects ever reported to forensic lab (regardless of conviction)	1.37	1.93	1.47	.003
Number of suspects convicted for this crime	1.15	1.45	1.20	.001
Percentage of known suspects who were not convicted for this crime	8%	11%	8%	.363
Number of victims	1.12	1.03	1.10	.289

In Table 16, we compared a large number of factors measuring convicted offender/victim demographics in each conviction and found no statistically significant associations between any factor and the likelihood that DNA testing results would be exculpatory. Notably, our focus in this section is on all sexual assault convictions with determinate testing outcomes, so virtually all suspects were male and most victims were female. Still, there was sufficient variation with regard to convicted offender/victim age and race, and the combinations thereof, to have detected differences had they existed. Yet, contrary to findings from other studies showing that black/African-American convicted offenders are overrepresented among exonerees (Garrett 2008) or that the judicial system is partial to white/Caucasian victims (e.g., Paternoster et al. 2003), we found no evidence of variation in the likelihood of exculpatory DNA testing results across many tested combinations of convicted offender/victim race and age compositions.

Table 16. Bivariate Comparison of Sexual Assault Convictions with Exculpatory and Inculpatory Results: Convicted offender/Victim Demographics

	Proportion / Mean			
	Inculpatory (n=187)	Exculpatory (n=40)	Total (n=227)	Significance of Difference
Convicted Offender/Victim Demographics				
Convicted offender age	24.37	25.76	24.62	.203
Convicted offender under 18	3%	3%	3%	.939
Convicted offender gender is male	99%	100%	100%	N/A
Convicted offender race is black/African American	61%	60%	61%	.885
Convicted offender race is white/Caucasian	39%	40%	39%	.885
Average victim age	26.01	23.51	25.55	.345
Oldest victim age	26.33	24.24	25.94	.438
Youngest victim age	25.75	22.79	25.20	.267
Any victim under 18	25%	18%	24%	.373
Any victim 65 or older	5%	3%	4%	.560
Any female victim(s)	94%	93%	94%	.683
All female victim(s)	92%	93%	92%	.901
All female and/or juvenile (<18) victim(s)	98%	95%	97%	.360
All juvenile (<18) victim(s)	23%	18%	23%	.501
All female and/or juvenile (<18) and/or elderly (65+) victim(s)	98%	95%	97%	.360
Male convicted offender, all female victim(s)	92%	93%	92%	.982
Male convicted offender, all female and/or juvenile (<18) victim(s)	98%	95%	98%	.241
Male convicted offender, all female and/or juvenile (<18) and/or elderly (65+) victim(s)	98%	95%	98%	.241
Convicted offender is black/African-American male stranger to victim(s)	56%	52%	55%	.678
All victims are black/African American	29%	20%	28%	.234
Any victim is black/African American	29%	20%	28%	.234
All victims are white/Caucasian	70%	80%	72%	.209
Any victim is white/Caucasian	70%	80%	72%	.234
Any victim is white/Caucasian female	68%	73%	69%	.552
Black male convicted offender, any white female victim	32%	35%	33%	.747
Black convicted offender, any white victim	33%	40%	34%	.399
Convicted offender and at least one victim are different races	35%	40%	36%	.581

Next, we examined the bivariate associations between each of 30 different measures of county characteristics for the counties in which determinate sexual assault convictions had occurred and the likelihood of exculpatory DNA testing results. We found only one association that approached statistical significance. Specifically, convictions that occurred in counties where local government spent more on police protection were associated with a somewhat greater likelihood of exculpatory findings.

However, we also note that, although not achieving statistical significance, all measures of county-level criminal activity were higher in convictions that resulted in exculpatory DNA findings than in those with inculpatory findings; and conversely, measures of personal/household income and the percentage of persons living in rural areas were lower in convictions with exculpatory results than in those with inculpatory findings. Thus, these bivariate comparisons provide some (albeit insignificant) support for the fact that poorer urban counties with higher crime rates were more likely to yield convictions with exculpatory results. Two of these factors (violent crime rate and median household income) were highly correlated with the percentage of black/African-American persons living in a county. Not unrelatedly, other measures of county characteristics captured in the economic deprivation scale indicated that there were higher levels of population density, vacant and renter-occupied housing, and residential instability (living in different house than five years prior) in counties that yielded convictions with exculpatory results than in those with inculpatory findings, though these differences did not achieve statistical significance.

Table 17. Bivariate Comparison of Sexual Assault Convictions with Exculpatory and Inculpatory Results: Conviction County Characteristics

	Proportion / Mean			
	Inculpatory (n=187)	Exculpatory (n=40)	Total (n=227)	Significance of Difference
Conviction County Characteristics (Virginia)				
Number of offenses known to police per 1,000 persons (1978)	52.24	55.47	52.81	.387
Number of violent crimes (murder, rape, robbery, aggravated assault) known to police per 1,000 persons (1981)	5.24	5.81	5.34	.363
Number of murders and rapes known to police per 1,000 persons (1981)	.53	.57	.53	.470
Number of robberies known to police per 1,000 persons (1979)	1.87	2.13	1.92	.333
Number of aggravated assaults known to police per 1,000 persons (1980)	2.29	2.54	2.33	.350
Number of property crimes (burglary, motor vehicle theft, larceny-theft) known to police per 1,000 persons (1981)	57.79	60.34	58.24	.567
Number of burglaries known to police per 1,000 persons (1979)	14.19	14.61	14.26	.700
Number of larceny-thefts known to police per 1,000 persons (1981)	39.12	41.08	39.46	.542
Number of police officers per 1,000 persons (1977)	1.88	2.00	1.90	.278
Percentage 25 and older with no high school diploma (1980)	36%	38%	36%	.421
Percentage 18 and older who did not vote in presidential election (1980)	53%	54%	54%	.471
Local government expenditure on police protection per 1,000 persons (1977)	.03	.04	.03	.255
Percentage local government revenue spent on police protection (1977)	4.8%	5.3%	4.9%	.085
Percentage female-headed households with children (1980)	8%	8%	8%	.627
Percentage female-headed households (1980)	13%	13%	13%	.252
Percentage vacant housing units (1980)	6%	7%	7%	.227
Percentage unemployed persons (1980)	6%	6%	6%	.504
Median household income (1979)	$16,743	$15,866	$16,589	.226
Per capita personal income (1978)	$7,874	$7,701	$7,844	.642
Percentage of county black/African American (1980)	27%	30%	28%	.327
Percentage Hispanic/Spanish-origin population (1980)	2%	2%	2%	.701
Percentage unmarried males 15 and older (1980)	17%	18%	17%	.254
Percentage youth 15 to 21 (1980)	14%	15%	14%	.124
Percentage rural population (1980)	19%	16%	19%	.521
Percentage living below poverty level (1979)	13%	14%	13%	.459
Percentage black/African-American persons living below poverty level (1979)	7%	8%	7%	.295
Percentage receiving Aid to Families with Dependent Children (1980)	5%	5%	5%	.325
Economic deprivation scale (standardized, alpha=.796)	-.02	.13	.003	.345

What model predicts whether determinate DNA testing results on a conviction will be exculpatory or inculpatory regarding a convicted offender's actual innocence?

In this section, we iteratively estimate a model predicting exculpatory DNA testing results based on the significant bivariate associates identified in the previous section. Toward this end, the first model includes preconviction forensic testing variables, the second adds case characteristics, the third adds convicted offender/victim demographics, and the fourth adds county conviction characteristics.

Notably, we also include a number of statistical controls in these multivariate models. Some controls are included because of their significance in the previously described model predicting determinate DNA testing results; these controls measure whether ABO blood group typing included the convicted offender, racial origin of hair analysis was done in the case, age of the case, indoor offense location,[42] number of convicted persons, whether the convicted offender was a stranger, and the convicted offender's age. Two other controls are included because of their theoretical relevance to the model—murder as the most serious offense type (versus rape) and number of victims.

In Table 18, we present the four iterations of the model predicting exculpatory DNA testing results, along with the fifth iteration (final model), which contains all predictors that were statistically significant in at least one prior stage plus the control variables. Interpretation of these results focuses on the final model.

[42] Although technically offense location in the victim's home/apartment was previously found to be related to determinate DNA testing results, given its high correlation (r>.5) with indoor locations in general and given the bivariate relevance of indoor locations to exculpatory cases, we instead included indoor location in the multivariate model predicting exculpatory DNA testing outcomes.

Table 18. Multivariate Logit Models Predicting Exculpatory DNA Testing Results

	(1)	(2)	(3)	(4)	Final Model
Model N	227	171	162	162	162
Akaike information criterion (AIC) corrected[a]	202.40	131.32	125.58	127.88	128.10
Nagelkerke R-square	0.120	0.373	0.401	0.402	0.400
Preconviction Forensic Testing Variables	Beta	Beta	Beta	Beta	Beta
ABO blood group typing included convicted offender	0.273	0.423	0.479	0.477	0.647
Enzyme typing done in case	-1.381†	-1.888†	-2.237*	-2.235†	-2.218*
Racial origin of hair analysis done in case	0.998*	0.809	0.633	0.632	0.518
Racial origin of hair was only forensic test that included convicted offender	0.671	-0.100	-0.427	-0.418	
Case Characteristics					
Murder is most serious offense		1.461†	1.488†	1.498†	1.424†
Age of case in years (time from offense to Jan. 1, 2012)		-0.196*	-0.219**	-0.220**	-0.221**
Location of offense: Indoors (inside home/apartment/building)[b]		1.354*	1.394*	1.396*	1.372*
Convicted offender was stranger (not known prior to day of crime)[b]		-1.426†	-1.302	-1.306	-1.293
Number of suspects convicted for this crime		1.987***	2.082***	2.069***	2.120***
Number of victims		-0.563	-0.556	-0.550	-0.572
Convicted Offender /Victim Demographics					
Convicted offender age			0.054	0.054	0.055
Conviction County Characteristics (Virginia)					
Percentage local government revenue spent on police protection (1977)				2.508	
Constant	-2.291***	2.410	1.695	1.594	1.615

Notes: [a] K. P. Burnham and D. R. Anderson, 2002, *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd ed. Springer-Verlag.
[b] Missing values for 24 percent–27 percent of convictions. Significance levels defined as † p<.10, * p<.05, ** p<.01, *** p<.001.

All else equal, there were five significant predictors of whether determinate DNA testing of evidence from a sexual assault conviction (in Virginia in the 1970s/80s) yielded exculpatory evidence indicative of wrongful conviction, in the final multivariate predictive model. Specifically, as shown in Table 19—

- More recent offenses were more likely to have an exculpatory DNA results, although we note that the difference in the averages was only two years.

- Sexual assault convictions for which enzyme typing was done were significantly less likely to yield exculpatory DNA testing results. As noted previously, enzyme typing increased the specificity of forensic serological tests, especially when combined with ABO typing results, meaning that stronger conclusions about a convicted offender's inclusion as the source of forensic evidence could have been made prior to the original conviction.
- Convictions for both murder and sexual assault were more likely to yield exculpatory DNA results than were convictions for sexual assault alone. This finding is difficult to explain, given that greater amounts of physical evidence were likely available in murder and sexual assault cases than in those involving only sexual assault.
- Sexual assault convictions for offenses that occurred indoors, such as inside the victim's or convicted offender's home, were significantly more likely to yield exculpatory DNA results. Although untestable in the current data set, this relationship may be indicative of the lack of reliable eyewitness testimony in such cases. The crime descriptions for many indoor sexual assaults indicated that they frequently occurred at nighttime (in the dark) and involved only the victim and convicted offender and no other potential witnesses.
- The more suspects convicted for a sexual assault, the more likely any individual suspect's conviction was to have exculpatory DNA results.

Other variables in the final model had significant bivariate associations with exculpatory DNA testing results, but did not have significant relationships in the multivariate that controlled for other factors. These variables included racial origin of hair analysis being done in the case and the single, county-level indicator: percentage of local government revenue spent on police protection. These associations in the final model were in the directions anticipated from their bivariate associations (e.g., cases where racial origin of hair tests were done were more likely to be exculpatory), yet failed to achieve statistical significance. The remaining variables in the final predictive model, which were included only as statistical controls, were not significantly predictive of exculpatory DNA results; these included ABO blood group typing, convicted offender was a stranger, number of victims, and convicted offender age.

.

Table 19. Final Multivariate Logit Model Predicting Exculpatory DNA Testing Results

	Beta	SE	Exp(B)
Model N	162		
Akaike information criterion (AIC) corrected[a]	128.10		
Nagelkerke R-square	0.400		
ABO blood group typing included convicted offender	0.647	0.546	1.910
Enzyme typing done in case	-2.218*	1.117	0.109
Racial origin of hair analysis done in case	0.518	0.551	1.679
Murder is most serious offense	1.424†	0.841	4.152
Age of case in years (time from offense to Jan. 1, 2012)	-0.221**	0.084	0.802
Location of offense: Indoors (inside home/apartment/building)[b]	1.372*	0.659	3.942
Convicted offender was stranger (not known prior to day of crime)[b]	-1.293	0.848	0.275
Number of convicted offender convicted for this crime	2.120***	0.550	8.331
Number of victims	-0.572	0.945	0.565
Convicted offender age	0.055	0.043	1.057
Constant	1.615	3.149	

Notes: [a] K. P. Burnham and D. R. Anderson, 2002, *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd ed. Springer-Verlag.
[b] Missing values for 24percent to 27 percent of convictions. Significance levels defined as † p<.10, * p<.05, ** p<.01, *** p<.001.

Using results from the final model presented in Table 19, we calculated the predicted probability that each sexual assault conviction in the final model would yield exculpatory DNA testing results. Based on these calculations, we note that these predicted probabilities ranged from .001 to .877, with a mean of .167 and median .072.

Focusing first on the five statistically significant relationships in the final model, we note that controlling for all other known factors, the average predicted probability that determinate DNA testing on sexual assault convictions in this sample would yield exculpatory results was—

- .08 for convictions where enzyme typing was done in the case, compared to .18 for convictions where it was not (difference of negative .10);
- .26 for convictions where murder was the most serious offense, compared to .15 when rape was the most serious offense (difference of .11);
- .31 for convictions when the case was 24 to 29 years old, .16 when the case was 30 to 34 years old, and .09 when the case was 35 to 39 years old (difference ranging from .07 to .22);
- .21 for convictions where the offense occurred indoors, compared to .10 for convictions where it occurred outdoors (difference of .11); and
- .83 for cases where three suspects were convicted, .40 for cases where two suspects were convicted, and .12 if only one suspect was convicted (difference ranging from .28 to .71).

Clearly the number of convicted suspects had the strongest relationship to exculpatory DNA testing results in this final model. Notably, of the sexual assault convictions with determinate results, 8 percent of those exculpatory involved three convicted suspects, compared to 4 percent of those inculpatory; 30 percent of those exculpatory ones involved two convicted suspects, compared to 8 percent of those inculpatory; and 63 percent of those exculpatory involved just one convicted suspect, compared to 89 percent of those inculpatory. The other four relationships between predictors and exculpatory results were of relatively equal weighting.

In addition to the predicted probabilities above, the average predicted probabilities of exculpatory DNA results for variables that did not achieve statistical significance in the final model were as follows:

- .18 for convictions where ABO blood group typing included the convicted offender, compared to .15 for convictions where it did not;
- .24 for convictions where racial origin of hair analysis was done in the case, compared to .09 for convictions where it was not;
- .16 for convictions where the convicted offender was a stranger, compared to .29 for convictions where he was known to the victim;
- .18 for convictions where there was one victim, .09 when there were two victims, and .04 or less when there were three or more victims; and
- .14 for convictions where the convicted offender was 14 to 20 years old, .17 where the convicted offender was 21 to 29 years old, and .20 where the convicted offender was 30 years or older.

Though none of these differences achieved statistical significance in the final model, the most sizable in the data were those involving racial origin of hair analysis and number of victims.

Does the same model predict exculpatory DNA testing results supporting exoneration, as opposed to inculpatory results?

In this section, we take the same predictor variables from the final model predicting exculpatory DNA results (as shown in Table 19) and use them in a model predicting convictions with exculpatory results that support exoneration. In other words, whereas in the last section we focused on any exculpatory/elimination evidence, as compared to inculpatory evidence, here we look only at those exculpatory eliminations that support exoneration (again, as compared to inculpatory outcomes).

In Table 20, we find that the results are virtually identical to those looking at all convictions with exculpatory outcomes, with two exceptions. In the convictions with exculpatory results that support exoneration, whether murder is the most serious offense is no longer statistically significant, and the whether the convicted offender was a stranger is now significant. The other three significant predictors (location of the crime, number of suspects, and enzyme typing done) remain significant, and the odds ratios of each are slightly greater than in Table 19.

Table 20. Final Multivariate Logit Model Predicting Exculpatory DNA Testing Results, Estimated Only on Convictions with Exculpatory Results that Support Exoneration (versus Inculpatory)

	Beta	SE	Exp(B)
Model N	158		
Akaike information criterion (AIC) corrected[a]	107.83		
Nagelkerke R-square	0.476		
ABO blood group typing included convicted offender	0.898	.626	2.455
Enzyme typing done in case	-2.382†	1.284	.092
Racial origin of hair analysis done in case	0.702	.647	2.018
Murder is most serious offense	1.196	1.017	3.308
Age of case in years (time from offense to Jan. 1, 2012)	-0.325**	.102	.723
Location of offense: Indoors (inside home/apartment/building)[b]	1.881*	.824	6.560
Convicted offender was stranger (not known prior to day of crime)[b]	-1.594†	.946	.203
Number of convicted offenders convicted for this crime	2.308***	.608	10.056
Number of victims	-0.430	1.097	.651
Convicted offender age	0.071	.048	1.074
Constant	3.416	3.618	

Notes: [a] K. P. Burnham and D. R. Anderson, 2002, *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd ed. Springer-Verlag.
[b] Missing values for 24 percent to 27 percent of convictions. Significance levels defined as † p<.10, * p<.05, ** p<.01, *** p<.001.

Again, we used results in Table 20 to calculate the predicted probability that each conviction would result in DNA testing results that were exculpatory supporting exoneration. Here we discuss those probabilities, which ranged from .0004 to .867 with a mean of .145 and median .049, for each of the significant predictors. While holding all other predictors constant, the predicted probability of exculpatory supporting exoneration results was as follows:

- .08 for convictions where enzyme typing was done in the case, compared to .16 for convictions where it was not (difference of negative .08);
- .32 for convictions when the case was 24 to 29 years old, .13 when the case was 30 to 34 years old, and .07 when the case was 35 to 39 years old (difference ranging from .06 to .25);
- .19 for convictions where the offense occurred indoors, compared to .07 for convictions where it occurred outdoors (difference of .12);
- .13 for convictions where the convicted offender was a stranger, compared to .29 for convictions where he was known to the victim (difference of .16); and
- .79 for cases where three suspects were convicted, .33 for cases where two suspects were convicted, and .11 where only one suspect was convicted (difference ranging from .22 to .68).

Again, the number of convicted suspects has the substantively strongest relationship, followed by age of the case, location of the offense, stranger offenders and enzyme typing.

Case Studies

Next, we present summaries of several cases in this data set (in no particular order) to illustrate the three types of determinate post-conviction DNA testing outcomes defined by UI researchers: inculpatory, exculpatory but insufficient for exoneration, and exculpatory and supportive of exoneration (which includes all known exonerations).[43] Available information on these cases was limited to data present in the DFS forensic files, which mainly included basic facts about the crime, results of the original forensic tests, and the results of more recent DNA analysis. Therefore, except in unusual situations where there was a subpoena for the expert witness or record of a court appearance, or if the case was included in our three-court pilot study, we cannot qualitatively understand how the original forensic test results influenced the original investigation or prosecution. Given these limitations, we identify the following case studies as exoneration (if the convicted suspect has been officially exonerated by the Commonwealth of Virginia), exculpatory and supportive of exoneration, or may be exculpatory but insufficient to support exoneration.

What follows is *not* an illustration of a random sample of cases taken from our sample. Rather, we have sought to highlight specific examples, including all four known exonerations in the data set, to show how the available forensic evidence fits the broader pattern of facts in the case. These examples alternatively show the power—and limitations—of post-conviction DNA testing in helping inform a review of old cases resulting in a conviction where physical evidence was retained.

Case Study #1: Exoneration

In 1984, a non-English-speaking white female was allegedly sexually assaulted in a courtyard by a black male stranger. The police identified two black male suspects in the case. The forensic examiner (who was called to testify) conducted blood group typing on the victim PERK and identified a blood type match to suspect 1's reference sample. Suspect 1 was arrested two months after the offense, and suspect 2 was never arrested. Suspect 1 had a court-appointed attorney and was convicted after a four-day jury trial. He appealed the conviction, but it was upheld. DNA testing results conducted for this study eliminated suspect 1 as the contributor of the male DNA profile in the victim PERK. A subsequent search of the Virginia DNA database identified suspect 2 as the true offender. Suspect 1 was pardoned and released from prison in 2005.

Case Study #2: Exoneration

In 1979, a white female was awakened in her home and allegedly sexually assaulted by an unknown black male suspect. A suspect was identified and charged. Again, the forensic examiner determined that the suspect's blood type matched the blood type from the questioned evidence collected at the crime scene. A forensic examiner also determined that the suspect's hair and the hair found at the scene belong to the same racial class. The suspect was convicted and sentenced to 16 years in prison. In the course of this study, a male DNA profile developed from textiles found at the crime scene and a vaginal swab from the victim PERK eliminated the convicted offender as the contributor of the profile. The DNA profile did not hit to any individual in the FBI's Combined DNA Index

---

[43] Outcome 1, Indeterminate, is explained in the Methodology section.

System (CODIS), and the real perpetrator remains unknown. The convicted suspect was exonerated in 2011.

Case Study #3: Exoneration

In 1979, a white female was allegedly sexually assaulted by an unknown white man. The victim identified the suspect the day after the assault. A forensic examiner conducted blood group typing and a racial origin of hair analysis in the case. Blood group typing did not match the suspect. All questioned hairs were classified as Caucasian; however, both the suspect and victim were white. The suspect had a criminal record prior to this case (but not for sexual assault), and he was convicted and sentenced to 25 years. However, DNA testing during the course of this project identified a profile from a sperm fraction of the victim's vaginal swab that eliminated the convicted suspect as the source of that DNA. This finding was used to support exoneration. Unfortunately, while the profile could be used to exclude the original suspect, it was not suitable for searching in CODIS and no new suspect has been identified.[44]

Case Study #4: Exoneration

In 1984, an unknown black male broke into a church, threatened a white female with a knife, and allegedly sexually assaulted her. A suspect was identified days later by the victim and was arrested. The forensic examiner conducted blood group typing and determined the racial origin of hairs. The suspect blood type matched the blood type found at the crime scene. Hairs found in the victim PERK were determined to be Caucasian and therefore, the suspect was eliminated as the source of those hairs. However, post-conviction DNA testing for this study identified a profile developed from the sperm fraction of vaginal swabs in the victim PERK that eliminated the convicted suspect as the source. This profile also hit to another offender in CODIS, and the convicted suspect was exonerated.

Case Study #5: May Be Exculpatory and Supporting/Inculpatory

In 1977, a white female was allegedly sexual assault and robbed by two black male strangers. Two suspects were arrested the day after the assault; both had prior records and knew each other. Blood group typing included suspect 1 but not suspect 2 as the source of evidence collected from the victim PERK. The victim identified both suspects but only after undergoing hypnosis. Suspect 1 initially pled guilty but later withdrew the plea. Both suspects had court-appointed attorneys, were convicted by jury trial and were sentenced to more than 60 years (suspect 2 had a longer sentence than suspect 1). Both suspects appealed their conviction; suspect 1 appealed four times and suspect 2 appealed two times. DNA testing for this study identified a male profile from the vaginal swabs of the victim PERK. Suspect 1 was included as a contributor of this profile, while suspect 2 was eliminated. Thus, the DNA results were inculpatory for suspect 1 and may be supportive of exoneration for suspect 2. However, since the victim reported two attackers and only one DNA profile was developed, the elimination of suspect 2 from the PERK suggests that other information

---

44 An often overlooked value of DNA analysis is that a very partial profile can be used to eliminate a suspect. DNA profiles are produced from commercial kits that target a set number of loci. For example, the kit PowerPlex 16™ develops a 16-loci profile and includes the 13 targeted for CODIS entry. The more loci shared between matching profiles, the stronger the association is between them. However, only a few loci are necessary to exclude a person as the source of that biological material. If a partial profile (i.e., less than the targeted number of loci) is developed (say six loci) and those loci do not match a known standard, that subject can be eliminated as the source of that DNA.

is necessary for exoneration. This case example illustrates how an exculpatory result in the VA model is the starting point for a determination of wrongful conviction, not the terminus.

Case Study #6: May Be Exculpatory and Supporting

In 1977, a black male allegedly forced his way into a white female's home at gunpoint and sexually assaulted her. The forensic examiner conducted blood group typing and racial origin of hair classification. No blood type match was found. Hairs recovered from the crime scene were of the same racial class as the suspect. However, other characteristics of the hairs were not consistent with the suspect's samples. The suspect was convicted in a jury trial and sentenced to five years, despite not matching the victim's description of her attacker and having an alibi supported by several witnesses. DNA testing for this study identified a male profile from a sperm fraction on the victim's panties. The convicted suspect was eliminated as a possible source of the profile, which hit to another offender in CODIS. Though the convicted suspect has not been exonerated yet, the state is currently reviewing the case for potential exoneration.

Case Study #7: May Be Exculpatory and Supporting/Inculpatory/Indeterminate

In 1976, a white female was allegedly sexual assault in her home by three male strangers. Three suspects were arrested within days of the assault. Forensic testing compared suspect reference blood and hair samples to crime scene evidence. Suspect 1's hair samples were determined to be of the same racial class as those collected at the crime scene, but his blood type did not match the questioned evidence. However, suspect 2's blood type and suspect 3's blood type matched biological evidence collected at the crime scene. Suspect 1 had a court-appointed attorney and did not confess or enter a guilty plea. He was convicted in a jury trial and sentenced to more than 25 years. Suspect 2 confessed while under the influence of drugs (and was later diagnosed as mentally ill), and suspect 3 (who was also later diagnosed as mentally ill) pled guilty. All three suspects appealed their conviction. DNA testing produced different outcomes for each suspect. A profile from a male contributor was developed from the victim's underwear, and suspect 1 was eliminated as the source while suspect 2 was identified as a contributor. No reference profile was developed for suspect 3, so he could not be included or excluded as a contributor of any profile. Thus, UI researchers coded suspect 2's conviction as inculpatory, suspect 3's as indeterminate, and suspect 1's as exculpatory supporting exoneration. Again, however, we note that since the victim reported three attackers and only one profile was developed, elimination of convicted suspect 1 from DNA found in the PERK suggests that other information may be necessary for an exoneration.

Case Study #8: May Be Exculpatory but Insufficient

In 1986, when an older black male victim was killed, the only suspect in the case was also an older black male. At the time, DFS examined a knife and bullet found at the crime scene, but was only able to conduct blood group typing on stains from the suspect's clothes. The blood found at the scene was the same blood type as the suspect but not as the victim. The suspect was charged with manslaughter and sentenced to five years. DFS obtained the convicted suspect's profile from the VA DNA data bank and compared it to DNA from the bloodstain on his clothes. The suspect could not be eliminated as the source of that blood. However, the convicted suspect's profile was eliminated as the contributor of DNA found on the knife. Still, without a victim reference sample DFS was unable to conclude whether the DNA profile present on the knife belonged to the victim or to an unknown suspect. If the knife's profile belonged to another suspect, the results are exculpatory and supportive of exoneration; however, if the knife's profile belonged to the victim, there is no exculpatory evidence in favor of the convicted suspect. Additionally, it is not known whether any nonforensic factors in the original case link the convicted suspect to the knife or if he admitted to being at the scene of the crime. Thus, these DNA testing results were classified as exculpatory (given elimination of the suspect's profile on the questioned evidence) but insufficient for exoneration.

Discussion

This study is the first to analyze DNA testing results for an unbiased sample of serious person crime convictions involving biological evidence. Previous analyses of post-conviction DNA testing results have been based on samples principally derived from detected wrongful convictions alone or used insufficient proxies for actual wrongful convictions, with little available evidence about non-exonerations for comparison (Gould and Leo 2010).

Usually, post-conviction DNA testing is performed only after extensive legal review with regard to the potentially probative value of the evidence. As a result, almost all instances of known wrongful convictions prior to this study were those detected after innocence was actively claimed. Innocent persons who have not actively pursued exoneration have to date remain undetected. In contrast, this study identified potential wrongful convictions based on an unbiased sampling of violent crime convictions—the governor of Virginia ordered DNA testing on all eligible convictions, regardless of whether evidence pointed to the guilt or innocence of a convicted suspect. This approach allowed us to make predictions about the efficacy of DNA testing at reaching determinate conclusions about the rightful or wrongful nature of such convictions, and ultimately, at the estimated rate of wrongful conviction in homicides and sexual assaults in Virginia during the years studied.

The VA model of post-conviction DNA testing takes the traditional model and turns it on its head. As a result, the results of the DNA testing are a starting point for detecting wrongful convictions, rather than an endpoint. As illustrated in Figure 1, exculpatory results should be the trigger for additional investigation by law enforcement or prosecutor's offices to determine the probative value of that exculpatory result. And for those that hold sufficient weight, courts should proceed toward exoneration or other post-conviction relief. These post-DNA testing activities were not supported by this NIJ grant funding, and were therefore not observed as part of this research.

Our results from this study are consistent with some prior literature on the influence of forensic evidence on conviction. Our findings both support and dispute Garrett's (2008) claim that some types of forensic evidence (including hair comparisons) are particularly unreliable. Our findings support this claim only for racial origin of hair testing. All other connections to those convicted by other forensic methods were not associated with exculpatory results. Inculpatory results from the original forensic testing, including ABO typing, microscopic hair analysis, fingerprints, and ballistics, were not associated with exculpatory results from post-conviction DNA testing. However, an inculpatory result from the racial origin of hairs was a predictor of exculpatory results in the bivariate comparison but not in the final multivariate model. Additionally, an inculpatory result from the enzyme typing analysis was a predictor of inculpatory results from DNA testing in the final multivariate model.

Within the convictions with determinate DNA testing results, we distinguished between outcomes that were exculpatory and supportive of exoneration and outcomes that were exculpatory but insufficient. This is an important distinction, but does not mean that all supportive exculpatory outcomes have results that could lead to exoneration. An outcome that is exculpatory and supportive of exoneration means that DNA testing conclusively eliminated the suspect as contributor of any evidence for which there were DNA testing results. Exculpatory but insufficient outcomes have DNA results that are more inconclusive (for example, the suspect could be eliminated from one swab in the PERK, but other contextual factors in the case may make this finding highly non-probative). This distinction is important for interpreting our results, particularly when it comes to estimating the rate of wrongful conviction. Essentially, the rates presented in this report are an upper bound.

As discussed previously, one of the main limitations of this data set is the fact that determinate results were not obtained from DNA testing in about two-thirds of the convictions. This attrition may bias results to the extent that unobserved heterogeneity related to an indeterminate finding is also related to the likely outcome of the DNA testing. Therefore, our biggest data limitation is omitted variable bias, primarily the lack of court data. We believe that our analysis would have been greatly improved by additional court variables (particularly method of conviction (jury/bench trial or guilty plea)), type of defense attorney (court-appointed or retained), whether the offender confessed or gave incriminating statements, victim and eyewitness identification, offender's prior record and mental health problems, and results from those appeals and would have allowed us to test theories put forth in prior studies, particularly about the impact of witness identification, trial type, and confessions on wrongful conviction (Conners et al. 1996; Garret 2008; Gross et al. 2005). We recommend further investigation of court data to address these limitations.

The physical evidence that was retained in these VA cases was very old and in many instances had already been subject to forensic testing. As a result, two-thirds yielded no determinate results. The central challenge of this study is how to interpolate the results of the one-third of convictions that yielded determinate results to the two-thirds of convictions that did not. While we are confident that these convictions are an unbiased sample of sexual assaults and homicides from 1973 to 1987 in VA and thus are generalizable to all convictions of the same type from the same period, we are less confident that the convictions with determinate results are a random sample of all convictions from the period. Thus, it is much less clear what the findings for the convictions with determinate outcomes mean for those with indeterminate outcomes.

This issue is critical to the determination of a rate of wrongful conviction, which is the ratio of convictions with exculpatory results that support exoneration over the number of convictions examined. Both of those numbers are debatable from our study. In order to calculate a rate of wrongful conviction, we would need to know how many of the convictions with indeterminate DNA testing results would have eliminated the convicted offender as the contributor of probative evidence. As it stands, the numerator in our wrongful conviction ratio is 38 and the denominator is 715 (if all convictions that were tested is the denominator) or the numerator is 33 and the denominator is either 422 (if all sexual assault convictions are included in the denominator), or 227 (if only sexual assaults with a determinate outcome are included in the denominator).

We believe that two findings are not in dispute:

- First, we find that in convictions from VA between 1973 and 1987 where evidence was retained in a sample of **homicides and sexual assault** cases that resulted in a conviction, the suspect is eliminated as a contributor for a probative evidence item, and that is supportive of exoneration in 5 percent of convictions.

- Second, we find that in convictions from VA between 1973 and 1987 where evidence was retained in an unbiased sample of convictions for **sexual assault cases**, the convicted offender is eliminated as a contributor for a probative evidence item, and that is supportive of exoneration in between 8 and 15 percent of convictions.[45] We note again that additional facts about the case not included in the forensic file may ultimately include the convicted offender. However, given that these are sexual assault convictions where the profile was determined to be male and excluded the convicted offender, we anticipate this will be relatively rare.

We also believe that since fewer than 10 percent of homicides where there was no sexual assault have a determinate result after DNA testing was performed on questioned evidence, the second finding is better supported by the data than the first. The second finding then leads to a follow-up, which is, where between 8 and 15 percent is the real rate of wrongful conviction?

Thus, the critical issue is how to impute outcomes for the convictions where evidence was indeterminate. Logically, there are three possible outcomes for the convictions with indeterminate results. First, it is possible that the 38 convictions with probative evidence that eliminates the convicted offender as the source include all of the convicted offenders who would have been eliminated had a determinate result been obtained. Second, it is possible that there are others who had indeterminate results who would have been eliminated as the contributor of probative evidence had a determinate result been obtained. However, the cohort of convictions with determinate evidence may have included a disproportionate number of convictions that eliminated the convicted offender. This would be the case, for instance, if cases with a PERK were more likely to be determinate *and* included a disproportionate number of convicted offenders who were eliminated as the contributors of probative evidence. Third, it may be the case that the cohort with a determinate result effectively approximates a random sample of all convictions, and thus it is appropriate to interpolate the determinate results on to the convictions with indeterminate results. There is a fourth possible outcome, that the convictions with determinate results underestimate the rate of elimination in the convictions with indeterminate results. However, there is little support for this claim in the data we have examined. Given the differences in the yield of physical evidence (e.g., the likelihood physical evidence would generate a profile and that profile would be determinate) described in Table 6, it seems likely that the answer lies in the second option, somewhere between the two extremes.

[45] The 8 and 15 percent statistics are not a range; rather, they are estimates for two different policy questions. The first answers the question, "What percentage of cases would eliminate a convicted offender if DNA evidence in a sample of convicted offenders with retained evidence were tested?"The convicted offender was eliminated as the source of questioned evidence in 33 out of 422 convictions (8 percent), and that elimination was supportive of exoneration. If the same question were asked, but only about those cases where a determination about the evidence could be made, than the answer would be that the convicted offender was eliminated as the source of questioned evidence in 33 out of 227 convictions (15 percent) where a determination could be made from the DNA analysis and that elimination was supportive of exoneration.

As was discussed in the report, it is technically possible to use regression models to impute the likely outcomes for each conviction with an indeterminate result. We chose not to do so and would counsel others to do the same. We follow Allison (2001), who cautions that data that are missing more than 15 percent of the time cannot be assumed to be missing at random. In this case, a determinate outcome is missing two-thirds of the time. Thus, we cannot assume that the convictions with indeterminate results are similar enough to convictions with determinate results to model their expected outcomes. Unless we can demonstrate that the finding of determinate/indeterminate is unrelated to DNA testing outcomes or we are able to observe these differences and account for them in our statistical models, such modeling is not appropriate. Since there are significant predictors of whether DNA testing results are determinate or indeterminate, and there are significant predictors of attributes that are related to convictions outcome, it is reasonable to presume that they differ on unobservable attributes as well. More important, while we can explain a substantial amount of the variation in the DNA testing outcomes, our models explain very little of the variation in whether a DNA testing result was determinate and the presence of unobservable heterogeneity likely lead to biased results.

It is tempting to make a back-of-the-envelope calculation to estimate where between 8 and 15 percent the truth lies. To do so, one could simply assume that the relationship between the type of evidence in convictions with determinate results and the outcome (inclusion/elimination) is the same in convictions with determinate and indeterminate results. Then, one would need only to look at the prevalence of evidence types in all convictions (determinate and indeterminate) to estimate the wrongful conviction rate. So, for instance, if X percent of convictions with a PERK are found to be eliminations, and the prevalence of PERK is the same in convictions with determinate and indeterminate results, then we could simply interpolate those same convictions outcomes for those with indeterminate results. However, our data suggest that many factors are related to the conviction outcome beyond evidence type, and such simplifying assumptions are unlikely to yield robust estimates.

We note that a standard question in social science is whether an observed outcome is large or not. In this case, given that even our most conservative estimate of exclusion in support of exoneration is larger than previous estimates, we believe our result is unquestionably a large number. Even our most conservative estimate suggests that 8 percent (or more) of sexual assault convictions in a 15-year period may have been wrongful. That means hundreds, if not more than a thousand, convicted offenders may have been wrongfully convicted.[46] That also means hundreds (if not more) victims have not received the just result, as previously believed. Therefore, whether the true rate of potential wrongful conviction is 8 percent or 15 percent in sexual assaults in Virginia between 1973 and 1987 is not as important as the finding that these results require a strong and coordinated policy response.

Finally, we encourage policymakers to consider one final effect of this study on victims of sexual assault in VA between 1973 and 1987. The identities of the convicted offenders who were excluded from DNA testing as the contributor of questioned evidence cannot be shared due to the need to protect the confidentiality of the human subjects involved in this study. Thus, the number of victims of sexual assault who can be legitimately concerned that justice was not done in their case

[46] In order to determine how many wrongful convictions there are in the period, we would need to know how many of the more than 20,000 forcible rapes resulted in a felony conviction. That statistic is not available.

includes all victims of sexual assault where the case resulted in a convicted offender, not just in cases where a convicted offender was eliminated. Only in cases where a convicted offender has been exonerated can that distinction be publicly observed.

References

Allison, Paul. 2001. *Missing Data.* Thousand Oaks, CA: Sage Publications, Inc.

Burnham, K. P. and D. R. Anderson. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd ed. Springer-Verlag.

Conners, E., T. Lundregan, N. Miller, and T. McEwen. 1996. *Convicted by Juries, Exonerated by Science: Case Studies in the Use of DNA Evidence to Establish Innocence After Trial.* Washington, DC: National Institute of Justice.

DeForest Peter R.,. Robert E. Gaensslen, and Henry Lee. 1983. *Forensic Science: An Introduction to Criminalistics*. New York: McGraw-Hill.

Friedman, A. L. 1999. "Forensic DNA Profiling in the 21st Century." *International Journal of Offender Therapy and Comparative Criminology 43*(168).

Garrett, Brandon. 2008. "Judging Innocence." *Columbia Law Review 108*(1).

Gross, Samuel, Jacoby Kristen, Daniel Matheson, Montgomery Nicholas, and Sujata Patil. 2005. "Exonerations in the United States, 1989 through 2003." *Journal of Law and Criminology* 95(2).

Gould, J., and R. Leo R. 2010. "Centennial Symposium: A Century of Criminal Justice: II. 'Justice' in Action: One Hundred Years Later: Wrongful Convictions After a Century of Research." *Journal of Criminal Law and Criminology 100*(3).

Hickman, M. J,. and J. L. Petersen. 2004. *50 Largest Crime Labs, 2002*. Bureau of Justice Statistics Fact Sheet. Washington, DC: Bureau of Justice Statistics.

Innocence Project web site. http://www.innocenceproject.org/

Jeffreys, A. J., V. Wilson, and S. L. Thein. 1985. "Hypervariable 'Minisatellite' Regions in Human DNA." *Nature* 314(6006).

Jobling, M. A., and P. Gill. 2004. "Encoded Evidence: DNA in Forensic Analysis." *Nature Reviews Genetics 5*(10).

Kansas v. March, 278 Kan. 520, 102 P. 3d 445, 2006. Concurring Opinion, Justice Antonin Scalia.

Kreimer, S. F., and D. Rudovsky. 2002. "Double Helix, Double Bind: Factual Innocence and Post Conviction DNA Testing." 151 *University of Pennsylvania Law Review 151*(547): 554.

Marquis, Joshua. 2006. "The Innocent and the Shammed." *New York Times.* http://www.nytimes.com/2006/01/26/opinion/26marquis.html.

Paternoster, R., R. Brame, S. Bacon, A. Ditchfield, K. Beckman, N. Frederique, et al. 2003. *An Empirical Analysis of Maryland's Death Sentencing System with Respect to the Influence of Race and Legal Jurisdiction*. University of Maryland, Department of Criminology. College Park: Report to the Governor of Maryland.

Peterson, J. L., S. Mihajlovic, and J. L. Bedrosian. 1985. "The Capabilities, Uses, and Effects of the Nation's Criminalistics Laboratories." *Journal of Forensic Sciences* 30(1).

Peterson, J. L., J. P. Ryan, P. J. Houlden, and S. Mihajlovic. 1987. "The Uses and Effects of Forensic Science in Adjudicating Felony Cases." *Journal of Forensic Sciences* 32(6): 1730–53.

Peterson, J. L., and M. J. Hickman. 2005. *Census of Publicly Funded Forensic Crime Laboratories, 2002*. Washington, DC: U.S. Department of Justice, Bureau of Justice Statistics.

Roman, J, S. Reid, A. Chalfin, and C. Knight. 2009. "The DNA Field Experiment: A Randomized Trial of the Cost- Effectiveness of Using DNA To Solve Property Crimes." *Journal of Experimental Criminology 5*(4).

USDOC Exports. 1984. Washington, DC: United States Department of Commerce. Bureau of the Census.

Weedn, V. W., and J. Hicks. 1998. *The Unrealized Potential of DNA Testing*. Report to the National Institute of Justice. Washington, DC: National Institute of Justice.

Wise, J. 2004. "Under the Microscope: Legal Challenges to Fingerprints and DNA as Methods of Forensic Identification." *International Review of Law Computers & Technology* 18(3).