Patterns of Concordance Between Hair Assays and Urinalysis for Cocaine: Longitudinal Analysis of Probationers in Pinellas County, Florida

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ABSTRACT

This chapter reports on a field trial involving the application of hair assays to a probation population. The objectives were to evaluate the general reactions of probation officers and probationers to the collection of hair samples, to compare the outcomes of the hair samples with the outcomes of urinalyses (which the probationers undergo routinely), to note and react to differences in the prevalence as indicated by the two assay types, and to assess the general monitoring potential for hair assays in a correctional setting. In general, hair assays showed an increased capability of detecting cocaine exposure when compared to urinalysis. The detection of cannabis was, however, problematic for hair. The hair assays, using urine as a comparator, appeared to result in several apparent false negatives for cannabinoids. There were no false negatives for cocaine, and an approximately fourfold increase in the detection rate when compared to urine. The collection of hair samples was not difficult and the cooperation of the probationers was quite good. Probation officers appear to prefer the use of hair specimens to urine specimen collection, and appeared enthusiastic about the potential use of hair analysis in their routine monitoring of clients.

INTRODUCTION

This chapter reports on a pilot study evaluating probationers' use of illicit drugs. Normally, probationers would undergo drug testing by urinalysis alone, but they were also monitored by hair assays. Among the major objectives of the project were to evaluate the differences, if any, in drug prevalence rates as measured using both hair and urine specimens and assess the clinical utility of using hair assays as a

supplement to urine testing in evaluating the likelihood of drug use or exposure in this sample group.

This chapter focuses primarily on the concordance outcomes of cocaine assays for hair and urine specimens. Data are presented on the overall concordance of hair and urine assays and the configurations of individual case assay results. The authors discuss the possible interpretation of these outcomes as they bear on the potential utility of hair analysis in various field settings.

BACKGROUND

Criminal justice and correctional agencies are often required by law or executive mandate to do drug testing on persons under their control. Consequently, persons who are convicted of a crime and sentenced to probation frequently are required to submit to on-demand random drug testing. Urinalysis testing, based on low-cost, rapidly readable, immuno-assay technology, often is done with small portable kits read directly by the case officer; it has become universally used by correctional agencies.

Refraining from use of illegal drugs is a typical condition imposed on probationers. In the attempt to monitor convicted persons and their potential use of drugs, correctional agencies are often the most active users of drug-testing services within State criminal justice agencies. The Bureau of Justice Statistics (1992), for example, recently estimated that approximately 500,000 urinalysis tests for illicit drug use are conducted annually by correctional agencies.

Drug testing also has been shown to be effective in reducing drug consumption when implemented in probationary settings and a useful, even critical, component of treatment (Speckart et al. 1989). It also helps classify incoming offenders into particular programs (Deschenes and Anglin 1992), and can be used to verify claims of drug addiction or to monitor for exposure to methadone (Brewer 1993). Having accurate data on prevalence of drug use by type may also aid officials seeking a more effective use of system resources. It must be remembered that probation officers do not automatically issue a violation to probationers who test drug positive (+) by a bioassay. They will view the occurrence of a (+) test in a larger context and may choose to ignore it, offer some warning or minor operational penalty, or even write an official violation. The utility of a drug assay for a probationary setting is directly tied to the extent to which

it reveals accurate and refined information about a probationer's drug activities. Officers use assays in an investigatory manner in making judgments about probationers and their involvement with drugs. But it is important to stress that the assay outcomes are not judgments in and of themselves from which punitive consequences inevitably flow.

Cocaine, by a very large order of magnitude, continues to be one of the most prevalent abused, illicit drugs within the criminal justice system. Cocaine arrests nationwide, for example, occur at rates 2 to 3 times those of other popular drugs such as marijuana, heroin, or lysergic acid diethylamide (LSD) (National Institute of Justice 1993). If one examines self-reported prevalence in Pinellas County, Florida, cocaine ranks second only to marijuana among criminal offenders as the most prevalent drug of choice (Mieczkowski and Newel 1993). Its use is twice (or more) that of other hard drugs in national prevalence in criminal justice populations at all levels of processing (Bureau of Justice Statistics 1992).

Because cocaine and its metabolites are rapidly excreted from the body via urine, evasion of detection by urinalysis is a widespread problem for agencies concerned with drug monitoring. Being drug positive can result in punitive action, so probationers generally do not want to reveal drug use to their probation officer, and will normally attempt to evade detec- tion. Random testing, which can make evasion difficult, is often proble-matic and expensive to effectively implement on a wide scale. This is to a large degree a result of the typically large caseloads of probation officers (see, for example, Mieczkowski et al. 1994). Users can often enhance their chances of defeating the testing with a variety of simple tactics. For example, skipping an appointment and receiving even a 24-hour delay in providing a urine specimen dramatically increases the probability of falling below the cutoff value for cocaine. Another fre-quently used tactic, often combined with the first, is to consume large quantities of fluids during the delay period. There is also a thriving retail trade that sells a number of organic and natural urinalysis-defeating compounds.

Evasion Tactics for Urinalysis

As a consequence, hair analysis has been suggested as a supplement to urine testing because it offers a long retrospective window of detection and is more difficult to evade. Hair can reveal cocaine exposure from approximately 1 week to several months after it has occurred, provided the person has hair of sufficient length. It has also been suggested, although there is controversy about this, that hair

assay values may correlate with the amount of cocaine ingested, and thus might be used to evaluate both qualitative and quantitative exposure to the drug (Mieczkowski et al. 1991). Several studies have established correlations between self-reported cocaine use and aggregate hair assay values (Hoffman et al. 1993; Magura and Kang, in press; Mieczkowski and Newel 1993) and between mother and neonatal hair levels (Callahan et al. 1992). Others, however, have reported inconsistent correlation outcomes with controlled-dose cocaine-administration trials with human volunteers (Henderson et al. 1993).

Preliminary research shows that it is difficult to remove sequestered drugs from hair in sufficient amounts to defeat a sensitive assay entirely (Allgood et al. 1991). Hair also has other advantageous properties: It is relatively inert, low in septic potential, easy to transport, and easy to store. Hair assay is thus an appealing technology in correctional settings.

Hair analysis has other potential uses in settings beyond drug monitoring in correctional settings. It has forensic utility, for example, in evaluation of suspicious deaths (Staub 1993). It has potential utility in drug epidemiology, especially for validation of data based on drug use self-reports. The Committee on Government Operations of the House of Representatives (1993) has recently recommended that in major drug use surveys conducted by the Federal Government, researchers investigate ways to evaluate the study's validity by using hair assays. Hair analysis has proven useful in medical contexts, both as a diagnostic tool for determining exposure to cocaine (Marques et al. 1993; Welch et al. 1990), and a therapeutic tool in drug treatment settings (Brewer 1993; Mieczkowski et al. 1994).

A review of the basic literature on hair assay technology is beyond the scope of this chapter. It has been done at length previously, and the size of this literature has now grown so large that such a discussion would fill scores of pages. Several excellent articles comprehensively review the technology of hair assays (Chatt and Katz 1988; Harkey and Henderson 1989; Mieczkowski 1992; NIDA 1995).

ASSUMPTIONS ABOUT HAIR ASSAY TECHNOLOGY

The following assumptions regarding hair assay technology have underpinned the preparation of this chapter.

1. Hair assays are able to detect cocaine and its principal metabolites benzoylecognine, ecognine methyl ester (EME), norcocaine, and several other metabolic cocaine byproducts. Detection of cocaine is possible by several different analytic techniques and can be done at high levels of sensitivity and specificity (Harkey et al. 1991). Hair assay technology for cocaine is effective whether or not the underlying technique is an immunoassay-based procedure or a chromatographic and spectrometric procedure. In effect, there is no major scientific disagreement about whether cocaine can be detected in hair. However, the appropriate interpretation of the assays has engendered controversy, a few examples of which follow. Can sufficient cocaine be acquired through casual environmental contact to confound the interpretation of the test? Does externally applied cocaine bond strongly enough to hair to defeat washing or wash-to-analyte ratios as criteria for passive versus active exposure?

2. Although individual variation of dose-assay values has not been widely studied in controlled environments, existing epidemiological data support the observation that with aggregated data sets, groups of persons who on average are more intensely using cocaine (large amounts, frequently consumed) will have higher average hair assay values than groups of persons using cocaine in smaller amounts less frequently (Graham et al. 1989; Hoffman et al. 1993; Mieczkowski and Newel 1993). However, no average dosage consumption can be quantitatively determined by reference to the quantitative value of a hair assay outcome. The authors have elsewhere recommended that quantitative hair assay data be treated as rank-order data and comparisons of repeat assays be used only intrasubjectively in clinical applications (Mieczkowski and Newel 1993).

3. Because the range of individual biovariability for cocaine assays of hair is not known, the comparison of assay values across subjects is done with substantial risk of accurate interpretation. But the comparisons of assay values taken over time for a specific individual appear to be a useful method in many circumstances for determining relative intensity of exposure over time (Brewer 1993; Martz et al. 1991).

4. Hair assays, like all other assays of tissues and fluids, measure only exposure to a substance. Generally, assays cannot themselves determine the actual method or conditions under which the exposure took place. They can only provide limited information. Decisions regarding the volitional ingestion of illicit drugs will always require human judgment. Biological assays can help support or refute particular judgments but cannot make them.

5. Passive contamination is an important consideration in making decisions about the nature of drug exposure in any assay procedure, including urine, blood, or other tissues. Researchers, for example, have reported that they cannot completely remove passively applied cocaine from the hair surface after in vitro vapor contamination (Cone et al. 1991). However, the distinction between external contamination and ingestion is sometimes clinically irrelevant. It has been proposed that passively exposed hair and hair from cocaine users can be distinguished on the basis of the ratios of wash assay values to analyte values, and, when possible, of endogenous metabolites (Baumgartner and Hill 1990, 1992). If this is correct, then a complete removal of external contaminants may not be required in many clinical circumstances. Koren and colleagues (1992) have reported on an application of this procedure that allowed them to readily distinguish passive from active contamination. Cone (1994) has recently suggested that cocaine-to-benzoylecognine ratios greater than 0.05 nanograms/milligram (ng/mg) may distinguish use from contamination, and that norcocaine and cocaethylene may, in some circumstances, act as definitive markers of cocaine ingestion as opposed to environmental exposure and surface contamination.[1]

In this chapter, the authors hold the view that the distinction between inadvertent casual exposure and meaningful, frequent contact via consumption can be made with a relatively small chance of error in most clinically relevant circumstances. External contamination versus internal (inadvertent or unknown) contamination can be evaluated by using both wash kinetic procedures and relying, when possible, on detecting endogenous metabolites (Koren et al. 1992).[1] Furthermore, the use of conservative cutoff values for evidentiary applications can help further reduce the likelihood of a false determination. Walsh (unpublished data), for example, has done a long-term quality assurance study of Baumgartner's assay technique. Walsh found that during the submission of more than 900 blind samples using both positive and negative standards, no false positive

assays (i.e., reporting the presence of a drug in a negative control) were reported; there were only five false negatives (i.e., failure to detect a drug in a known positive standard) and these were all in samples categorized as low-concentration standards.

METHODOLOGY

The present study relied upon volunteer participation by both probation officers and probationers. It is thus a convenience sample, and there are no statistically meaningful ways that these data can be generalized. The sample was created with the permission and cooperation of the Florida Department of Corrections. A detailed description of the study methods can be found in Mieczkowski and colleagues (1994).

A solicitation to all active probation officers in the Pinellas/Pasco County region was issued by the research team to recruit 20 volunteer officers as participants. As an incentive, the volunteer officers were given a training stipend of $200, a commendation and recognition plaque, and a letter of recognition for their files on completion of their participation. Each volunteer officer was asked to identify and recruit 8 to 10 probationers in his or her caseload who were currently undergoing regular monthly urinalysis. Their task was to enlist the cooperation of these persons during a 6-month project in which the officer would collect a monthly urine and hair specimen from each probationer. Probationers who volunteered received the incentive of having the project pay for the routine urinalysis (which they would normally have to pay for themselves), which represented a cost savings to them of approximately $36 in laboratory fees (note that these probationers had to undergo monthly urinalysis as a normal condition of probation, regardless of their participation in the project).

Probationers who volunteered also underwent a special, one-time interview at the project startup, administered by their case officer. This interview queried them about, among other things, their drug use history, their hair hygiene habits, and several aspects of their activities, such as recreation and water sports, that have been suggested as having possible impact on the outcome of the hair assays. Outside of this intake interview, all other interactions between probation officer and probationer were designed to be as they would occur routinely. The objective was to make the hair assay protocol as unobtrusive and natural to the normal operational context as possible.

While urinalysis outcomes were reported to probation officers (as would be true of the normal routine), hair assay values were not. No decisions of any sort were made on the basis of using hair assays to establish abstinence or exposure to illicit drugs.

The urinalyses were done by Operation PAR's certified laboratory using enzyme-multiplied immunoassay technology (EMIT) and employing current National Institute on Drug Abuse (NIDA)-endorsed cutoffs for urinalysis. Hair segments were collected; the first 2.6 centimeters (cm) were used in the assay. (Hair samples roughly correspond to behavior over the past 60 days.) Only about 1 percent of hair specimens were of shorter length, and that length ranged from 1.4 to 2.0 cm. The hair assays were analyzed using thresholds recommended by the testing laboratory for epidemiological research work. For cocaine, this threshold is 2 ng/10 mg of hair specimen. In field applications, a higher cutoff value of 5 ng/10 mg is generally recommended. Tandem mass spectrometry confirmations were done on a number of cannabinoid cases (approximately 75). Data on the outcomes of these confirmations have been reported elsewhere (Mieczkowski 1995).

DATA

The volunteer officers were able to recruit 152 probationers, and over the course of the 6-month project 62 were lost for a variety of reasons. By the end of the project, there were 89 probationers who had been enrolled since the first month. Recruitment and retention of probationers and the number of hair and urine samples retrieved each month are reported in table 1.

Of the 89 cases with 100 percent participation, 36 were negative on all assays (both hair and urine) for all drugs; 53 had at least one drug (+) assay on at least one sample. Thirty-six completed cases were drug (-) for all assays and all specimens, as were 26 incomplete cases. Thus, "double-drug negatives" was the most common outcome. The second most frequent outcome was "double positive," that is, if one specimen were positive, it was highly likely that the other specimen would be positive as well. There were 33 such complete cases with at least one (+) assay for each specimen. The complete series of these 33 outcomes for cocaine, cannabinoids, and opiates is listed in appendix 1.

TABLE 1. *Summary count of samples.*

Number of hair and urine samples	Number of cases	Percent (rounded)
1	152	21.7
2	135	19.3
3	117	16.7
4	104	14.9
5	101	14.3
6	89	13.0
Total	698	100.0

The least likely outcome was the occurrence of a positive urine assay with a negative hair assay, and that was equally true for complete and incomplete cases. The final alternative, a (-) urine assay but a (+) hair assay, was also less likely than the double (+) or double (-) outcomes, but more frequently occurring than hair (-)/urine (+) outcomes.

Table 2 is a cross-tabulation that compares dichotomous hair and urine outcomes for cases with six pairs of specimens. There was a loss of some samples due to insufficient mass, leaving the number of assayable urine and hair sample pairs at 503. Table 2 presents the joint outcome distribution of the hair assays for any drug in the hair panel, and any drug in the urine panel for which both hair and urine specimens were tested (n.b., this excludes benzodiazepines and amphetamines, which were a part of the urinalysis panel but not included in the hair assay). The single most frequent outcome is the concordance between double negative cases (N = 260), while the least frequent outcome is a urine (+)/hair (-) (N = 12). Hair (+)/urine (-) cases constitute the second most frequent combination (N = 145), and double (+) cases the third most prevalent (N = 86).

The basis of the analytic approach here is to assume that different outcome probabilities are associated with different cells. These differential outcome likelihoods are based on what the concordant and nonconcordant cells are likely to represent in clinical reality. In addition,

TABLE 2. *Contrasting hair and urine samples for any assayed drug.*

Hair assay for any drug	Urinalysis for any drug (-)	(+)	Row total
(-)	260	12	272 (54.1%)
(+)	145	86	231 (45.1%)
Column total	405 (80.5%)	98 (19.5%)	503 (100.0%)

these assumed probabilities reflect the experiences of the authors' earlier work and the outcome patterns found in approximately 2,000 cases they have previously examined.

CONCORDANT CASES

In any given criminal justice population, some number of persons will test negative by both assays, cases the authors characterize as "double (-)'s." In Pinellas County, this "double (-)" pattern has consistently been the most prevalent of all possible cell outcomes. Generally, the authors believe that the most plausible clinical interpretation of this outcome is that it indicates a person who is not exposed, or is exposed below the measurable limit of detection or cutoff value for the assayed drug for both chronic and acute time frames.

The authors have usually found subjects who are (+) on both hair and urine assays ("double (+)'s") to be third in ranking the prevalence of cell frequencies for the 2-by-2 tables. The most plausible interpretation of this finding seems to be that it indicates chronic exposure to the assayed substance. The authors have also found in earlier work with cocaine users that persons in this category who show a high concentration of cocaine in their hair assay are very likely to test urine (+) for cocaine (Mieczkowski and Newel 1993). Research on arrestee populations in Pinellas County showed that when the concentration of cocaine exceeds 10 ng/mg of hair, the likelihood of being simultaneously urine positive for cocaine approaches 90 percent (Mieczkowski and Newel 1994).

NONCONCORDANT CASES

There are two possible nonconcordant outcomes: hair (+) and urine (-) or hair (-) and urine (+). While each of these outcomes is nonconcordant, each implies quite different interpretative possibilities. The authors have found in previous work that, with cocaine, there are substantial numbers of cases that are hair (+)/urine (-) and few urine (+)/hair (-) cases.

The authors have interpreted this general pattern—that over many cocaine assays one should find substantially more hair (+)/urine (-) outcomes—as an indicator of the ability of the hair assay to accurately detect cocaine for a longer retrospective time than urinalysis. However, this capability and its exact relationship can obviously be influenced by many factors, including the amount of drug consumed, the potential to become heavily environmentally contaminated, the purity of drug consumed, and the use of particular cutoff values for the assay procedures.

Considering cocaine in particular, one category of nonconcordant cases, hair (-)/urine (+), is of special significance. These cases are of particular interest because one expects to find very few, if any, such cases in these sample populations. Because cocaine is rapidly excreted from the urine, the plausible ways by which a person can become hair negative and urine positive are limited. Previous work has supported this conjecture. The authors believe that for a drug rapidly excreted via urine (e.g., cocaine) it would be difficult to explain a high rate of frequency for these cases, especially in a criminal justice-based population with a substantial history of drug involvement. While one would expect a few persons to be assayed as urine (+)/hair (-) for cocaine, large numbers would be an indication of the failure of the hair assay. The authors have previously published hair and urine data on cocaine prevalence rates within criminal justice populations that have corroborated the expectations of few hair (-)/urine (+) cases. In the authors' previous work, these cases appear at rates of less than 1 out of every 100 persons tested.

As table 2 has shown, considering any drug for which both the urine and hair were assayed, 12 samples derived from 9 cases fall into the "least plausible" category (cell II) of being hair (-) but urine (+). These cases are termed "paradoxical" given the reasons outlined above. Table 3 is a listing of the 9 cases from which these 12 paradoxical samples were derived and the substance detected.

As table 3 shows, of the 12 samples, 10 are (+) for cannabinoids and 2 are positive for opiates. It is important to note that none of these cases involves cocaine. If the analysis is expanded to include probationers who

TABLE 3. *Urine (+)/hair (-) cases.*

Case #	Sample #	Substance detected
2-8	2	Cannabinoids
	3	Cannabinoids
	6	Cannabinoids
4-4	1	Cannabinoids
5-4	1	Cannabinoids
11-9	1	Cannabinoids
12-11	1	Cannabinoids
	2	Cannabinoids
13-5	6	Opiates
13-8	1	Cannabinoids
15-6	1	Opiates
17-3	1	Cannabinoids

did not complete the study, one finds two cases that have single cocaine (+) urine and no cocaine (+) hair. Table 4 displays the concordance of hair and urine cocaine assays for all cases, both completed and non-completed.

Table 4 includes all 698 hair and urine specimens from the 152 original probationers, including specimens from cases that did not complete the project. In cell II, one finds two cocaine (+) urines that have corres-ponding hair (-) assays for cocaine, both coming from incomplete cases.

In both situations, the cocaine (+) urine was obtained on the last proba- tioner visitation, so no subsequent hair samples were gathered to evaluate whether the hair in later assays would test cocaine (+). Remember that cocaine detected in the urine at time t_1 would not be detected in the hair for at least 7 days. Because of this time differential for the two specimens, one would not expect the hair assay to detect very recent cocaine use. Had additional hair specimens been taken from these persons, the assay

TABLE 4. *Contrasting hair and urinalysis outcomes for cocaine.*

Hair assay cocaine	Urinalysis for cocaine (+)	(-)	Row total
(-)	592	2	594 (85.2%)
(+)	80	24	104 (14.8%)
Column total	672 (96.3%)	26 (3.7%)	698 (100.0%)

might have detected the cocaine indicated by the urine. Pertinent infor-mation on these two paradoxical cases (#18-8 and #4-5) is listed below. Table 5 shows the concentration of drug in hair (in ng/10 mg hair analyte) except for marijuana, which is dichotomized. The case tables also show whether the urinalysis was positive or negative, and, if positive, for what drug or drugs. The last column shows the time interval in weeks between each specimen collection. Self-reported drug use is not shown in the tables.

TABLE 5. *Findings for two paradoxical cases.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
Case #18-8							
1	0	0	QNS	(+)	Cannabis	0	
2	0	0	QNS	(+)	Cannabis	0	2
3	0	0	QNS	(+)	Cocaine	0	4
Case #4-5							
1	0	0	(+)	(-)	0	0	
2	5	0	(+)	(-)	0	0	6
3	19	0	QNS	(-)	0	0	7
4	0	0	QNS	(-)	0	0	6
5	0	0	(+)	(+)	Cocaine	0	2

KEY: Coc = cocaine, Ops=opiates, Mj=cannabinoids, hr = hair, QNS = hair sample quantity insufficient for analysis. These abbreviations also apply to subsequent case tables.

Case #18-8 was a noncompleted case with a cocaine (+) urinalysis on the final urine specimen. Case #4-5 has a similar configuration to

case #18-8. Both had a single cocaine positive urine on their last collected sample. But notice that for case #4-5, cocaine had been detected in the hair in earlier samples (2 and 3).

If one considers the cocaine outcomes using only cases that completed the entire 6 months of the study, there are no paradoxical outcomes in the data set; that is, no cases that had a urine (+) for cocaine, but a (-) hair assay for cocaine. In short, when cocaine was found in the urine, it was always found in the hair.

LOOKING AT INDIVIDUAL CASES: ALL COMPLETED PERSONS TESTING (+) FOR A DRUG

Considered next are the 33 cases that have the common characteristic that they tested (+) for a drug in one or more specimens, either hair, urine, or both. These cases and their respective assay outcomes are listed in appendix 1. Recall that of the 89 completed cases, 56 were (-) for any drug, and 33 were (+) for at least one drug in at least one specimen.

Of these 33 cases, 17 were (+) for a drug other than cocaine. That is, although these cases were (+) for one of the screened drugs, they were (-) for cocaine in all urine and hair specimens. Sixteen cases were cocaine (+) in one or both specimens. The complete breakdown of these 33 cases is illustrated in figure 1.

Figure 1 shows that 6 cases had one or more cocaine (+) hair assays, but had no cocaine (+) urine outcomes and 10 cases tested cocaine (+) in both the hair and urine specimens. In no cases were there more (+) urine outcomes than (+) hair outcomes. In every case but one, the hair assay detected cocaine more frequently than did urine. In a single case cocaine was detected once by each specimen.

THE SIX COCAINE (+) CASES IDENTIFIED BY HAIR ASSAYS ONLY

The following series of tables summarizes and describes the six cases that had no cocaine (+) urine outcomes but had one or more cocaine (+)

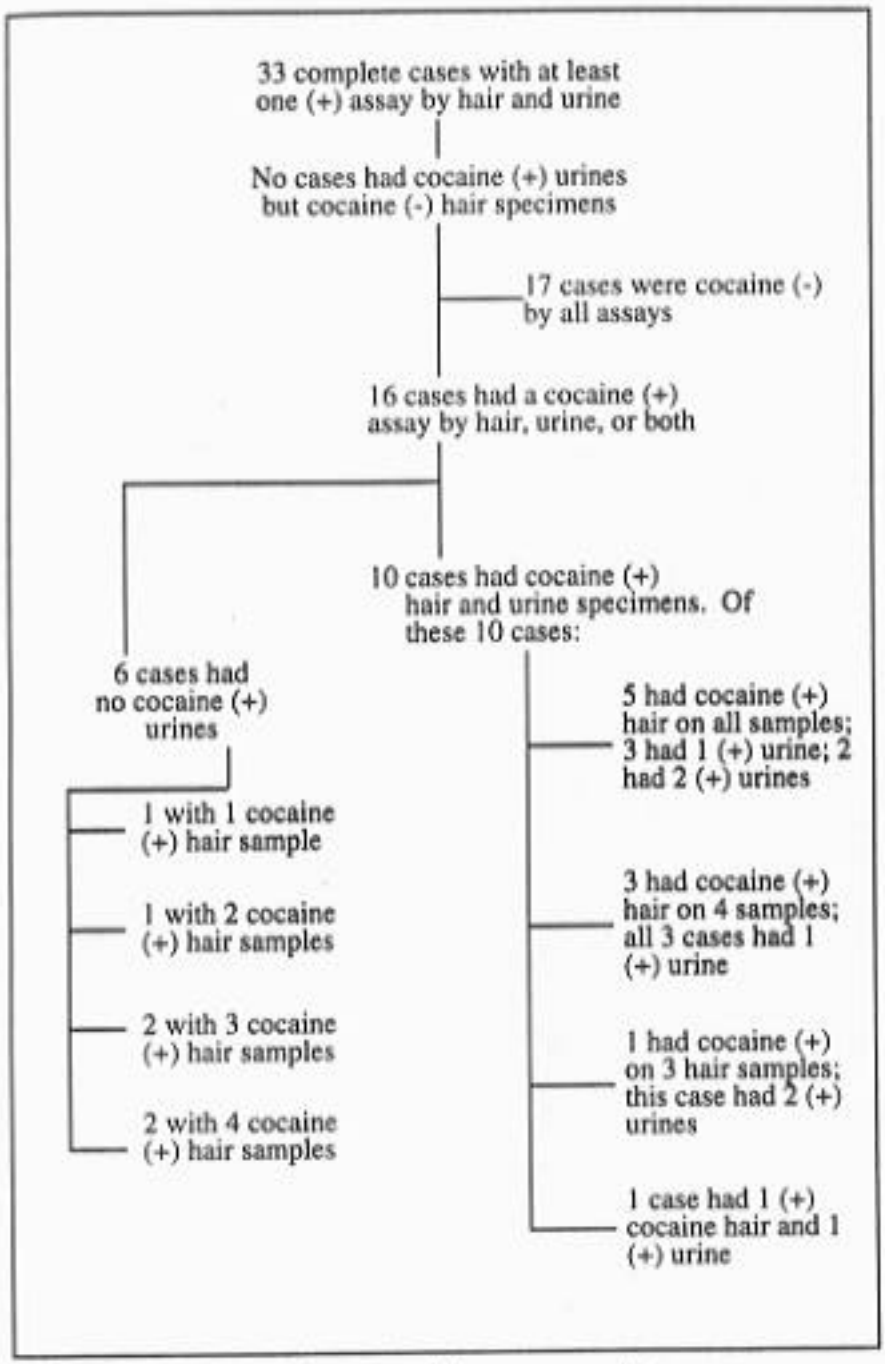

FIGURE 1. *Outcomes for cases with one or more (+) assays.*

hair assays. These probationers would have been identified as cocaine (+) if hair assays were part of the monitoring program.

Case #3-5 (table 6) had a self-reported history of cocaine and marijuana use, but assay outcomes seem to indicate abstinence during the study. Cocaine appears in the first two hair samples, but never appears in the urine. Diazepines, however, were detected in the final urinalysis.

Case #11-9 (table 7) presents an interesting pattern. This person self-reported a history of alcohol and cocaine use. Initial urine assay showed that the person tested (+) for cannabinoids at intake, but tested (-) in all five subsequent urinalyses. For samples 4, 5, and 6, the person tested hair (+) for cocaine at very high levels, but did not test urine (+) for cocaine. Also notice that the level of cocaine in the hair specimen dropped in each

TABLE 6. *Case #3-5. Urine (-), hair (+) cocaine assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	40	0	(-)	(-)	0	0	
2	9	0	(-)	(-)	0	0	4
3	0	0	QNS	(-)	0	0	2
4	0	0	QNS	(-)	0	0	3
5	0	0	(-)	(-)	0	0	4
6	0	0	(-)	(+)	Diazpn.	0	4

hair assay by roughly half over each test period, even though the testing time interval was shortened for samples 5 and 6. These reductions may indicate abstinence or markedly reduced cocaine use after the time of harvesting the fourth sample.

Case #12-1 (table 8) refused to provide any self-report information on drug use. The outcome pattern is somewhat like case #11-9 (table 7). This person tested (+) for diazepines on five out of six urinalyses, but did not test (+) for any other drug in the urine. However, every hair assay

TABLE 7. *Case #11-9. Urine (-), hair (+) cocaine assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	0	0	(-)	(+)	Cannabis	0	
2	0	0	(-)	(-)	0	0	4
3	0	0	(-)	(-)	0	0	4
4	561	0	(-)	(-)	0	0	4
5	361	0	(-)	(-)	0	0	2
6	153	0	(-)	(-)	0	0	3

TABLE 8. *Case #12-1. Urine (-), hair (+) cocaine assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	0	142	(-)	(+)	Diazpn.	0	
2	0	96	(+)	(+)	Diazpn.	0	4
3	53	850	(+)	(-)	0	0	4
4	113	75	(+)	(+)	Diazpn.	0	4
5	64	79	(+)	(+)	Diazpn.	0	4
6	26	145	(+)	(+)	Diazpn.	0	4

was opiate (+), and the quantitative values for the test were very elevated. As well, results were cocaine (+) for hair on four consecutive samples (3, 4, 5, and 6).

Case #12-8 (table 9) also refused to provide any self-report information on illicit drug use. Hair and urine samples 1 and 2 were (+) for cannabinoids, and hair samples 4 and 5 were cannabinoid (+) as well. Hair samples 1 and 2 were confirmed for cannabinoids by gas chromatography/mass

TABLE 9. *Case #12-8. Urine (-), hair (+) cocaine assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	0	0	(+)	(+)	Cannabis	0	
2	0	0	(+)	(+)	Cannabis	0	4
3	0	0	QNS	(-)	0	0	4
4	30	0	(+)	(-)	0	0	5
5	25	0	(+)	(-)	0	0	4
6	5	0	QNS	(-)	0	0	4

spectrometry/mass spectrometry (GC/MS/MS). Notice that hair samples 4, 5, and 6 were cocaine (+), but no cocaine was ever detected in the urine.

Case #13-5 (table 10) refused to provide any information on drug use and was negative for all assays on intake. However, there was a very large time gap (14 weeks) between the first and second sample collection. The second hair sample tested (+) for cocaine, but at a low level. All subsequent hair assays were (-), and only the final urine specimen has a (+) outcome

TABLE 10. *Case #13-5. Urine (-), hair (+) cocaine assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	0	0	(-)	(-)	0	0	
2	9	0	(-)	(-)	0	0	14
3	0	0	(-)	(-)	0	0	3
4	0	0	(-)	(-)	0	0	4
5	0	0	(-)	(-)	0	0	4
6	0	0	(-)	(+)	ops.	0	2

for opiates. Since there were no subsequent hair samples, the appearance of opiates in the hair following this (+) urine cannot be evaluated.

Case #14-5 (table 11) represents the last case of those persons who had at least one cocaine (+) hair sample but no cocaine detected in the urine. This person self-reported use of marijuana, but did not report any use of cocaine or opiates. As the table indicates, the person had three urine (+) outcomes for cannabinoids and two for diazepines. This person tested cannabinoid (Mj) (+) by hair assay for every hair

specimen collected during the study. Additionally, the person had two low-level opiate (+) hair samples (2 and 4) and four consecutive cocaine (+) hair specimens. Neither of these substances was ever detected in the urine.

TABLE 11. *Case #14-5. Urine (-), hair (+) cocaine assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	30	0	(+)	(+)	Cannabis	0	
2	26	5	(+)	(-)	0	0	4
3	7	0	(+)	(+)	Cannabis	0	4
4	26	3	(+)	(+)	Cannabis	0	5
5	0	0	(+)	(+)	Diazpn.	0	6
6	0	0	(+)	(+)	Diazpn.	0	4

CASES HAVING BOTH HAIR AND URINE COCAINE (+) SPECIMENS

As noted in figure 1, 10 cases were cocaine (+) in both their hair and urine specimens. In the following section the authors examine these 10 cases and their outcome configurations.

Cases With All Hair Assays Cocaine (+)

Five cases had all six hair specimens as cocaine (+) and either one, two, or three urine specimens as cocaine (+). The following set of tables presents the outcomes of these five cases. The consistently (+) cocaine hair assays support an interpretation of cocaine use, or very substantive and consistent exposure to cocaine. If a person with this pattern of assays denies using cocaine, one would certainly want to explore how these exposure levels could be attained, especially for those who have (+) urinalyses as well as consistently (+) hair outcomes.

Although case #2-4 (table 12) self-reported use of cocaine and marijuana, it was not detected in any hair or urine specimens provided by the subject. However, 4 of the 6 samples were QNS for cannabinoid assays. Cocaine was consistently detected in every hair sample at moderate levels, and was also detected in urine sample 6.

TABLE 12. *Case #2-4. All hair assays cocaine (+).*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	35	0	(-)	(-)	0	0	
2	14	0	QNS	(-)	0	0	5
3	21	0	(-)	(-)	0	0	4
4	32	0	QNS	(-)	0	0	4
5	16	0	QNS	(-)	0	0	4
6	38	0	QNS	(+)	Cocaine	0	5

Case #3-2 (table 13) self-reported use of marijuana and heroin, but did not report use of cocaine. Neither opiates nor cannabinoids were ever detected in any samples during the course of the study. Cocaine was detected in every hair specimen at low to moderate levels, and was detected twice in the urine (samples 2 and 4). Again, the cocaine (+) urinalyses linked with the consistent testing of the hair as cocaine (+) are indicative of cocaine use or exposure.

In case #3-11 (table 14), the person refused to provide any information on illicit drug use. This person tested cocaine (+) in hair on every sample at elevated values, and also tested cannabinoid (Mj) (+) on every hair

TABLE 13. *Case #3-2. All hair assays cocaine (+).*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	11	0	(-)	(-)	0	0	
2	34	0	QNS	(+)	Cocaine	0	6
3	33	0	QNS	(-)	0	0	4
4	29	0	QNS	(+)	Cocaine	0	6
5	53	0	(-)	(-)	0	0	4
6	28	0	(-)	(-)	0	0	4

TABLE 14. *Case #3-11. All hair assays cocaine (+).*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	527	0	(+)	(+)	Diazpn.	0	
2	901	0	(+)	(+)	Cocaine	0	4
3	550	0	(+)	(+)	0	0	4
4	330	0	(+)	(-)	0	0	8
5	399	0	(+)	(+)	Cocaine	0	4
6	265	0	(+)	(-)	0	0	4

sample. Only 2 cocaine urinalyses were positive (2 and 5), and there were no cannabinoid (+) urinalyses. In this situation, one sees an outcome very similar to case #3-2 (table 13), only here the cocaine hair assay values are much higher.

In case #5-2 (table 15), the person refused to provide any information on illicit drug use. This person tested cocaine (+) on every hair assay at moderate levels, and also tested cocaine (+) on a single urinalysis

TABLE 15. *Case #5-2. All hair assays cocaine (+).*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	37	0	(-)	(-)	0	0	
2	25	0	(-)	(-)	0	0	6
3	66	0	QNS	(+)	Cocaine	0	8
4	52	0	QNS	(-)	0	0	3
5	21	0	QNS	(-)	0	0	6
6	17	0	(+)	(-)	0	0	4

(sample 3). A single cannabinoid hair sample was positive (sample 6), and half the hair samples were too small to permit a cannabinoid assay.

In case #8-3 (table 16), the person refused to provide any information on illicit drug use. The person tested cocaine (+) at moderate to high levels for every hair sample, and tested cocaine (+) for a single urinalysis (sample 2). The quantitative values are consistent in samples 1 through 4, then increased by almost twofold in samples 5 and 6. This individual tested (-) for all other drugs.

In the authors' view, these cases demonstrate either failure to detect, or sporadic detection of, cocaine by urinalysis with unreliable self-reports to the probation officer. This stands in contrast with the consistent detection of cocaine by hair assay. This analytic result suggests that hair analysis can be a useful comparison for urine outcomes.

Cases With Four or Fewer Cocaine (+) Hair Assays

There are three cases where four of the six hair samples tested cocaine (+). In all three of these cases, there was only one cocaine (+) urine specimen. The following tables present the outcomes for these three cases.

TABLE 16. *Case #8-3. All hair assays cocaine (+).*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	112	0	(-)	(-)	0	0	
2	117	0	(-)	(+)	Cocaine	0	4
3	103	0	(-)	(-)	0	0	4
4	134	0	(-)	(-)	0	0	3
5	222	0	(-)	(-)	0	0	3
6	207	0	(-)	(-)	0	0	5

Case #6-12 (table 17) self-reported use of cocaine. The pattern demonstrated is interesting in that it is compatible with desistence from use at the outset of the study and a binge episode detected by the fourth

TABLE 17. *Case #6-12. Four cocaine (+) hair assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	43	0	QNS	(-)	0	0	
2	0	0	(-)	(-)	0	0	4
3	0	0	QNS	(-)	0	0	2
4	230	0	QNS	(+)	Cocaine	0	8
5	120	0	QNS	(-)	0	0	6
6	11	4	QNS	(-)	0	0	3

hair and urine samples. Notice the 8-week gap between samples 3 and 4, and the high corresponding cocaine value for sample 4. The drop in hair assay values over the following two samples is interesting and consistent with the possibility that abstinence or marked reduction of cocaine use occurred after the fourth sample was collected.

Case #13-2 (table 18) self-reported use of cocaine and exhibited fairly consistent cocaine (+) values in hair. Notice the 7-week gap between samples 2 and 3, and then the consequent detection of cocaine in both hair and urine specimens. Note as well that while cocaine continued to be detected in hair samples 4, 5, and 6, all subsequent urinalyses were negative. Case #17-1 (table 19) self-reported use of opiates and cocaine. Cocaine was detected in the second hair and urine samples, with the hair assays showing several sequential (+) outcomes, although the quantitative measure of the subsequent samples diminishes to very low levels by

the fourth sample. Also note that although opiates appear in three urine specimens, they are never detected in the hair specimens at the same time.

TABLE 18. *Case #13-2. Four cocaine (+) hair assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	0	0	(-)	(-)	0	0	
2	0	0	(-)	(-)	0	0	3
3	33	0	(-)	(+)	Cocaine	0	7
4	84	3	(-)	(-)	0	0	3
5	104	0	(-)	(-)	0	0	5
6	50	0	(-)	(-)	0	0	3

One case (table 20) had three cocaine (+) hair samples and two cocaine (+) urinalysis. One case (table 21) had a single cocaine (+) hair assay and a single cocaine (+) urinalysis. The outcomes of these two cases are presented in the following tables.

Case #20-5 (table 20) self-reported use of marijuana only and was (+) for cannabinoids in hair for every sample taken. Although the initial cocaine hair sample was positive, the simultaneously taken urine sample tested (+) for opiates but negative for cocaine and cannabinoids. However, note that for samples 5 and 6 the person tested cocaine (+) by both hair and urine; the timespan between these two samples was relatively short.

TABLE 19. *Case #17-1. Four cocaine (+) hair assays.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	32	0	(-)	(+)	Opiates	0	
2	34	0	(-)	(+)	Cocaine	0	4
3	11	0	QNS	(-)	0	0	4
4	5	QNS	QNS	(-)	0	0	4
5	QNS	QNS	QNS	(+)	Opiates	0	5
6	0	0	QNS	(+)	Opiates	0	4

TABLE 20. *Case #20-5. Cocaine (+) hair samples, 2 cocaine (+) urinalyses.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	43	0	(+)	(+)	Opiates	0	
2	0	0	(+)	(-)	0	0	6
3	0	0	(+)	(-)	0	0	8
4	0	0	(+)	(-)	0	0	5
5	53	0	(+)	(+)	Cocaine	0	4
6	5	0	(+)	(+)	Cocaine	0	2

This case also shows that the hair assays failed to detect the opiate (+), which should have appeared in a later hair sample. The ability to evaluate opiates, and specifically heroin, in hair and urine has been constrained by a number of factors, the most important of which is the very low numbers of opiates in the samples, less than 0.5 percent cumulatively for all the authors' sampling over the past 5 years. Furthermore, opiate detection by immunoassay is problematic because so many codeine-based opiates and opiate analogs are used in legitimate medications. The hair assay reagent used in this study is insensitive to codeine-based opiates, and optimized for morphine sensitivity in order to recognize heroin exposure. Of course, identification of a specific opiate compound requires the use of a nonimmunoassay-based GC/MS analytic procedure.

Case #6-6 (table 21) self-reported use of marijuana and cocaine. A single (+) initial urinalysis indicated the presence of both cocaine and cannabinoids, but the first three hair specimens were of insufficient mass to be tested for cannabinoids. The third hair sample tested as a low (+) for cocaine, which was the only substance detected by the hair assays, approximately 8 weeks after the initial cocaine (+) urine result.

TABLE 21. *Case #6-6. A single cocaine (+) hair and urine assay.*

Sample #	Coc hr	Ops hr	Mj hr	Urine assay	Urine1 result	Urine2 result	Interval (weeks)
1	0	0	QNS	(+)	Cocaine	Cannabis	
2	0	0	QNS	(-)	0	0	4
3	10	0	QNS	(-)	0	0	4
4	0	0	(-)	(-)	0	0	10
5	0	0	(-)	(-)	0	0	3
6	0	0	(-)	(-)	0	0	4

DISCUSSION

The use of hair assays as a drug-monitoring technique, as noted in the introduction, offers several potential advantages not available with urinalysis. Experiences during this pilot project indicate that hair assays can be used in probationary drug monitoring without major impediments to their introduction. Based on survey and interview data with the field officers, the authors believe the assays would be well received by both correctional officers and probationers themselves.

Basic Detection Capabilities

The data collected in this project, in the authors' view, demonstrate a consistent and recognizable outcome pattern for cocaine. As elaborated in the body of the chapter, the authors believe these configurations support an interpretation of the efficacy of the hair assay for cocaine analysis. Occurrences of hair (-)/urine (+) outcomes (which the authors have termed the "paradoxical" type) continue to be rare. This is true not only for the data presented here for probationers; over the past 5 years in analyses of slightly more than 2,000 cases, only a dozen or so cases of this type have been identified. Furthermore, this pattern has been reported by others, including Wish (1994), Feucht and colleagues (1994), Magura and Kang (in press), Mieczkowski and coworkers (in press), and Baer and colleagues (1991). Because cocaine is rapidly excreted in the urine, and if the hair assay reliably detects exposure to cocaine, then the patterns of outcomes must generally conform to the type delineated here.

Findings related to marijuana are not presented in this chapter, but it is mentioned here in passing that the marijuana assay patterns also support the authors' interpretation of the critical role excretion rate plays. When one looks at marijuana, which has a much longer half-life in the urine than does cocaine (i.e., it is excreted much more slowly), one can see a marked lessening of the effect consistently seen with cocaine. That is, a considerable number of cases are cannabinoid (+) in urine but (-) in hair. The authors believe that this is due to the compound effect of urine being a particularly good medium for cannabinoids and hair being a weak one. For several reasons, and ones that are not well researched, cannabinoids concentrate relatively poorly in the hair. For example, while nanograms are the typical unit of measure for cocaine, picograms and femtograms (one quadrillionth of a gram) are the ranges in which marijuana is typically assayed.

It is commonly recognized that an indirect approach such as used here is not the ideal or optimal method to evaluate hair assay technology. How- ever, it is a useful and pragmatic approach if one considers the constraints upon any researcher seeking to use a controlled-dose administration method. In fact, such an approach has been done (Henderson et al. 1993) and, as noted earlier, it produced ambiguous results. However, the researchers were compelled to use low doses of cocaine relative to typical consumption levels because of limitations imposed by the use of human subjects. Doses in Henderson and colleagues' study were many times lower than what would be considered normal for heavy and chronic users of cocaine in criminal justice populations. It is important to bear in mind that at the lowest recommended clinical cutoff value of 5 ng/10 mg of hair, not a single hair segment in the Henderson and colleagues' study would meet the standard required by the present research to be called a clinical positive.

An epidemiological and clinical approach represents the only realistic way to determine the outcomes of hair assays in consistent, chronic, and high-dose users of cocaine and crack cocaine. It is unlikely (and rightly so) that the sorts of conditions that prevail in the cocaine and crack sub-culture regarding quantities and modes of drug administration will ever be duplicated under laboratory conditions, or would ever be permitted to be done in a laboratory setting. Cocaine users on the street have rela-tively open access to cocaine, constrained only by their financial resources. In the authors' experience with binge users of cocaine, it is common that they may consume several grams a day.

The general experiences of this project also lead to the conclusion that the hair assays in probationary field settings could be both feasible and useful in communities with high cocaine prevalence rates. Indeed, it has already been done and continues to be done in a variety of settings. The data show that it would be welcomed in some circumstances if it would reduce the demand on correctional officers for obtaining urine specimens from their cases. (In Florida, at any rate, officers in this study expressed extreme distaste for observing urination and would much prefer to take hair specimens.) Furthermore, the authors believe many probationers would prefer giving hair specimens to observed urinations. Hair assays, for example, could be used as an initial screening device to assign probationers to risk pools with different rates of urinalysis testing. It is likely that this would be well received in the field.

Difficulties in Implementation

The most significant problem facing implementation is the lack of widely recognized threshold or cutoff values for the hair assay for cocaine. Currently, individuals and institutions that use hair assays arrive at their own standards, typically in consultation with the analyzing laboratory. Cutoffs for any assay procedure using any sort of specimen are ultimately fixed at the technique's limit of detection (LOD). However, since cutoffs as they are used with urinalysis, for example, reflect a concern with passive environmental exposure and inadvertent microingestion, they are typically set higher—and sometimes much higher—than the LOD in order to accommodate some quantity of detectable drug that may be present due to inadvertent exposure.

Certainly this can also be done for hair. The authors have used several cutoff points to rank order cases along a continuum of exposure. While recognizing that a person can be passively exposed and may attain detectable quantities of cocaine in the hair, the authors believe a conservative threshold, perhaps something in the range of 5 to 10 ng of cocaine/mg of hair, is an acceptable value. While there has been much speculation about passive contamination as a meaningful clinical problem, there have not been substantial published findings suggesting this would prove to be an insuperable obstacle for hair analysis. Even in the work of those most sensitive to passive contamination as a problem in the utilization of hair assays (Cone et al. 1991; Goldberger et al. 1991), experimental findings have never failed to distinguish negative controls from positive users. Furthermore, recent work by Maloney and colleagues (1994) has demonstrated that casual physical contact of cocaine-contaminated objects by drug-abstinent persons does not result in the transfer of cocaine to their person in quantities detectable even at the lowest limit of detection by GC/MS. The authors' view is that there is no compelling evidence that environmental contamination is an unresolvable clinical problem for hair analysis of cocaine, provided one is willing to accept that marginal cocaine use, because of high cutoff values, may be classified as passive contamination. In effect, by adopting very high cut-offs one accepts some false negative assays as inevitable. This is precisely the approach currently used for interpreting cocaine detection by urinalysis. Cocaine can readily be detected at levels more than 10 times lower than the current Federal guidelines of 300 ng/mL of urine. Persons who fall below this value

are considered drug negative, even though they may have readily detectable amounts of cocaine metabolite in the urine.

Finally, the authors caution that the facile use of bioassays can also create a false sense of certainty about the meaning and utility of biological testing of any kind. All bioassays require prudent use and careful interpretation. When they are used solely for epidemiological estimations or other work that does not have potentially negative individual consequences, the level of error tolerance is greater than if one had to make punitive decisions based on an assay result. In fact, it seems apparent that using both hair and urine assays in combination would be an inherently safer approach in these contexts. It is noteworthy that much of the criticism directed at hair assays is not unique to hair as a testing matrix; it is equally applicable to urinalysis, yet the sensitivity to the potential misinterpretation of urinalysis seems relatively muted in comparison.

Urinary excretion curves, for example, change as people age, yet the same concentration criteria are applied to human subjects of urinalysis for cocaine without using age-graded cutoffs. Research also shows that the excretion rate of cannabinoids is quite variable, and can result in dramatic fluctuations in the presence of cannabinoids in the urine. In some cases cannabinoids may appear months after the cessation of active use (Dackis et al. 1982; Ellis et al. 1985). Even in regard to cocaine excretion via urine, it has been reliably reported that chronic users of cocaine may produce cocaine positive urine specimens at a 300 ng/mL threshold for several weeks after cessation of use, and that their urine concentration levels may move back and forth across the 300 ng/mL cutoff threshold (Burke et al. 1990; Weiss and Gawin 1988). Thus an abstinent person subject to a urinalysis could be defined as a recent user of the substance when, in fact, use may have ceased well before the conventionally accepted 72-hour window.

These concerns with the clinical use of bioassays are well founded, in the authors' view, because one is apt to treat the bioassay as the behavior that is presumed to underlie the bioassay result. Hair assays, especially for cocaine with its potentially long retrospective period, make persons more vulnerable to detection than urinalysis. But relying in any clinical situation on any single assay is, the authors believe, unwise. Bioassays should always be viewed as pieces of information that can help a person make a clinical inference, but not as a substitute for an inference. The toleration for error in the assay procedure is tied to the consequences of the inference. When high degrees of certainty are required, repetition of tests, testing by

multiple technologies, use of multiple specimens from the same subject, and other such steps should be employed. Drug assay outcomes are only pieces of information. They must be integrated into a meaningful whole and interpreted in the exercise of human judgment. Clinical applications of bioassays, including hair assays, have as their objective the provision of information. Ideally, this information will be integrated into a meaningful whole by a human evaluator who, equipped with additional knowledge, will be less likely to make an error in judgment than if he or she were deprived of that information.

Hair assays should certainly be used when the outcome cannot put the person undergoing the testing in jeopardy. It is hard to imagine why this should be objectionable. For example, hair assays could be readily used in epidemiological work where personal identification is not obtained. Furthermore, it seems that hair assays could be used in clinical settings to determine the absence of exposure to cocaine, since a false negative represents no legal encumbrance to the person being tested. Clearly hair assays can be used when those tested have given their permission to use them as a component, for example, to voluntary admission to a treatment program.

The additional benefits to this approach are that as they are so used, know- ledge regarding their interpretation will broaden. As these first uses unfold, they will provide a larger database from which further refinements and more profound understanding will emerge about this new technology.

ENDNOTE

1. Refer to the Technical Note at the end of the Introduction (p. 13).

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APPENDIX I. *The 33 cases with at least one (+) assay are displayed below. A (+) sign indicates the assay was positive for that drug, a (-) indicates the opposite. An asterisk (*) means that the specimen could not be analyzed due to insufficient quantity of hair. Abbreviations are for cocaine, marijuana, and opiates.*

Case #1-3			Case #3-4		
hair	coc	– – – – – –	hair	coc	– – – – – –
	mrj	+ + + + + +		mrj	– – + + + +
	ops	– – + – – –		ops	– – – – – –
urine	coc	– – – – – –	urine	coc	– – – – – –
	mrj	+ – – – – –		mrj	– – – + – +
	ops	– – – – – –		ops	– – – – – –
Case #2-4			Case #3-5		
hair	coc	+ + + + + +	hair	coc	+ + – – – –
	mrj	– * – – * *		mrj	– – – – – –
	ops	– – – – – –		ops	– – – – – –
urine	coc	– – – – – +	urine	coc	– – – – – –
	mrj	– – – – – –		mrj	– – – – – –
	ops	– – – – – –		ops	– – – – – –
Case #2-8			Case #5-2		
hair	coc	– – – – – –	hair	coc	+ + + + + +
	mrj	+ – – + + –		mrj	– – * – * +
	ops	– – – – – –		ops	– – – – – –
urine	coc	– – – – – –	urine	coc	– – + – – –
	mrj	+ + + + + +		mrj	– – – – – –
	ops	– – – – – –		ops	– – – – – –
Case #3-2			Case #6-6		
hair	coc	+ + + + + +	hair	coc	– – + – – –
	mrj	– * * *– –		mrj	* * * – – –
	ops	– – – – – –		ops	– – – – – –
urine	coc	– + – + – –	urine	coc	+ – – – – –
	mrj	– – – – – –		mrj	+ – – – – –
	ops	– – – – – –		ops	– – – – – –

Case #6-12			Case #12-8		
hair	coc	+ – – + + +	hair	coc	– – – + + +
	mrj	* – * * * *		mrj	+ + * + + *
	ops	– – – – – –		ops	– – – – – –
urine	coc	– – – + – –	urine	coc	– – – – – –
	mrj	– – – – – –		mrj	+ +– – – –
	ops	– – – – – –		ops	– – – – – –
					– – – – – –

Case #8-3			Case #13-2		
hair	coc	+ + + + + +	hair	coc	– – + + + +
	mrj	– – – – – –		mrj	– – – – – –
	ops	– – – – – –		ops	– – – + – –
urine	coc	– + – – – –	urine	coc	– – + – – –
	mrj	– – – – – –		mrj	– – – – – –
	ops	– – – – – –		ops	– – – – – –

Case #11-7			Case #13-3		
hair	coc	– – – – – –	hair	coc	– – – – – –
	mrj	+ + + * * +		mrj	+ + * + + *
	ops	– – – – – –		ops	– – – – – –
urine	coc	– – – – – –	urine	coc	– – – – – –
	mrj	– – + + + –		mrj	+ + + + – –
	ops	– – – – – –		ops	– – – – – –

Case #11-9			Case #13-4		
hair	coc	– – – + + +	hair	coc	– – – – – –
	mrj	– – – – – –		mrj	+ + + – + +
	ops	– – – – – –		ops	– – – – – –
urine	coc	– – – – – –	urine	coc	– – – – – –
	mrj	+– – – – –		mrj	+ + + – – +
	ops	– – – – – –		ops	– – – – – –

Case #12-1			Case #13-5		
hair	coc	– – + + + +	hair	coc	– + – – – –
	mrj	– + + + + +		mrj	– – – – – –
	ops	+ + + + + +		ops	– – – – – –
urine	coc	– – – – – –	urine	coc	– – – – – –
	mrj	— – – – –		mrj	– – – – – –
	ops	– – – – – –		ops	– – – – – +

Case #13-6			Case #15-6		
hair	coc	– – – – – –	hair	coc	– – – – – –
	mrj	+ + – – – –		mrj	– – – – – *
	ops	– – – – – –		ops	– – + + + +
urine	coc	– – – – – –	urine	coc	– – – – – –

	mrj	+ – – – – –		mrj	– – – – – –
	ops	– – – – – –		ops	+ – – – – –

Case #14-1			Case #16-1		
hair	coc	– – – – – –	hair	coc	– – – – * *
	mrj	+ + + + + +		mrj	+ * * * * *
	ops	– – – – – –		ops	– – – – * *
urine	coc	– – – – – –	urine	coc	– – – – – –
	mrj	+ + + + + +		mrj	+ – – – – –
	ops	– – – – – –		ops	– – – – – –

Case #14-3			Case #16-2		
hair	coc	– – – – – –	hair	coc	– * – – * –
	mrj	+ + + + + +		mrj	* * * * * *
	ops	– – – – – –		ops	– * + + * +
urine	coc	– – – – – –	urine	coc	– – – – – –
	mrj	+ + + + + +		mrj	+ – – – – –
	ops	– – – – – –		ops	– + – + + –

Case #14-4			Case #16-3		
hair	coc	– – – – – –	hair	coc	– – – * * –
	mrj	+ + + + + –		mrj	* + * * * *
	ops	– – – – – –		ops	– – – * * –
urine	coc	– – – – – –	urine	coc	– – – – – –
	mrj	+ – – – – –		mrj	+ + – – – –
	ops	– – – – – –		ops	– – – – – –

Case #14-5			Case #17-1		
hair	coc	+ + + + – –	hair	coc	+ + + + * –
	mrj	+ + + + + +		mrj	– – * * * *
	ops	– + – + – –		ops	– – – – * –
urine	coc	– – – – – –	urine	coc	– + – – – –
	mrj	+ – + + – –		mrj	– – – – – –
	ops	– – – – – –		ops	+ – – – + +

Case #17-2			Case #20-2		
hair	coc	– – – – * –	hair	coc	– – – – – –
	mrj	+ – * * * *		mrj	+ +– + – *
	ops	– – – – – –		ops	– – + – – –
urine	coc	– – – – – –	urine	coc	– – – – – –
	mrj	– – + – – –		mrj	– + + – – +
	ops	– – – – – –		ops	– – – – – –

Case #18-10			Case #20-5		
hair	coc	– – – – * –	hair	coc	+ – – – + +
	mrj	* * * * * +		mrj	+ + + + + +
	ops	– – – – * –		ops	– – – – – –
urine	coc	– – – – – –	urine	coc	– – – – + +
	mrj	– – – – – –		mrj	– – – – – –
	ops	– – – – + –		ops	+ – – – – –

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