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**Proceedings of the 1st European Meeting on Hair Analysis. Clinical,
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Distinguishing passive contamination from active cocaine consumption: assessing the occupational exposure of narcotics officers to cocaine

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Abstract

Hair analysis has been used in probationary and parole populations to monitor for cocaine use, but only in very limited settings or circumstances. Its wider adoption has been limited by questions regarding the ability to distinguish environmental contamination of hair via casual contact from actual ingestion. To evaluate this capability we sought to identify persons routinely exposed to cocaine, who were not cocaine users. Undercover narcotics officers engaged in cocaine-centered enforcement activities and evidence room clerks who have no history of cocaine use were identified as an appropriate example population. Thirty-six active undercover officers and four evidence technicians were asked to voluntarily submit hair samples for analysis. Additionally two cocaine contaminated (aqueous soaked), three negative control samples, and hair from a self-reported crack smoker were also blindly submitted to the testing laboratory. The hair samples were washed and after washing, enzyme digested. The wash solutions and hair digest were each analyzed for the presence of cocaine. The results indicate that nearly every person had trace amounts of cocaine contamination in the wash fraction, and one person had cocaine present in their hair digest. That person, when retested, was a negative. The laboratory correctly identified and characterized the contaminated, negative, and positive controls. The study concludes that the findings support the capability of hair analysis to distinguish cocaine use from exposure under normal field conditions. The study results indicate that cocaine-abstinent persons who are in chronic, casual environmental contact with cocaine are not likely to test hair positive for cocaine using the analysis protocols followed in this project. The study also indicates that passive microingestion of cocaine needs to be considered when examining persons who are in cocaine intensive environments. © 1997 Elsevier Science Ireland Ltd. All rights reserved

Keywords: Passive contamination; Active cocaine consumption; Occupational exposure; Narcotics

1. Introduction

Cocaine is a drug which appears to be used at very high rates in populations undergoing treatment for drug abuse as well as criminal offender populations. However, it is relatively difficult to detect cocaine by urinalysis except in the immediate day or two after it is consumed. As a consequence the true prevalence rate for cocaine use remains unknown, and estimates for this rate which rely solely on reporting of use have consistently proven to be underestimates [1]. Furthermore, cocaine's rapid excretion rate also makes defeating urine testing relatively easy. For example, in many criminological settings (such as probation or parole management) the combination of high caseload, the client's ability to delay an appearance for a testing appointment, or deliberate evasive maneuvers such as the use of diuretics, have all contributed to a relatively low credibility of the true detection efficacy of urine testing in routine monitoring circumstances [2,3]. A nascent industry has emerged, devoted to helping persons 'beat' their urinalysis tests, and operates openly and legally in most major urban areas around the United States.

Hair analysis has been proposed as a desirable alternative or supplement to urine testing. It has already been employed as a monitoring technology in several criminal justice contexts, including intensive probationary supervision programs, work release programs, experimental programs designed to monitor routine probationers, and pretrial diversion programs. A literature has also accumulated on the effectiveness of hair analysis in these roles, and generally these reviews have been positive, especially in regards to the increased ability to detect cocaine exposure [4-10]. Hair analysis has also withstood court examination of its suitability as evidence. To date hair assays results have been accepted in most criminal and civil cases in which they have been introduced as evidence, up to the level of the Federal District Court (see for example, Nevada Employment Security Department v Cynthia Holmes, Supreme Court, State of Nevada 26157 [11] or United States v. Anthony Medina, 1990, 749 F. Supp. 59; US District Court, New York [12]).

2. The fundamentals of hair assay technology

Hair analysis is based upon the premise that many drugs become entrapped and stabilized in the keratin matrix of hair. This trapping appears to be especially effective for cocaine [13] and is well demonstrated even at low dosages, as shown by the work of Henderson et al. [14]. Entrapped drugs appear to enter hair by several routes; from the plasma, transcellular diffusion during keratinization, sweat and sebum bathing, etc. These materials, acquired in the development of the hair, appear to be firmly held in microstructural elements of the hair. Once bonded to these elements the materials are not able to be removed by extensive washing. In hair analysis these analytes are accessed by hair digestion or extraction procedures whose aim is to liberate and identify the particular chemical entities under scrutiny. It appears that with cocaine and several of its various metabolic products this sequestering is extremely stable [15]. As well, the amount of cocaine use in

terms of gross quantities of substances ingested, appears to bear a discernible relationship to the concentration attained in hair, provided it is measured over a sufficiently wide dosage range. Cocaine and other entities are also capable of attachment to hair via environmental exposure, but they do not appear to attain the same bonding or attachment strength, under normal circumstances, as do drugs which are ingested. These environmentally acquired drugs, in most circumstances, can be removed by appropriate washes.

The primary advantage of hair analysis is the relatively long retrospective identification of classes of drugs which normally quickly disappear from blood or plasma. Cocaine and several other popularly abused psychoactives are stable when embedded in the hair and can be detected for months, and in some cases even years after exposure. A second advantage is quantifying the drug recovered in the hair and estimating from that value the amount of drug ingested (i.e. establishing a dose/assay relationship). The dose/assay relationship appears to be limited in its utility to a rank-order assignment of values. There are relatively high degrees of inter-subject variability regarding the regression relationship between dose consumed/drug recovered. However, hair appears useful for tracking drug exposure within individuals, where a baseline value is established for any given individual and they can subsequently act as their own control [16-18]. Some research has shown that good correlation exists between self admitted cocaine use and hair assays values [19], that the probability of having a cocaine positive urinalysis outcomes and the quantitative value of a cocaine positive hair specimen are very strongly positively related [4], that cocaine concentration values attained in the hair are positively related to the efficiency of the consumption method [20], and that the correlation between maternal and neonatal hair assays for cocaine is quite strong [21-24].

The use of hair as a specimen for toxicological identifications is not novel. Hair was first used in criminal proceedings in the United States in the nineteenth century, with testimony about hair analysis first admitted in 1882 in *Knoll v. State*, 55 Wis. 249, 12 N.W. 369 [25]. The first reported recovery of a psychoactive drug from the hair of guinea pigs was published in the United States more than 40 years ago [26]. In recent years concern with drug monitoring has created sufficient demand to make development of a low-cost, immunoassay based screening technology economically attractive. This has resulted in several commercial laboratories in both the US and Europe developing and offering hair analysis services to detect psychoactive drugs. In a recent laboratory evaluation exercise, for example, 11 different laboratories participated in a round-robin review to detect cocaine and morphine in hair samples [27].

3. Hair analysis of cocaine exposure and its controversies

The identification of cocaine and its metabolites in hair has, itself, not been particularly controversial. Virtually all published research has shown that cocaine, as well as its major metabolites, can be readily identified in hair by a wide variety of analytic techniques, including the use of radioimmunoassay (RIA), high perfor-

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mance liquid chromatography (HPLC), gas chromatography/mass spectrometry (GC/MS), and gas chromatography/tandem mass spectrometry (GC/MS/MS) [28]. As with all diagnostic procedures controversy has arisen, however, about how to interpret the detection of drugs in hair [29]. Clearly, the detection of a substance in hair is an indication of exposure to that substance. Indeed, as Kidwell [30] has noted:

'Certainly, many positive hair analysis results are due to ingestion of drugs but passive exposure must be considered when evaluating any particular case. What does hair analysis for drugs of abuse measure? It measures exposure. Methods to distinguish use from exposure are still undiscovered.'

The crux of the controversy is contained in the last statement, namely the determination of the nature or cause of exposure. If the individual denies using the drug, what is its source? This interpretative problem has intensely focused on the issue of passive contamination and the ability to distinguish passive exposure from active (i.e. willful, knowing) ingestion [31].

The term 'passive contamination' is generally used to describe cocaine which has been environmentally deposited on the surface of the hair. A second, related issue is passive ingestion. Passive ingestion generally is taken to mean the secondary consumption of cocaine via inhalation of smoke, oral contact, or other similar acts by which small traces of cocaine are actually consumed, but not consumed willfully or knowingly by the person. This can result from known contact with persons who use cocaine (e.g. kissing a person who has just smoked crack cocaine), or could result from unknown contact with contaminated persons or objects. Passive and active ingestion are not biochemically distinct, of course. However, as a practical matter, under most clinical circumstances passive ingestion entails microscopic (nanogram) quantities of a drug, while active ingestion usually involves taking thousands of milligrams of the material.

Some confusion exists regarding the concept of contamination and the deposition of cocaine into hair from sweat or sebum. The sweat of a cocaine user contains cocaine, and this source of cocaine is often reflexively treated as 'environmental contamination.' Cocaine deposited into hair via the sweat of the individual cannot be considered as an environmental contaminant, since the cocaine arises from an endogenous source, namely the various somatic pools of drug in plasma, cellular fluids, etc. Thus while sweat may make some contribution to the total quantity of drug found in the hair of the drug user, its role does not represent a problematic one from the point of view of identification of drug users. Contamination via sweat between persons, which would be true environmental contamination, may occur with chronic and prolonged skin-to-skin contact, or the sharing of wet clothing, applied to hair, and heavily laden with sweat. However, no study has shown that such contamination would be confused with cocaine arising from endogenous sources, although specific studies examining this issue should continue to be pursued. The circumstances under which this type of inter-person sweat transfer might occur would be rather specialized, and do not appear to be frequently encountered in clinical populations studied. Problems of this sort are normally resolvable by extensive washing of samples with water or methanol.

4. Clinical determinations of the source of drugs found in hair

One erroneous characterization of clinical application of drug analysis is that practitioners do not utilize assays in a diagnostic fashion, i.e. as merely one of a series of informational items upon which a decision is based, but rather in a sort of 'all or none' fashion. For example Kidwell [30] states that:

'Those using hair analysis seek a definitive yes/no answer to the question: Did this individual ingest drugs? An individual's mere contact with drugs is seldom at issue.'

This statement is not accurate. While it may be true in some circumstances that critical decisions are made on the basis of a single assay outcome, this is not true for most other uses of drug analysis. In criminal justice and treatment monitoring, as well as employee assistance programs, actions taken in response to apparent drug use arise out of long-term relationships and assessment periods, and consideration of multiple measures of drug involvement.

Furthermore, the term 'mere contact,' as Kidwell labels the phenomenon, obscures the clinical significance of the difference between trivial, microscopic levels of contamination and massive, overwhelming levels of contamination. The determination of massive exposure to an illicit drug is indeed relevant to criminal justice monitoring, treatment program monitoring, and a variety of security-based drug monitoring contexts. For example, what is called 'mere contact' may be a critical issue in a court-supervised diversion program where a condition of participation is to avoid contact with drugs, places where drugs are bought and sold, and social associations with drug users. A person showing high degrees of cocaine contamination on their clothing, etc. would be a situation of clinical and legal concern. Likewise the massive contamination of an infant by cocaine would be of importance. Kidwell's statement implies that those who utilize hair analysis are (or perhaps ought to be) unconcerned about cocaine exposure, but are (or can legitimately be) concerned with cocaine use. It would be more accurate to state that those using hair analysis for cocaine detection seek an answer to the question 'did the individual experience trivial, incidental, or meaningless exposure that can be plausibly explained by background effects, or is this exposure of a magnitude that calls into question the person's denial of cocaine use or involvement?'

In clinical use, the outcome of a single hair assay is rarely treated as a definitive informational item. Rather, it is treated as one of a series of informational items, all gleaned from various sources available to the clinician. The gathering of information regarding a final decision on the interpretation of an assay depends on both available concomitant data (e.g. urine testing, saliva testing, interviewing, etc.) as well as historic data (e.g. how does this assay value rank relative to other assays taken in the past?). A little-mentioned but important aspect of clinic experiences with both hair and urine testing in criminal justice and clinical treatment contexts is that challenges are very rare and self-admissions are the norm [7,17]. A simplified flow diagram illustrating this process is shown in Fig. 1.

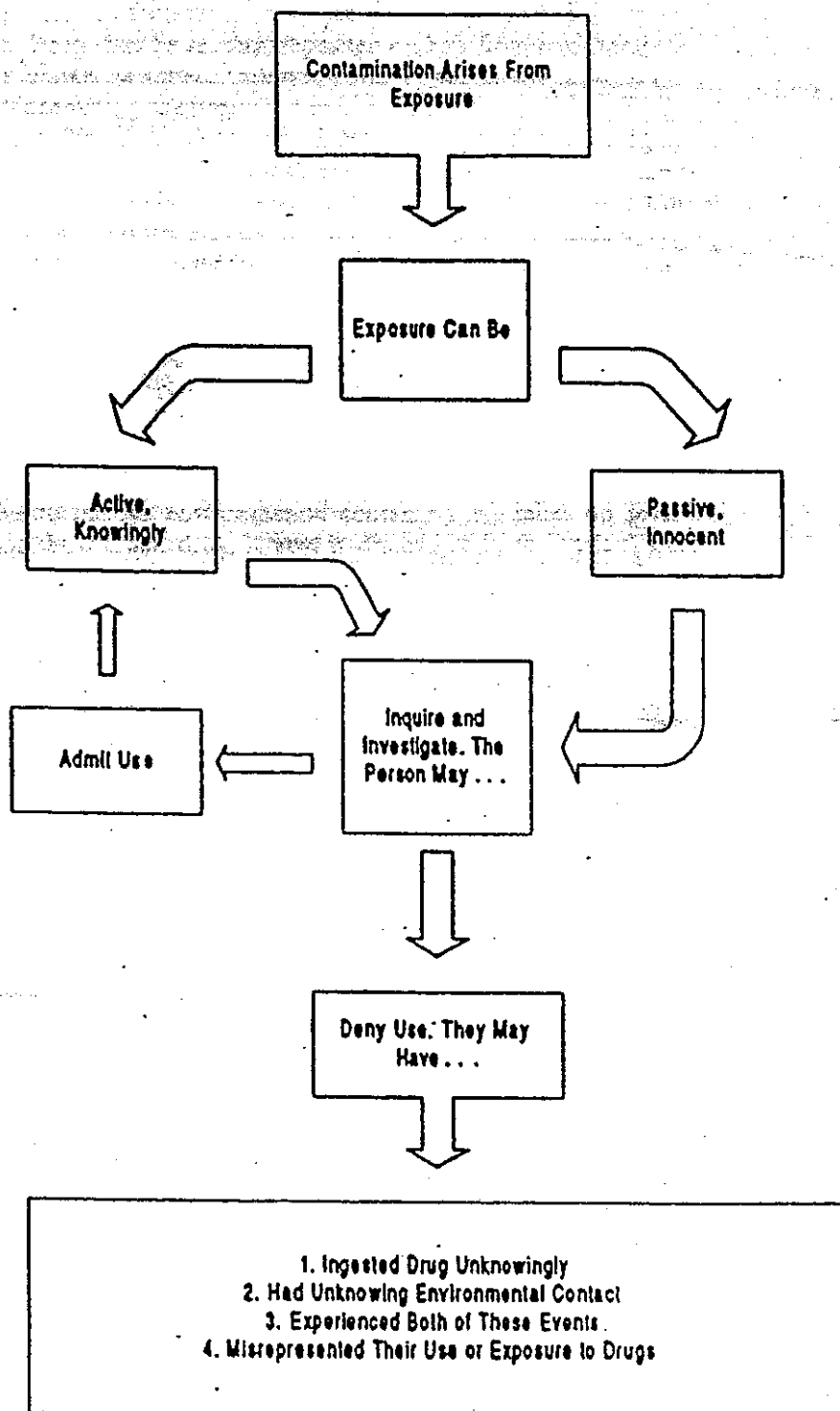


Fig. 1. A decision tree for assessing contamination.

4.1. Passive contamination and wash processes

Hair, being on the exterior of the body, is subject to environmental contact and hence contamination. Drugs can be readily deposited on hair from environmental sources, such as dust, smoke, or aqueous sprays. Critics of hair assays contend that hair analysis cannot adequately distinguish between active use and inadvertent environmental contamination because environmentally deposited cocaine tightly bonds to hair, and cannot be removed [31]. This effectively obliterates the difference between surface-contamination and cocaine which may enter the hair from the consumption of cocaine. Alternately, others have argued that wash procedures, properly done, can remove all or nearly all of any normally acquired environmental contaminants [32,33].

The argument that any environmental contamination, no matter how small, renders hair assays unreliable is not accurate. Hair assay interpretation does not need to assume that the hair is absolutely free of any trace of contamination. The simple value of the drug extracted from hair is not used by itself to determine the outcome of the assay. The procedure compares the outcome from specific sequential washes applied to the hair with drug recovered from the hair. Interpretation of a hair assay, relative to passive environmental contamination, relies on several pieces of information; how much drug, if any, is discovered in the various wash series (which are done to cleanse the hair and identify any contaminants), and second, how much residual drug remains in the hair after the wash procedure is completed. Thus hair assay values/wash assay values must attain a series of specific ratios to be properly interpreted. Baumgartner and Hill [34] have developed the most specific of these criteria. They are presented below in Table 1.

Positive specimens must pass all three criteria to be considered a cocaine positive. Additionally, one can also utilize assays to detect the presence of cocaine metabolites, typically benzoylecgonine (BE), ecgonine methyl ester (EME), norcocaine (NE) and cocaethylene (CE). The presence or absence of these metabolic products adds further information in interpreting a particular assay outcome. The use of metabolites is premised on the observation that these arise largely or exclusively from internal metabolic processes which occur in the body, or they are

Table 1
Wash kinetic criteria of Baumgartner and Hill

| Criteria | Calculation | Required ratio |
|---------------------|--|----------------|
| Extended wash ratio | (Amt. of drug per 10 mg hair in digest)/ (amt. of drug per 10 mg hair in last PO ₄ wash) | ≥ 10 |
| Safety zone ratio | (Amt. of drug per 10 mg hair in digest)/ (amt. of drug per 10 mg hair in all 4 PO ₄ wash) | ≥ 0.33 |
| Curvature ratio | (Amt. of drug per 10 mg hair in 3 PO ₄ wash)/ (3 times the amt. of drug per 10 mg hair in last PO ₄ wash) | ≥ 1.3 |

not typically found in cocaine hydrochloride or 'crack' cocaine as it is vended. Rather than rely on the simple presence or absence of these substances, one can use ratios of the parent drug to the metabolite in order to help in interpreting the assay outcome. For example, Cone [35] has suggested that the presence of CE and NE are indicative of active drug use and that BE/cocaine ratios which exceed a value of 0.05 are also indicative of active drug use. Koren et al. [33] have argued for a similar interpretive approach, as have Baumgartner and Hill [34].

The problem of passive, inadvertent ingestion is one which presents a somewhat different interpretive issue. Because passive ingestion can produce the same qualitative biological outcome and same metabolic outcomes as 'knowing use' one must take the same approach as has been done with urinalysis. This requires an operational assumption that casual, inadvertent 'use' (i.e. ingestion) normally differs substantially in quantitative dimensions from active use. This is essentially a statistical distinction. Inadvertent users and deliberate users have the same experience, in a qualitative biological sense. However, they do not have the same experience in a quantitative sense. Inadvertent use (except under the most bizarre circumstances) is an event premised on minor exposure, while willful use is an event which typically is characterized by large-scale consumption, especially for cocaine abusers.

4.2. *The use of threshold criteria*

When it is necessary to control for passive ingestion of cocaine (e.g. by passive inhalation of crack smoke, by contamination due to exchange of body fluids such as semen or sweat), hair analysis uses the same methodology as urinalysis, statistically-based cut-off values. The value of the assay must exceed a specific threshold in order to be labeled as a diagnostic positive outcome. This is quite distinct from a technical positive. A technical positive is defined by the analytic technology's limit of detection (LOD). A diagnostic negative test may result from a specimen that is technically positive. That is, the specimen has a technically detectable amount of the particular analyte present, but an insufficient amount of the drug is recovered to 'cross' the cutoff threshold.

Where should such a threshold be established? Unless one decides that the LOD is appropriate, there is no technically imposed answer to this question. The threshold represents a marker at which it is generally recognized that explanations of passive or inadvertent exposure are implausible. This is intrinsically a statistical phenomenon and is related to the scatter caused by biochemical clinical individuality and the correlation between dosage and cocaine levels in hair. Unlike urine, the statistics of hair analysis are not effected by excretion kinetics. Kintz and Mangin [29] have addressed this issue and recommend a 'stand alone' value for cocaine of 1 ng/mg of hair (i.e. by 'stand alone' is meant that hair is used in the absence of any other corroborating specimen), and suggest that this cut-off may be lowered to 0.5 ng/mg when 'supported by other evidence of drug intake.' Baumgartner and Hill [36] have argued for the use of a 0.5 ng/mg cut-off value.

In clinical practice there is no need to require a universal cutoff value for all monitoring circumstances. Indeed, in current practice there are a wide variety of thresholds employed in urinalysis testing for cocaine, dependent on the perceived needs of the testing program and its goals. For example, over the last 2 decades the thresholds for cannabinoids has been consistently edged downwards in response to epidemiological reports that initial values were so high as to produce substantial numbers of diagnostic false negative urinalyses. Quite unlike other illicit drugs, marijuana has been shown to be often over-reported; that is, more people report marijuana use than are identified by either hair or urine assays [37]. The lowering of cannabinoid cutoff values was not based on any theoretical model, but solely on clinical experience.

The selection of thresholds varies considerable in clinical practice. Commercial test kits are readily available to test urine for cocaine at a threshold of 25 ng/mg, even though in the US the federal government employs a threshold in its workplace testing more than ten times this value. Some clinical programs have utilized a 'zone' approach to interpretation of assays values [6]. In this setting — criminal justice-based treatment program — persons testing positive for cocaine in hair at values between 0.5 and 3.5 ng/mg are monitored with increased scrutiny but are not presumed to be using the drug. Those who test positive at values greater than 3.5 ng/mg are treated as users, unless some compelling alternative explanation is apparent. Over the history of this program these particular cutoffs, based on actual clinical conditions and experiences of the treatment staff, have proven to be very useful. The clients are also randomly urine tested, consistently interviewed and counseled, and subject to surface contamination analysis. Program clients also have long-term clinical histories and a baseline hair assay value determined at program intake. Thus hair assay value changes for an individual are tracked over time. All this data is weighed and evaluated as potentially corroborating or clarifying information available to lend support to a particular case analysis. The effectiveness and utility of hair analysis in this context serves as an example of the prudent and careful use of hair assay technology. It contradicts the assertions that hair assays are inevitably used as simple binary indicators of cocaine ingestion.

5. Laboratory-based contamination studies

Laboratory studies have shown that hair can be contaminated by cocaine. These studies have been criticized, however, because they have generally used 'extreme contamination scenarios' in order to simulate contamination [38]. Laboratory studies have typically depended on prolonged aqueous soaks of hair in concentrated cocaine solutions, or suspensions of hair samples over a pyrolyzed cocaine base [13]. There are problems in linking these in vitro studies to the hypothesis that casual contact, such as inadvertent touching of cocaine contaminated objects, could contaminate the hair of a non-user by subsequent touch. While clearly a contamination event is likely to occur, the issue is whether this contamination is so severe as to obliterate the distinction between use and non-use. It has been suggested, for example, that simple and transitory touching of contaminated objects could result

in a positive hair assay and might lead to the labeling of an innocent person as a cocaine user [14]. On a practical level, for example, could a barber who cut the hair of a crack smoker then transfer sufficient cocaine to other customers by physical contact to the degree that wash procedures and cutoff values could not distinguish such persons from the crack smoker?

Such an event has never been demonstrated in any field setting and studies which have reported on field-based samples do not support the argument that such a phenomenon represents an impediment to the use of hair analysis. Contamination by physical touch appears to require rather specific or peculiar conditions to be significant enough to confound a properly executed assay. Avolio et al. [39] have shown, for example, that dry hair samples placed in physical contact with cocaine-impregnated silica, removed periodically, and washed with methanol, did not begin to acquire methanol-resistant cocaine contamination even at the picogram level until after approximately 7 days of continuous contact.

In general, the literature reveals that studies have distinguished quite readily between known cocaine users and known cocaine abstainers when those studies have been done under controlled conditions (e.g. see the work of Cone et al. [40]). Koren et al. [33] reported on both laboratory based hair sample manipulation as well as the exposure of human volunteers to cocaine contamination. In one study they had human volunteers exposed to 100 mg of vaporized cocaine in a confined space, and reported an average concentration for cocaine of 27 ng/mg of hair, and no detection of BE. Subsequent washing of the volunteers' hair resulted in removal of both cocaine and BE below the LOD. Wang and Cone [13] exposed hair samples *in vitro* and also exposed human volunteers to similar amounts of vaporized cocaine under conditions similar to Koren et al. They reported comparable values for initial contamination concentrations. They reported that hair samples — vapor contaminated by 100 mg of vaporized cocaine, and soaked for 24 h in a small volume of mild commercial shampoo — showed substantial loss of the contamination. The contaminated hair had initial values of 19.6 ng/mg in the wash fragment and 7.3 ng/mg in the extract. After one shampoo wash cycle, no cocaine could be detected in the wash fragment, and 0.7 ng/mg were detected in the hair extract. After the third shampoo wash cycle the cocaine values in the extract reduced to 0.4 ng/mg. A very similar pattern was reported for the cocaine pyrolysis metabolite anhydroecgonine methyl ester (AME).

The two cocaine vapor-exposed human volunteers examined by Wang and Cone attained a mean value for cocaine of 29.5 ng/mg in the wash fraction and 7.1 ng/mg in the extract. They had concentrations of 6.2 ng/mg and 1.8 ng/mg for AME. After 8 days of routine hair hygiene the wash values for cocaine had reached 0.0 for one volunteer and 0.5 ng/mg for the second. The extract values were 0.6 and 0.5. The AME values were zero in both wash and extract fractions for both volunteers after 8 days. Wang and Cone [13] found that aqueous contamination, as opposed to vapor, resulted in elevated values for initial contamination readings in hair samples. However, under mild and moderate soaking conditions repeated shampooing (up to ten cycles) removed substantial amounts of the cocaine contaminants. In the mildest soaking scenario (0.01 mg/ml HCl solution), cocaine

recoverable from washing was zero and the concentration reduction in the extract fraction was 94.3% after the second wash cycle. By the tenth wash cycle the cocaine reduction was slightly greater than 99.5%. As the soaking solutions concentration were increased, the washing was less effective in removing the cocaine. Some hair samples were subject to a fivefold and a hundredfold increase in soaking concentrations (0.05 and 0.1 mg/ml). In each case, after ten shampoo washing cycles, the percentage of original contaminate removed exceeded 99% of the original contaminate concentration. Also notable in Wang and Cone's report is that in the cocaine hydrochloride aqueous soaks BE was either absent or quickly removed by a single shampoo cycle. And in a contamination scenario in which the hair was contaminated with cocaine and added BE, the BE values dropped rapidly after shampooing, and approached or attained zero values.

6. Field-based contamination studies: background contamination by cocaine

Another source of information on the plausibility of the contamination problem for hair assays is to take field measurements in circumstances where cocaine contamination is likely to occur. Cocaine is known to be present as an environmental contaminant. For example, it is widely recognized that a sizable percentage of United States currency is cocaine-contaminated. Also, it is quite plausible that any number of public objects are touched by cocaine users, potentially contaminated by them, and then these objects may, in turn, contaminate innocent persons touching these objects at a later time. Public drinking fountains, pay telephones, door handles and a host of other objects might be sources of cocaine transfer from users to non-users.

Field studies attempting to assess the degree to which this type of contamination occurs have shown that measurable amounts of cocaine are not easily transferred to hands by simply touching contaminated objects. Maloney et al. [41], for example, have shown that after handling cocaine-contaminated objects such as crack pipes, non-users failed to transfer measurable amounts of cocaine to their hands. Maloney and his colleagues also assayed the hands of bank tellers in a pre/post design to measure contamination of the hands based on handling cocaine-contaminated currency. Fifteen tellers from three different banks handled contaminated currency for the entirety of a normal 4-h shift (and refrained from washing their hands at any time during the work period). Tests on the currency showed it to be contaminated with cocaine, but no cocaine was detectable on the hands of the tellers. They likewise were able to demonstrate that cocaine did not transfer to individuals who drove cocaine-contaminated vehicles which were seized from drug dealers by the police, even though the steering wheels of the cars tested cocaine positive. Nor could the researchers detect cocaine on public objects likely to be used by cocaine users or sellers such as pay telephones in high drug trafficking areas. The only scenario under which cocaine was readily transferred from contaminated person to negative control was under condition of direct skin-to-skin contact when volunteers handled 'rocks' of crack cocaine, and then rubbed hands with negative control volunteers.

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Ulvick et al. [42] and Demirgian et al. [43] have also evaluated cocaine contamination, including the transference of cocaine from currency to persons. They concluded that while the total percentage of American currency in circulation contaminated with cocaine is 'very high', currency with high levels of cocaine near the surface are 'much rarer.' By examining contaminated currency with scanning electron microscopy, they determined that currency can be contaminated by direct contact with cocaine, but 'soon after initial contact most of the cocaine falls off.' Some remnant cocaine penetrates the subsurface, but this cocaine, which is trapped in the currency's fiber matrix, does not contaminate the hands unless the surface is abraded by 'hard rubbing'. These findings explain why Maloney et al. [41] were unable to detect any contamination on the hands of bank tellers, even after many hours of handling currency which was cocaine contaminated. Demirgian et al. [43] also found that 'contamination did not occur by normal handling of highly contaminated bills' and Ulvick et al. [42] also concluded that their data 'indicate that transmission of cocaine from currency to a person is unlikely.' As well, Demirgian et al. also examined the potential for cocaine contamination by placing highly contaminated experimental subjects into a motor vehicle with negative control subjects. These people spent several hours driving around together, including periodically stopping and switching seating positions. They found that 'contamination did not occur from riding in vehicles with contaminated people.'

6.1. Contamination of children exposed to cocaine

Smith et al. [44,45] have reported on a field study of the cocaine contamination of the hair of children of cocaine smokers. Several of these children, presumably residing primarily in the parental household, were characterized as having hair assay values indistinguishable from their cocaine-using parents. The study reported on 20 adult, cocaine-using parents and 29 associated children. Sixteen of the 20 adults and 29 of the children were reported as cocaine positive by hair analysis. The authors concluded that:

'These results show that cocaine-related compounds were deposited in the hair of children when cocaine was present in the environment. Children living with a cocaine-dependent adult exhibited both cocaine and cocaine metabolite in their hair — if one assumes that young children are not intentional cocaine users and are not intentionally given cocaine by adults, these results show that their hair can become cocaine positive through unknowing exposure when they live with a cocaine user. Saliva and skin swabs suggest that external contamination, *not ingestion* (emphasis original), was the source of cocaine-related substances in the children's hair. Neither wash-out kinetics, metabolites, cut-off concentrations, nor re-test would exclude many of the children, presumed to be innocent non-users of cocaine, from being identified as cocaine users.'

Fig. 2 reproduces the outcomes for the 29 children and infants. Smith et al. reported these 29 cases as cocaine positive, including 5 cases at levels below quantification (which they refer to as 'trace' positives). These trace positive cases are indicated by the five bars which have no vertical dimension in Fig. 2.

Smith et al. conclude that 'cut-off concentrations' would not exclude 'many of the children' but this statement is not consistent with the data. In Fig. 2 there are

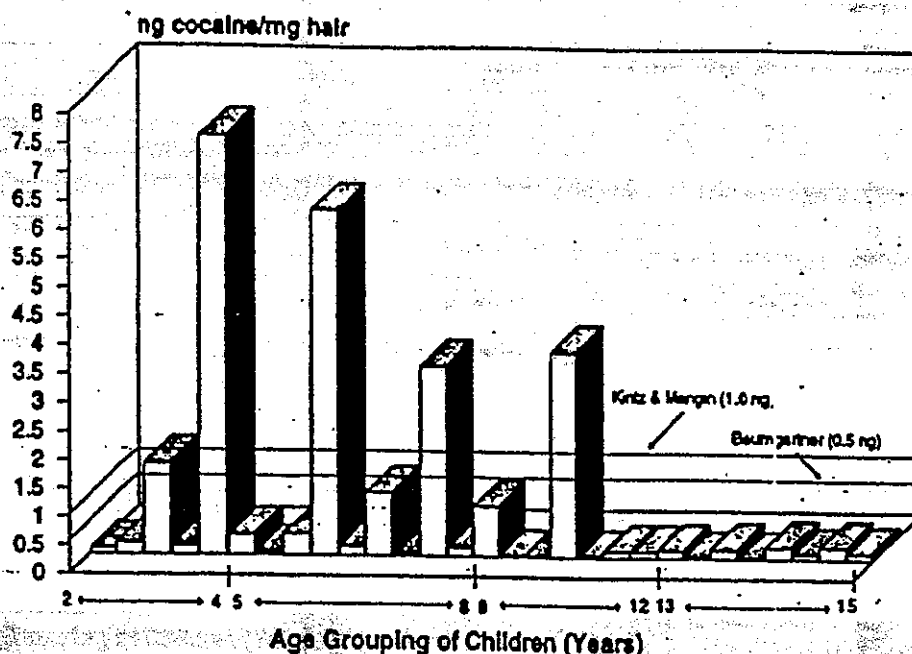


Fig. 2. Children reported as cocaine positive by Smith et al. [44].

two cutoff criteria superimposed on the graph, indicated by the lines marked 'Mangin and Kintz (1.0 ng)' and 'Baumgartner (0.5 ng)'. These represent two cut-off values for cocaine suggested in the literature. As each criterion line indicates, few of the children would be positive by either threshold criteria. Applying the 0.5-ng cutoff suggested by Baumgartner and Hill, only 7 of these 29 children would be classified as cocaine positive. Using the Kintz and Mangin 'stand-alone' criteria of 1.0 ng, only five children would be positive.

The authors further state that the wash-out kinetics as developed by Baumgartner and Hill would not identify these children as 'contaminated'. Unfortunately, they do not provide the complete wash data. However, based on their description the Baumgartner and Hill criteria are not applied appropriately in this study. There were major modifications to the wash method as described by Baumgartner and Hill and there is only a single criterion used. The wash kinetic procedure alluded to in the study requires all three criteria to be met simultaneously. Furthermore, they do not utilize a digestion method on the post-wash hair. The Baumgartner and Hill protocol specifically states that:

'It is also important to realize that the presently defined kinetic criteria (particularly the numerical values) are only valid if the residual drug in the hair fiber is measured by a method that guarantees the complete release of the entrapped drug, e.g. a digestion procedure.' [34]

Smith et al. also make direct comparisons between the assay values of the adults and children, noting that 'in some cases the child's hair contained quantities

greater than the adult user's hair.' Without providing concentrations relative to body weight, these comparisons are difficult to assess, since they could result from the children chronically consuming very small dosages, given their much lower body mass. The pattern in Fig. 2, indicating that the smallest children have the highest cocaine values, is a finding consistent with a hypothesized passive ingestion of small quantities of drugs, likely to be most pronounced in infants who are very orally active and who have very low body weights compared to other youths and adults in the sample. The data in Fig. 2 is also consistent with the risk and quantity of ingestion lessening as a child ages and matures. Aging would result in a decrease of the constant oral exploration and crawling activity of infancy. As well it would increase time spent outside the home, and increase the likelihood of eating food prepared out of the home environment (e.g. school cafeteria lunches). Fig. 2 may also be demonstrating another aging effect, that the impact of passive ingestion would also be lessened, given a constant rate of exposure, by increasing body weight due to growth.

Smith et al., however, reject passive ingestion as a potential basis for explaining their findings, stating that 'there is no evidence to support the hypothesis that ingestion was the primary route of cocaine entering hair.' They base this statement on the results of saliva analysis for cocaine, which was negative for most of the children and many of the adults, and skin swabs, which were positive for every subject in the study. This, they argue, indicates that all subjects had been passively exposed to cocaine.

It does not appear that the ruling out of passive ingestion can be made on the basis of this data. Skin swab data, while it may indicate passive contamination, is also compatible with the sweat excretion of ingested cocaine. The method by which the authors differentiate cocaine found on the skin (from passive deposition) versus cocaine found on the skin as a result of sweat (or sebum excretion) is not elaborated. It is a plausible explanation that these children continuously ingested small amounts of cocaine over a long period of time via actions such as the placing of their hands or contaminated objects in their mouths, and continuously living in an environment in which their foodstuffs, eating utensils, play items, clothing, etc. are grossly contaminated by cocaine vapor. Certainly if the subjects themselves are contaminated, as the authors emphasize, it must also be true that their physical environment is contaminated as well. Two children, for example, are reported as having positive saliva assays, indicating possible recent ingestion of cocaine, or placement cocaine-contaminated objects into their mouths. Adult crack users, who constitute the parent group, typically 'cook up' or 'rock up' cocaine in microwave ovens, often using ordinary household utensils [46]. The assessment of the degree of potential passive ingestion versus contamination would be strengthened by an evaluation of the degree of environmental contamination of the households and the clothing, eating utensils, foodstuffs, and play items of the children.

The interpretation of Smith et al.'s hair assay data is further complicated because hair samples collected for this study were taken in the course of a cosmetic styling of the hair. Such a collection process would presumably involve only the most distal ends of the hair shaft. During the course of the trim, the subject's hair

was allowed to fall into a collection bag, producing a random mix of hair lengths, loci, and hair shaft orientations. Such a procedure would randomly mix hairs of varying lengths, and would fail to preserve root-to-distal end shaft orientation, make any longitudinal analysis or comparison of hair assay data to other drug use indicators impossible. Thus long-term interpretations of the outcomes of the hair assays relative to either saliva or urine assays — short-term measures — cannot be made. Also, this sample collection method is, unfortunately, not comparable to any other reported field studies, which have collected hair samples specifically cut from the scalp, and preserved them in proper orientation for the purposes of sectioning and comparison to urine tests and self-reports of drug use (see, for example, Marques et al. [21]).

6.2. *Narcotics officers: field exposure to cocaine*

Field studies of naturally-occurring cocaine exposure are not easy to conduct. Because cocaine is a controlled substance with extremely limited medical use, it is difficult to identify occupational groups which have meaningful, known, and chronic environmental exposure to cocaine. However, one such group consists primarily of undercover narcotics officers and evidence custodians who manage the inventory of seized drugs. These individuals, in the course of their duties, have continuing contact with cocaine, cocaine-rich environments, cocaine users, and cocaine dealers. The officers function in environments where cocaine is consumed, they handle cocaine in the process of buying and selling it, they intimately handle cocaine during covert penetrations of drug selling organizations, when they make arrests and seize the associated contraband, and they transport and process the seized drug as part of the securing of the chain of evidence. Some of these officers also routinely handle cocaine as part of training exercises. Considering these factors, narcotics officers would appear to be a good study group for evaluating the degree of contamination acquired via incidental environmental exposure and, as well, the resistance of contamination to wash-based cleaning procedures. Certainly their exposure to cocaine far exceeds that which is likely to be incurred by the general public.

It is important to recognize that these officers often play covert roles as drug users and drug dealers. The narcotics control strategies they pursue includes posing as drug users, and convincing illegal drug sellers that they are 'customers', i.e. drug users themselves. This precludes their ability to take precautions against contamination as that would have meaning in any ordinary laboratory setting. They cannot wear gloves or masks, etc. as this would betray their attempts to pass as drug users. These officers, in other circumstances (such as handling evidence once it is in police custody) may employ the conventional prophylactic measure of using gloves.

Based on the exposure these persons have to cocaine, and assuming none of these persons consciously abuse cocaine, a series of simple hypotheses are suggested:

- (1) It is hypothesized that the individuals in this sample are exposed to

detectable levels of cocaine via environmental contamination. This contamination can be detected in the hair.

- (2) If their environmental contact and contamination results in micro-ingestion which emulates consumption characteristically seen in abusers of cocaine, these persons should have significant amounts of cocaine in their hair, after the hair is cleansed and tested. These amounts should be comparable to the values associated with self-admitted users of cocaine.
- (3) If they do have cocaine on or in their hair, but they are not similar in profile to willful consumers of cocaine, the wash procedures and ratio criteria designed to detect contamination as opposed to ingestion should identify these officers as contaminated non-ingesters of cocaine.

This study presents data based on the analysis of hair samples and responses to survey questions of 40 persons, 36 narcotics officers drawn from a number of police departments situated in a major metropolitan area of the southeastern United States, and 4 evidence room clerks who handle cocaine on a routine basis. Six challenge samples were also sent to the testing laboratory, which was unaware of their use in the study. Four officers were sampled twice, separated by approximately a 4-month interval.¹ One officer (case 19) did not complete a questionnaire. Thus there was a total of 50 samples analyzed for this project including six challenge samples. Thirty-nine questionnaires out of a possible 40 were completed. The participating officers and evidence clerks are employed as part of a county-wide, multi-departmental narcotics enforcement task force. These officers volunteered to provide a scalp hair specimen and answer a 24-item questionnaire on their undercover experience, their perceived exposure to cocaine, and their hair hygiene habits. The hair samples were gathered by two narcotics officers, who also administered the survey. All specimens and survey instruments were anonymous. Samples and surveys were common-coded to allow comparison of responses to values determined by assay of the hair specimen.

The hair was analyzed for cocaine by the Psychomedics Corporation, of Culver City, CA, using radioimmunoassay and the preparatory method described by Baumgartner and Hill [34]. All positive cases were confirmed with GC/MS. The hair samples ranged from 1 to 4 cm in length, and consisted of 20-40 strands of hair, cut at the scalp by surgical scissors. The hair was preserved with the root to distal orientation maintained. The hair was subject to an initial anhydrous isopropanol wash, and three subsequent phosphate buffer washes. After the third washing in buffer, the hair was digested by a proteinase enzyme at a neutral pH. Each wash and final hair digest was assayed by RIA. Complete technical description of the Psychomedics sample preparation and assessment, and confirmation procedure has been published elsewhere [47]. The criteria required to consider a sample cocaine positive are discussed in detail in Baumgartner and Hill [34,36]. The laboratory values are reported in units of ng/mg. The data reported here

¹The duplicate samples were as follows: cases 4 and 10, 1 and 14, 6 and 15, 2 and 18.

Table 2
Narcotics officer, descriptive data (N = 39)

| | |
|---------------------|----------|
| Age (mean) | 36 years |
| Gender | |
| Male | 33 |
| Female | 6 |
| Ethnicity | |
| White | 31 |
| Black | 4 |
| Hispanic | 4 |
| Experience (mean) | |
| Years in narcotics | 4.64 |
| Years in undercover | 4.56 |

included values for three phosphate buffer (PO₄) washes as well as the RIA values for the final hair digest.

As part of a laboratory challenge component, the field samples sent to the laboratory also contained two positive contamination samples, which were fortified by aqueous soaks in cocaine (24 h in 0.01 mg/ml cocaine HCl) per the method of Wang and Cone [13], three negative blanks, and one hair sample from a self-admitted, chronic crack cocaine smoker. The laboratory identified all challenge samples correctly.

There were 39 completed survey questionnaires. Table 2 presents basic descriptive information on the officers and their level of experience.

7. Reports of exposure

The officers reported relatively frequent handling of cocaine. Almost all (97.3%) reported handling cocaine during purchases and arrests, and every officer (100%) reported handling contaminated objects when making purchases and arrests. Fifty-six percent handled cocaine several times weekly or more frequently. Table 3 reports frequencies for handling.

The majority of the cases handled by these officers were cocaine cases (mean

Table 3
Frequency of handling cocaine

| | |
|---------------------------------------|------------|
| How frequently do you handle cocaine? | |
| Daily or near daily | 5 (12.8%) |
| Several times weekly | 17 (43.6%) |
| Several times monthly | 14 (35.9%) |
| Rarely | 3 (7.7%) |

value 65.9%; range from 2 to 100%). And the majority of the cocaine cases were crack cases as opposed to powder cocaine cases (mean value 60.1%; range from 0 to 100%). Nearly all officers (97.3%) reported consistent and ongoing activities relative to cocaine, which included handling, purchasing, seizing, field testing, and transporting cocaine. The handling of crack cocaine by many of these officers included intense, unprotected contact. Examples of this kind of contact included 'tongue tasting' (the touching of one finger to cocaine and the subsequent touching of the tongue) and 'bumping.' Bumping is a form of tipping. When one purchases cocaine via an introduction through an intermediary, it is customary to smoke some of the crack with the intermediary as a gratuity. Since these officers cannot smoke crack, they alternatively give a 'bump' as a gratuity. This is usually done by the officer crumbling or breaking of a piece of the 'rock' with their fingernail, and giving the fragment to the intermediary.

As Table 3 indicates, these officers have frequent contact with cocaine. Many also spend significant time in social settings with persons who use cocaine, who use cocaine in their presence, and periodically attempt to induce them to use cocaine. Table 4 reports the counts of contact type as reported by the officers.

The officers were also requested to self-estimate their own level of exposure. In Table 5 the officers' views on their degree of exposure are presented. More than half of these officers estimate their exposure to be from moderate to extreme. Although 64% report that they use some form of precautions (typically wearing rubber gloves) when handling cocaine, these measures are only employed in two circumstances. One is during the execution of some search warrants, and second during the transferring of cocaine within the department after it has been seized and taken into custody. More than 1/3 of the officers report that they do not use precautions under any circumstances. None of the officers, of course, use gloves or masks when making covert buys in the field.

7.1. Hair hygiene and cosmetic treatment

It is generally recognized that the washing and cosmetic manipulation of hair affects both its capacity to absorb and shed drugs and other materials it acquires from the environment. Examining the hair treatment practices of the sample revealed no notable departure from what one might perceive as normal washing patterns. Table 6 reports the frequency of hair washing by the officers.

As Table 6 indicates, daily washing of hair is clearly the modal practice. Other aspects of hair hygiene and cosmetic treatment are presented in Table 7. The types of cosmetic reported by the officers consisted primarily of 'perms' (7), followed by the use of hair sprays, gels, and mousses (2), with a single report each of dyeing and bleaching of the hair. Of the seven perms reported by the officers, four were reported by males and three by females. Since the study was retrospective, there was no concern with efforts on the part of officers to either avoid or engage in special hair treatment or hygiene which would affect the assays procedure.

Table 4
Number of officers reporting types of cocaine contacts

| Frequency of contact | Present around powder cocaine | Present when crack is smoked | Present in environment where crack is smoked |
|-----------------------|-------------------------------|------------------------------|--|
| Daily | 4 | 1 | 1 |
| Several times weekly | 8 | 3 | 6 |
| Weekly | 2 | 2 | 2 |
| Several times monthly | 7 | 4 | 9 |
| Monthly | 4 | 4 | 5 |
| Less than monthly | 12 | 19 | 10 |
| Never | 2 | 6 | 6 |

Table 5
Officers' self-estimates of exposure to cocaine

| Degree of perceived exposure | Number of officers (%) |
|------------------------------|------------------------|
| Non-existent | 4 (10.3) |
| Slight | 13 (33.3) |
| Moderate | 14 (35.9) |
| Heavy | 6 (15.4) |
| Extreme | 2 (5.1) |

Table 6
Frequency of hair washing

| Frequency of hair washing | Number of officers (%) |
|---------------------------|------------------------|
| More than daily | 2 (5.3) |
| Daily | 31 (81.6) |
| 3-5 times weekly | 4 (10.5) |
| Once weekly | 1 (2.6) |

Table 7
Shampooing and cosmetic treatment of hair

| Do you use... | Yes | No |
|--|-----|----|
| A regular commercial shampoo? | 38 | 1 |
| A cream rinse? | 23 | 16 |
| Do you... Cosmetically treat your hair? | 11 | 28 |

8. Hair analysis data

Table 8 displays the data outcome for the hair assays for cocaine for all subjects in the study. Samples for these cases represent approximately 90 days of retrospection — roughly 3.9 cm in length. Examination of the table reveals that every officer had some measurable amount of detectable cocaine on their hair, with the exception of two cases which had a zero value for every wash and the digest.

One sample, 27A, attained sufficient value for cocaine (0.52 ng/mg) to be considered a positive assay by the 0.5 ng/mg cutoff. A repeat sample (designated 27B in Table 8) was obtained from the subject. This sample was, on subsequent analysis, negative. The second sample, however, was not comparable in time sequence to the first, because a 4-month interval had elapsed. Given the circumstances of this case, it is quite possible that the first sample outcome represents passive ingestion of cocaine, since this sample met all wash and metabolite criteria. Only one other sample, 26 (which was obtained from an evidence technician of approximately 60 years of age), had a measurable amount of cocaine in the digest, 0.072 ng/mg, a value well below the cutoff. All other samples had zero values for the digest. The alcohol wash values are dominated by zero outcomes (35 samples), with nine cases having values above zero. The mean value for the alcohol wash for the group as a whole is 0.006 ng/mg. The mean value for the series of phosphate buffer washes are as follows: first PO₄ wash, 0.0531 ng/mg; second PO₄ wash, 0.0049 ng/mg; third PO₄ wash, 0.0010 ng/mg. In each case the series of PO₄ washes shows that in each subsequent wash step the concentration value was lowered, or reduced to zero. While 42 of the 44 samples has a value greater than zero in the first PO₄ wash, only 18 cases had cocaine in the second PO₄ wash, and only four cases had any cocaine remaining in the third wash.

8.1. Control and fortified samples

Table 9, below, presents data for the three negative control samples, two 'spiked' or fortified samples, and a sample submitted collected from a self-reported crack smoker.

9. Discussion

Based on the data presented here several observations may reasonably be made in reference to the suggested hypotheses.

The first hypothesis is consistent with the findings reported here. These persons are exposed to cocaine in the course of their work, and such exposure generally results in the environmental contamination of their hair. This contamination is detectable by RIA. The levels of the detected contamination are comparable to the amount of contamination reported by other *in vivo* contamination experiments. The values for the officers in this study are, for example, very close to the background contamination values reported by Koren et al. [33] for persons never reporting any cocaine use.

Table 8
Wash and hair digest assay values: cocaine (ng/mg)

| Sample No. | Alcohol wash | PO ₄ No. 1 | Buffer No. 2 | Washes No. 3 | Hair digest |
|------------------|--------------|-----------------------|--------------|--------------|-------------|
| 1 | 0.09 | 0.13 | 0.014 | 0 | 0 |
| 2 | 0 | 0.10 | 0.01 | 0 | 0 |
| 3 | 0 | 0.15 | 0.014 | 0 | 0 |
| 4 | 0 | 0.34 | 0.03 | 0.02 | 0 |
| 5 | 0 | 0.08 | 0.008 | 0 | 0 |
| 6 | 0.11 | 0.12 | 0 | 0 | 0 |
| 7 | 0 | 0.34 | 0.01 | 0.01 | 0 |
| 8 ^a | 0 | 0.11 | 0.007 | 0 | 0 |
| 9 | 0 | 0.15 | 0.018 | 0 | 0 |
| 10 | 0 | 0.05 | 0 | 0 | 0 |
| 11 | 0 | 0.03 | 0 | 0 | 0 |
| 12 | 0 | 0.01 | 0.01 | 0 | 0 |
| 13 | 0 | 0.06 | 0.01 | 0 | 0 |
| 14 | 0 | 0.07 | 0.01 | 0 | 0 |
| 15 | 0 | 0.04 | 0.01 | 0 | 0 |
| 16 | 0 | 0.01 | 0.01 | 0 | 0 |
| 17 | 0 | 0.10 | 0.01 | 0 | 0 |
| 18 | 0.01 | 0.02 | 0 | 0 | 0 |
| 19 | 0 | 0.04 | 0 | 0 | 0 |
| 20 | 0 | 0.05 | 0 | 0 | 0 |
| 21 | 0 | 0.06 | 0 | 0 | 0 |
| 22 | 0 | 0.05 | 0 | 0 | 0 |
| 23 | 0.004 | 0.30 | 0 | 0 | 0 |
| 24 | 0 | 0.004 | 0 | 0 | 0 |
| 25 ^a | 0 | 0.008 | 0 | 0 | 0 |
| 26 ^a | 0.002 | 0.018 | 0.009 | 0.003 | 0.072 |
| 27A | 0.006 | 0.03 | 0.019 | 0.016 | 0.52 |
| 27B ^b | 0 | 0 | 0 | 0 | 0 |
| 28 | 0 | 0.004 | 0 | 0 | 0 |
| 29 | 0 | 0.005 | 0 | 0 | 0 |
| 30 | 0 | 0.008 | 0 | 0 | 0 |
| 31 | 0 | 0.007 | 0 | 0 | 0 |
| 32 | 0 | 0.013 | 0 | 0 | 0 |
| 33 | 0 | 0.013 | 0 | 0 | 0 |
| 34 | 0 | 0.008 | 0 | 0 | 0 |
| 35 | 0 | 0.011 | 0 | 0 | 0 |
| 36 | 0 | 0.02 | 0 | 0 | 0 |
| 37 | 0 | 0.007 | 0 | 0 | 0 |
| 38 | 0 | 0.008 | 0 | 0 | 0 |
| 39 ^a | 0 | 0.008 | 0 | 0 | 0 |
| 40 | 0.011 | 0.007 | 0 | 0 | 0 |
| 41 | 0 | 0 | 0 | 0 | 0 |
| 48 | 0.020 | 0.021 | 0.007 | 0 | 0 |
| 49 | 0 | 0.010 | 0.005 | 0 | 0 |
| 50 | 0.011 | 0.018 | 0 | 0 | 0 |

^a These cases are evidence clerks.

^b This represents the values of a second sample on case 27 which is to a later time frame. The first sample was, as indicated, slightly above the cut-off threshold.

Table 9
Assay outcomes for negative and positive control samples (ng/mg)

| | Sample type | Alcohol wash | PO ₄ buffer washes | | | Hair digest |
|----|-------------|--------------|-------------------------------|-------|------|-------------|
| | | | 1 | 2 | 3 | |
| 42 | Negative | 0.018 | 0.008 | 0 | 0 | 0 |
| 43 | Spiked | 46.7 | 146.0 | 38.0 | 34.8 | 296.4 |
| 44 | Negative | 0.014 | 0 | 0 | 0 | 0 |
| 45 | Spiked | 26.6 | 53.3 | 17.8 | 8.9 | 103.6 |
| 46 | Negative | 0.008 | 0.017 | 0.006 | 0 | 0 |
| 47 | S/R user | 2.1 | 5.5 | 2.5 | 2.0 | 21.4 |

Second, it appears that although these officers are chronically exposed to cocaine through their work, their exposure as measured by hair analysis is slight. If they are also micro-ingesting cocaine, it is at a level so low as to clearly distinguish them from cocaine users. However, as described in this paper, contamination must always be considered as an aspect of assay interpretation. The findings related to case 27 serve as a reminder that intense exposure to cocaine may lead to contamination via microingestion. Bear in mind some officers in this study reported field practices which would lead directly and indirectly to oral contamination. Such techniques as 'tongue tasting' or 'bumping' must be considered when interpreting a low level positive, which is near the cutoff.

Third, it appears as a consequence of these findings that the alcohol and phosphate buffer wash procedures are an adequate method for removing external contamination from hair, at least for the type of exposure experienced by these individuals. Thus our data supports the findings of Koren et al. [33], and others who have argued that environmental contamination is not an insurmountable problem to the interpretation of hair assays under most normal circumstances where contamination is likely to occur.

This study also indicates that passive contamination of hair specimens as practiced in laboratory scenarios, at least based on the *in vitro* contamination processes reported to date, are not likely to be accurate reflections of 'real world' contamination for many groups of interest in criminal justice practice. Laboratory studies exposing hair to aqueous cocaine soaks or pyrolyzed cocaine vapors have reported contamination at concentrations many orders of magnitude greater than what appear in this field study. More intensive study of field populations and determining background levels of exposure for the purposes of developing interpretive guidelines is probably a far more useful approach to the issue of cutoff determination than synthetic laboratory contamination approaches.

The results of this study, especially when considered in light of the findings of Koren et al. [33], Maloney et al. [41], Ulvick et al. [42] and Demirgian et al. [43] encourage an approach to studying contamination problems in real-world environments. It is apparent that to accurately gauge the likelihood of misinterpretation of

assays based on contamination as opposed to ingestion, background values need to be empirically determined in field settings. It is a reasonable conjecture that establishment of these field-based parameters would likely show that for most routine situations, wash procedures and sample preparation techniques similar to those used in this study are adequate safeguards against confusing contamination with meaningful cocaine ingestion.

Surely there are going to be extraordinary cases when a person is significantly contaminated with cocaine. Perhaps, for example, by deliberate sabotage, through the deliberate 'spiking' of food. It may also be possible that with chronic, intimate skin-to-skin contact, augmented by exchange of body fluids through sexual activity that an 'innocent' person becomes contaminated via contact and ingestion and could attain sufficient concentration in the hair to cross the lowest threshold as an evidentiary positive. Persons (such as undercover narcotics officers) who are peripheral but chronically 'dabble' with cocaine may be detected as positive at low values. This may also be true for persons who sell or package cocaine, but do not regularly or recreationally use the drug in any active manner. However, there is little in the way of data to support this as a commonplace event, and considerable data to support the view that such events are rare. It seems implausible that such persons could attain the values we consistently find in active cocaine users.

The criticism made that a distinction between contamination and use is a 'fatal flaw' for hair analysis does not appear to be viable. In many criminal justice situations the difference between exposure and use is a moot issue in any event. Furthermore, there is always going to be some degree of environmental contamination when a person is using cocaine, and there is always some level of microingestion when a person is contaminated with measurable quantities of cocaine. Indeed, the same condition is true for urine-based testing, and is the *raison d'être* that cutoff values for assays exist. The same logic is applicable to hair analysis. While there may be some contention about precisely where those cutoffs ought to be placed, there does not appear to be evidence which indicates that a reasonable cutoff threshold is unattainable or would work any less efficiently and effectively than it works for urine, or plasma, or any other matrix used to test for drugs.

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