Hair specimens were analyzed for cocaine (COC), benzoylecgonine (BE), cocaethylene (CE) and norcocaine (NCOC) by liquid chromatography–tandem mass spectrometry. Drug-free hair was contaminated in vitro with COC from different sources with varied COC analyte concentrations. Results were compared to COC analyte concentrations in drug users’ hair following self-reported COC use (Street) and in hair from participants in controlled COC administration studies (Clinical) on a closed clinical research unit. Mean ± standard error analyte concentrations in Street drug users’ hair were COC 27,889 ± 7,846 (n = 38); BE 8,132 ± 2,523 (n = 38); CE 901 ± 320 (n = 20); NCOC 345 ± 72 pg/mg (n = 32). Mean percentages to COC concentration were BE 29%, CE 3% and NCOC 1%. Concentrations in hair were lower for Clinical participants. COC contamination with higher CE, BE or NCOC content produced significantly higher concentrations (P ≤ 0.0001) of all analytes. CE / COC and NCOC / COC ratios did not improve discrimination of COC use from COC contamination. COC concentrations in illicit and pharmaceutical COC affect concentrations in contaminated hair. Criteria for distinguishing COC use from contamination under realistic concentrations were not significantly improved by adding CE and NCOC criteria to COC cutoff concentration and BE / COC ratio criteria. Current criteria for COC hair testing in many forensic drug-testing laboratories may not effectively discriminate between COC use and environmental COC exposure.

Introduction

Cocaine (COC) detection in hair is not sufficient to identify COC use. Hair may be contaminated by COC in the surrounding environment during COC smoking, and contaminated hands can transfer COC powder residue into hair (1–5). For this reason, the presence of other COC analytes and analyte-transparent concentration ratios are evaluated in hair drug-testing programs to differentiate illicit COC use from environmental contamination.

Four analytes are routinely investigated in COC hair testing: COC, its primary metabolite benzoylecgonine (BE), cocaethylene (CE) and norcocaine (NCOC). Typically, COC is the most abundant analyte, followed by BE (5–50% COC concentration), CE (<20% COC) and NCOC (<10% COC) (6). In addition to analyte cutoff concentrations, a BE / COC ratio less than 0.05 suggests external COC contamination and a recommendation to report a negative COC hair test (7). Other COC analyte ratios have also been suggested, with less success (7–12).

Research evaluating COC analyte concentrations in hair following external contamination is limited (2, 3, 13, 14). Reported contamination studies focused on COC and BE after contaminating hair with COC, because these are the primary analytes in hair, and CE and NCOC were believed to be in vivo COC metabolites, not manufacturing by-products. Investigators did not expect to find CE or NCOC after exposing hair to high-purity COC. More recent studies (5, 12) demonstrated that these analytes can occur at appreciable concentrations after short COC exposure to hair followed by 10 weeks of daily hygiene treatment (i.e., shampooing), and following high-purity COC hydrochloride (HCl) subcutaneous administration.

Our laboratory previously investigated the issue of environmental COC contamination using five individuals of various hair color and types (3). None of the decontamination methods used in that study were effective at removing all contamination with the mean BE / COC ratio for all hair types exceeding 0.05, the proposed federal mandatory guidelines requirement (7), from 21 days post-contamination until the end of the study.

The aims of this research were to examine the effect of COC source (e.g., pharmaceutical or seized street drug) and hair specimen type (e.g., from self-reported street COC user, COC users receiving United States Pharmacopeia (USP) COC in controlled drug administration studies and dry COC HCl powder surface contaminated hair) on analyte concentrations and concentration ratios in human hair. This research evaluated realistic COC contamination situations and authentic COC-abusers’ hair to provide additional data on COC concentration and ratios, and the ability to accurately discriminate COC use from external COC contamination in hair COC tests. The proposed federal mandatory guidelines requirements were used to evaluate these data because they are the most stringent reporting limits in hair (7). Additionally, these are the only criteria that may currently have regulatory authority in the United States. Other criteria, including the use of various washes and wash criteria, are highly variable. To provide a consistent reference point, the proposed guidelines were applied in this study. These guidelines do not require a decontamination wash, but do preclude the use of decision criteria (such as wash criteria) other than the cutoff criteria described. Unlike our previous study (3), this investigation used one laboratory decontamination procedure, the one proven to be most effective in the prior study.

Methods

Human drug consumption studies

Human head hair specimens from 31 self-reported COC users in their native environment were collected; specimens were purchased from a commercial source, as previously described (3). All subjects provided informed consent and were compensated for participation. Demographic data, such as gender, age...
and race, were collected with hair specimens. In addition, head hair specimens were collected from COC users participating in an Institutional Review Board-approved protocol conducted by the Chemistry and Drug Metabolism Section of the National Institute on Drug Abuse’s Intramural Research Program (NIDA-IRP). All participants provided written informed consent. Hair collected prior to controlled drug administration represented previously self-administered street COC use. Detailed information about participants and study design was given in previous publications (10, 15–17). Briefly, participants with a self-reported history of COC use, confirmed by a positive urine drug test, enrolled in the 10-week residential study. Head hair was completely shaved on admission (Day 0) and weekly head shavings were obtained each week until discharge. Drugs were not administered during the first three weeks to allow time for all previously self-administered drugs to be removed from hair (i.e., the washout period). Hair was collected and analyzed during this period and was determined to be free of detectable cocaine-related compounds by the end of the washout period. Hair specimens from previously self-administered COC were grouped and evaluated with the drug-user population (Street specimens), for a total of 38 drug-user specimens (16 Caucasian, 5 African American, 17 unknown race). Participants ranged in age from 20 to 52 years, although no age data were available for 14 individuals.

Additional hair specimens were collected from the NIDA-IRP participants each week beginning in Week 4, when subjects were subcutaneously administered a low dose of COC HCl powder (75 mg/70 kg) on Monday, Wednesday and Friday. Following low dosing, subjects were administered placebo doses subcutaneously during Week 7, observing the same daily schedule, with weekly head shaving. Beginning in Week 8, subjects were administered a high dose of COC HCl (150 mg/70 kg) according to a similar dosing scheme. Doses were similar to a March 2002 report by the Drug Enforcement Administration on COC abuse that stated “it is reasonable to assume that 100 mg is the average dosage unit for crack or powder COC” (18). Because both of these methods of delivery would require a lower dose of cocaine for central nervous system effects than a subcutaneous dose, low and high subcutaneously administered doses were conservatively below and above the 100 mg dose. Specimen collection continued for one week after the final high COC dose. A total of 27 head hair specimens from 11 subjects (eight males, three females; ages 23–40 years; three Caucasians, eight African-Americans) were analyzed in the current study. These head hair samples were collected during admission ($n = 7$) and at Weeks 6 and 10 ($n = 20$), based on previous data from these specimens indicating that the highest analyte concentrations were expected at these times (10, 12, 15). Seven specimens collected at admission were included in the Street population (as detailed previously), representing unknown doses of self-administered illicit COC. The remaining 20 head hair specimens were included as part of the controlled drug administration (Clinical) population.

In vitro contamination studies

Hair from two drug-free subjects was purchased from a licensed cosmetologist and verified to be negative for parent COC and metabolites. Subject 1 was a 24-year-old brunette female and Subject 2 a 13-year-old blonde female. An 8-g sample of each hair specimen was prepared for three different COC contamination treatments for a total of six contaminated hair specimens as indicated in Figure 1. Analysis of these contaminated hair populations (Contamination) are summarized in Table 1. Experimental design was adapted from Stout and colleagues (3), as a three-way cross-design, with subsampling. The factors investigated were time, hair specimen type and COC source. There were a total of 14 collection time points for each contaminated hair specimen, once before contamination and 13 time points after contamination (Figure 1). Cocaine HCl powders for contamination were procured from three sources. First, NIDA’s Division of Neuroscience and Behavioral Research provided 25 different 1-g COC HCl powders from its drug repository. These COC HCl powders were US seized, “street” COC illicitly manufactured and of variable purity, as previously reported (5, 19). Second, the DEA Special Testing Laboratories inventory donated a 1-g specimen.
of HCl powder. Third, RTI purchased a pharmaceutical grade COC HCl powder from a commercially available source, USP (Rockville, MD). COC signature analyses were conducted by DEA Special Testing Laboratories using gas chromatography–mass spectrometry (GC–MS) and capillary GC with electron capture and flame ionization detection (5, 20–27) for all COC powders. Although the pharmaceutical grade COC is considered to be high purity (i.e., low presence of manufacturing by-products), COC analyte metabolite concentrations above 1% were considered to be high for this study. Three COC HCl powders were selected for the in vitro contamination study as representative of potential COC analyte concentrations due to manufacturing by-products in street and commercial sources. An equivalent of 8 mg COC was used from each source per contamination study as follows: 88.5% COC, 8.7% NCOC (HighNCOC); 82.0% COC, 10.0% BE, 1.4% CE (HighBE, CE); and a high COC content (98.9% COC, 1.1% CE) (PharmHIGH CE).

Table I

<table>
<thead>
<tr>
<th>Criteria for a positive COC hair test</th>
<th>Number (%) of COC positive hair tests from drug-user (Street), controlled COC administration (Clinical) and contaminated hair populations (Contamination) based on each criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Street</td>
</tr>
<tr>
<td></td>
<td>N = 38</td>
</tr>
<tr>
<td>Criteria 1 (BE criteria) COC ≥ 500 pg/mg and BE ≥ 50 pg/mg and BE/COC ≥ 0.05</td>
<td>36 (95)</td>
</tr>
<tr>
<td>Criteria 2 (CE criteria) COC ≥ 500 pg/mg and CE ≥ 50 pg/mg</td>
<td>19 (50)</td>
</tr>
<tr>
<td>Criteria 3 (NCOC criteria) COC ≥ 500 pg/mg and NCOC ≥ 50 pg/mg</td>
<td>33 (87)</td>
</tr>
<tr>
<td>Criteria 4 COC ≥ 500 pg/mg and NCOC ≥ 50 pg/mg and NCOC/COC ≥ 0.05</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Criteria 5 COC ≥ 500 pg/mg and NCOC ≥ 50 pg/mg and NCOC/COC ≥ 0.01</td>
<td>24 (63)</td>
</tr>
<tr>
<td>Criteria 6 COC ≥ 500 pg/mg and CE ≥ 50 pg/mg and CE/COC ≥ 0.05</td>
<td>37 (9.0)</td>
</tr>
<tr>
<td>Criteria 7 COC ≥ 500 pg/mg and CE ≥ 50 pg/mg and CE/COC ≥ 0.02</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Criteria 8 COC ≥ 500 pg/mg and CE ≥ 50 pg/mg and CE/COC ≥ 0.01</td>
<td>12 (32)</td>
</tr>
<tr>
<td>Criteria 9 COC ≥ 500 pg/mg and CE ≥ 50 pg/mg and CE/COC ≥ 0.002</td>
<td>17 (45)</td>
</tr>
</tbody>
</table>

*For contaminated hair populations, each COC source group (HighBE, CE, HighNCOC, Pharmhigh CE) contained 78 specimens (three replicate analysis of 13 time points for two subject hair types).

Results and Discussion

Nine decision criteria were evaluated to best differentiate COC use from environmental COC contamination. These nine criteria assessed COC analyte concentrations and analyte/COC concentration ratios in all Street, Clinical and Contamination hair specimens (Table I). Criteria 1 through 3 are the original criteria for hair testing in the proposed mandatory guidelines for federally regulated workplace drug testing programs (7).

Analysis of hair samples from human consumption and contamination studies

Before sending specimens to the reference hair-testing laboratory, hair was decontaminated according to a protocol published by Cairns and colleagues (11, 28) that included an extended aqueous buffer wash. Specimens and blind quality control hair samples were submitted to the laboratory in a blinded randomized fashion. Quantitative analysis of COC, BE, CE and NCOC in hair were conducted by Immunalysis Corporation (Pomona, CA) by liquid chromatography–tandem mass spectrometry (LC–MS-MS) (29). Briefly, each hair specimen was sonicated at 75°C for 3 h in an acidic phosphate buffer solution (0.025M, pH 2.7). The buffer solution was decontaminated and reconstituted with 0.1M sodium phosphate buffer (pH 6.0) before applying to a conditioned solid-phase extraction column. Methylene chloride–methanol–ammonium hydroxide (78:20:2, v/v/v) was used to elute the COC analytes. The extracts were evaporated to dryness under nitrogen at 40°C and reconstituted in methanol. The assays were performed on an Agilent Technologies (Santa Clara, CA) 1200 Series liquid chromatography system coupled to a 6410 triple quadrupole mass spectrometer, operated in positive APCI mode. Two multiple reaction-monitoring mode (MRM) transitions were monitored (dwell time 50 ms) and one ion ratio within ±20% of the ratio of calibration standards, retention time (±0.2 min calibration standard), acceptable chromatography and signal-to-noise (S/N) were included as identification criteria. Limits of detection (LOD) and quantification (LOQ) for all COC analytes, defined as an S/N of 3:1 and 10:1, were 25 and 50 pg/mg, respectively, with percent recovery at the LOQ (n = 5) of 99.3% (CE) to 108% (NCOC). The limit of linearity was 10,000 pg/mg. Within-assay and between-assay imprecision at 100 pg/mg for all analytes was less than 8% (BE) and 15% (CE), respectively. Statistical analyses were performed with SAS (PROC NONLIN version 9.1.3; Research Triangle Park, NC) to evaluate trends over time and compare compound concentrations. Mean and standard errors for individual treatments and data graphs were determined with Microsoft Excel (Office 2003, Redmond, WA).

Decontamination washes were not analyzed. The objective of the wash procedure was to provide information directly related to the proposed federal guidelines, which do not include any provision for post hoc calculations or criteria (such as a wash criteria).
Additional decision points were selected based on review of published hair concentration data and previously proposed criteria (5, 9, 30). Criteria 4 and 5 evaluated NCOC/COC ratios of ≥0.05 and ≥0.01, respectively, and Criteria 6 through 9 assessed CE/COC ratios of ≥0.05, ≥0.02, ≥0.01 and ≥0.002, respectively.

**COC and metabolites in hair from consumption in a street environment**

Mean ± SE (or standard error of the mean), median and range of concentrations (µg/mg) were determined for each analyte. COC and BE were quantified in all Street population specimens; NCOC was not detected in 16% (six out of 38) and CE in 47% (18 out of 38) of specimens. Mean concentrations were higher than the median for all analytes. In agreement with previous reports in the literature, mean ± SE analytic concentrations in Street drug users were COC 27,889 ± 7,846 (n = 38); BE 8,132 ± 2,523 (n = 38); CE 901 ± 320 (n = 20); NCOC 345 ± 72 pg/mg (n = 32). Approximate mean analytic percentages to COC concentration were BE 29%, CE 3% and NCOC 1%.

In 38 Street hair specimens (Table I), one subject was negative for all COC analytes, one additional subject was negative by BE criteria, 79% were positive for NCOC and only 50% were positive for CE (Criteria 2). Nineteen subjects met BE (Criteria 1), but not CE criteria (Criteria 2). Six subjects met BE (Criteria 1), but not NCOC criteria (Criteria 3). Conversely, one subject would be identified as a cocaine user with the presence of CE and NCOC, but not BE. Furthermore, a COC/CE ratio ≥0.002 (Criteria 9) and an NCOC/COC ratio ≥0.01 (Criteria 5) did not improve upon the original proposed mandatory guidelines criteria (Criteria 1–3) for differentiating COC use from COC contamination. Therefore, there was not an increase in the COC confirmatory rate when additional COC metabolites, NCOC and CE, at the proposed cut-off concentrations and additional ratios were included.

**COC and metabolites in hair from consumption in controlled, clinical environment**

Results from the Clinical study were included to evaluate COC and metabolites in hair after controlled COC administration (Table I). Analyte concentrations in all Clinical hair specimens were substantially lower than the other assessed drug-user populations. Although COC was detected in hair from all Clinical subjects (100%), BE was quantified in 85%, NCOC in 70% and CE in 30% of specimens. Again, mean concentrations were higher than median for all analytes. Mean ± SE analytic concentrations in Clinical drug users in pg/mg hair were COC 6,171 ± 1,569 (n = 20); BE 434 ± 80 (n = 17); CE 123 ± 47 (n = 7); NCOC 290 ± 139 pg/mg (n = 14). Approximate mean percentages to COC were BE 7%, CE 2% and NCOC 5% of COC hair concentration. Concentrations and ratios were compared to the proposed Substance Abuse and Mental Health Services Administration (SAMHSA) confirmatory cut-off concentrations (Table I, Criteria 1–5). For BE, three hair specimens met the confirmatory cut-off concentration of 50 pg/mg, but did not meet the BE/COC ≥ 0.05 criteria. For Clinical hair specimens that met the confirmatory cut-off concentration of 50 pg/mg for CE and NCOC, all met the CE/COC or NCOC/COC ≥ 0.05 criteria.

In 20 Clinical hair specimens (Table I), 10 subjects met BE (Criteria 1), but not CE criteria (Criteria 2). Four subjects met BE (Criteria 1), but not NCOC criteria (Criteria 3). Conversely, one subject would be identified as a cocaine user with the presence of CE and NCOC, but not BE. Therefore, there was not an overall increase in the COC confirmatory rate when additional COC metabolites, other than COC and BE, or metabolite/COC ratios were added as decision points for Clinical specimens.

Comparison of these two drug user populations indicates that the Street users’ hair had a different distribution of COC to BE compared to the Clinical specimens. The cocaine dose of the Street hair samples was unknown, but most likely much higher than the Clinical hair samples. Because the COC and BE concentrations were so much higher in the Street hair samples, this may have resulted in the BE/COC ratio being higher as well. In addition, the cocaine purity in the Street samples was unknown; the BE distribution in the hair would vary depending on the BE concentration in the cocaine source (e.g., %BE could be higher in some cases).

**COC and metabolites in hair from in vitro surface contamination**

COC concentrations were evaluated for each subject by each COC source treatment. Each time point had three replicate samples collected and analyzed (Figure 2). For Subject 1, the PharmHIGH CE treatment yielded significantly higher COC concentrations (P = 0.0001) than either the HighBE,CE or HighNCOC treatments; for Subject 2, the HighBE,CE treatment had significantly higher COC concentrations (P = 0.0001) than either the PharmHIGH CE or HighNCOC treated hair samples (Figures 2A and 2B). In Subject 1’s hair, the PharmHIGH CE and HighBE,CE contamination showed significantly higher BE concentrations than after the HighNCOC treatment (P < 0.0001). In Subject 2’s hair, HighBE,CE contamination produced significantly higher BE concentrations than after PharmHIGH CE or HighNCOC treatments, both exhibited low BE concentrations over time (Figures 2C and 2D). Contamination with HighNCOC produced no measurable CE (i.e., slope = 0) in either subject’s hair (Figures 2C and 2D), while significantly higher NCOC concentrations were observed (Figures 2G and 2H) that following PharmHIGH CE and HighBE,CE treatments, most pronounced in Subject 1’s hair samples.

In Subject 1’s hair, the PharmHIGH CE and HighNCOC treatments produced BE/COC ratios greater than 0.05 at approximately three weeks and all BE/COC results exceeded 0.05 after 40 days. However, the HighBE,CE treatment maintained significantly higher average ratios of BE/COC over time than either the PharmHIGH CE or HighNCOC treatments (P < 0.0001). For Subject 2, days 63 and 70 were removed from the analysis because COC concentrations were less than the LOQ for two COC treatments.

Inter-individual variability in hair testing and the presence of metabolite concentration in the source cocaine contribute significantly to these preliminary results. If there is an appreciable concentration of cocaine metabolite in the source cocaine (i.e., greater than 1%), then the presence of these analytes in hair
Figure 2. Mean COC analyte concentration after contamination with three different COC sources (pg/mg, n = 3 at each time point). Error bars represent SE for Subject 1 hair: COC (A), BE (C), CE (E), NCOC (G); and Subject 2 hair: COC (B), BE (D), CE (F), NCOC (H).
Figure 2. (Continued)
could be detected at or above cutoff concentrations, even after 70 days of hygienic treatment. Furthermore, BE concentrations remained more consistent after 30 days, whereas COC concentrations continue to decline, resulting in BE/COC ratios above the 0.05 cutoff after this time.

The effect of hair color on drug concentrations was not evaluated. The sample population of one dark hair and one light hair included in the in vitro surface contamination is not large enough to evaluate differences in hair color or type (e.g., ethnic) with sufficient statistical power. Rather, multiple hair colors were used to represent the inter-individual variability in hair. Although the contamination studies for both hair specimens were exactly the same treatment, the two samples showed concentration and pattern differences with each cocaine source. With these limited preliminary data, it appears that darker hair is more susceptible to drug incorporation from in vitro contamination than lighter hair. However, there were many variables contributing to observed concentration and pattern differences, including: (i) cocaine purities in the street (82% HighBE,CE) and pharmaceutical (99% PharmHIGH CE) cocaine samples, although a weight-equivalent COC amount was employed from each source for each contamination; (ii) concentrations for many of these time points exceeded the reference laboratories’ upper limit of linearity (10,000 pg/mg) and were reported as greater than the highest calibrator, reducing comparisons of these time points; (iii) incorporation kinetics for cocaine are different for earlier time points (0.2 and 1 day) when contamination occurred, but washing was minimal compared to later time points (time points 14 and 21).

Analyte concentration ratios, BE/COC, CE/COC and NCOC/COC, were compared for drug user populations (Street n = 38; Clinical n = 20) and in vitro surface contamination samples (n = 234). Table II summarizes the minimum, maximum and investigated metabolite-to-COC ratios for in vitro surface contamination samples, Street drug user samples and Clinical drug user samples from this study, as well as results obtained for drug user sample populations reported by Bourland et al. (9) and Cairns et al. (11). For all drug user sample populations, the minimum, maximum and investigated metabolite-to-COC ratios were in agreement, and the Clinical population showed the lowest values. Based on these data, a NCOC/COC value of ≥0.249 would be necessary to eliminate surface contaminated samples; however, none of the drug user hair samples would remain positive at this NCOC/COC criterion. Similarly, a CE/COC value ≥0.049 would be necessary to eliminate surface contaminated samples; 29 of 163 drug users’ hair samples (18%) would remain positive with this criteria (four Street drug users’ samples in our study, 13 of 75 samples in the Cairns et al. (10), 12 of 30 samples in Bourland et al. and none of the Clinical samples (9). Similarly, a BE/COC ≥0.630 criteria would result in only seven of 162 drug users’ hair (4%) as positive with this criterion (seven Street drug users’ samples). Results from Table II indicate that the lower the presence of a COC metabolite impurity (e.g., Pharm treatment with 1.1% CE and no BE or NCOC), the lower the metabolite-to-COC concentration ratios will be; however, it is not possible to know the purity of a drug ingested on the street.

As with drug user populations, analytical results from the in vitro surface contamination were compared against nine decision criteria. Table I summarizes the number of hair samples for each COC treatment and relative percentages of specimens that met Criteria 1–9. Percentages are relative to the total number of analyses conducted for that COC treatment group, including triplicate analyses.

Surface-contaminated hair specimens also were evaluated by Criteria 1 through 3, as originally proposed in the mandatory guidelines. COC contamination produced much lower BE/COC ratios (Criterion 1) than found in drug user populations (20%
positive versus 70 and 95% positive). For the CE criteria (Criteria 2), surface contamination with the higher CE content COC sources produced higher numbers of positive COC hair tests (58 and 52% positive in Contamination population compared to 30 and 50% positive in drug user populations, Street and Clinical). For the NCOC concentration (Criteria 3), surface contamination samples with a higher NCOC content in the COC source were slightly lower than the Street and Clinical drug user populations (63% positive versus 70 and 87% positive). Addition of a CE/COC ratio as low as ≥0.002 (Criteria 9) did not increase the number of positive tests as CE concentration (Criteria 2) alone for Street, Clinical or Contamination hair specimens. Addition of NCOC/COC ratio of ≥0.05 and ≥0.01 (Criteria 4 and 5) did achieve the same percent positive tests as NCOC concentration (Criteria 3) alone.

Conclusions

After evaluating analyze concentrations and ratios in hair from COC users, individuals receiving COC under controlled conditions, and contaminated hair with various sources of COC HCl powder, the use of cutoff concentrations for any or all of the analytes would not reliably discriminate a COC user’s hair from contaminated hair. The use of analyte ratios provides more information and some ability to discriminate user specimens from contaminated specimens; however, CE and NCOC concentrations and ratios did not discriminate more effectively than decision criteria based on only BE and COC that are currently employed by many hair drug-testing laboratories. All three metabolites (i.e., CE, NCOC and BE) can be present at varied concentrations in illicit COC as by-products of the manufacturing process, as discussed by Casale (20–22, 31). As such, this will confound the use of ratios to discriminate contamination from use. Contamination of hair with illicit and pharmaceutical COC materials containing 1–10% CE, BE and NCOC produced concentrations and ratios indicating COC use by currently used criteria. These hair specimens could not be discriminated from user hair even after decontamination.

These results suggest that although some ratio-based interpretation may coincide with usage rather than contamination, the presence of BE, CE and NCOC by mechanisms other than metabolism in potential contaminating COC material confounds the use of these compounds to definitively discriminate use from contamination. Refinements of decision criteria using these compounds may improve the potential risk of a “positive determination” from an incidental contamination, but will not eliminate the possibility. The presence of COC, BE, NCOC and CE definitively indicate an exposure to cocaine. However, these results indicate that it is not possible in all circumstances to interpret the presence of these compounds or any combination of these compounds as an indication of use.

One limitation of this study is the small sample size investigated. A sample population of three Caucasian and eight African-American subjects is not large enough to evaluate differences in hair color or type (e.g., ethnic) with sufficient statistical power. Additional studies to further investigate a larger, more diverse population may be needed to fully evaluate ethnicity while controlling for hair color (e.g., black hair in Caucasian-European, Hispanic, African American and Asian subjects).

Decision criteria for positive COC hair tests were evaluated to determine whether COC contamination could be differentiated. Laboratories would have to apply decision criteria under the proposed federal mandatory guidelines (7). These guidelines do not have provisions for the use of laboratory decontamination procedures or additional decision criteria, which include wash criteria or mathematical criteria that compare the presence of a drug in wash solutions to concentrations in hair. Review of the current literature suggests that decontamination procedures are highly variable and not consistently performed by forensic laboratories (5, 32, 33, 34). Consistent with what Cairns and colleagues (11, 28) and Tsanaclis and colleagues (35) have previously published, decision criteria may be necessary to adequately and reliably identify contamination.

These results have implications for the proposed mandatory guidelines because the decision criteria, as proposed, do not adequately discriminate COC contamination. This is of particular concern for those individuals whose occupation (e.g., law enforcement) may put them in contact with large amounts of COC in their work environment. Therefore, a requirement for decontamination and further research to determine the efficacy of comparative criteria from decontamination data may be necessary.

Acknowledgments

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References


