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

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[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

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[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.

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[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	Exculpatory	Total	Significance of Difference
	(n=187)	(n=40)	(n=227)	
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.

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[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.

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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

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[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

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[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

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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.

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[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

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[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.

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