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The Examination of Illicit Cocaine

REFERENCE: LeBelle, M., Lauriault, G., Callahan, S., Latham, D., Chiarelli, C., and Beckstead, H., **"The Examination of Illicit Cocaine,"** *Journal of Forensic Sciences,* JFSCA, Vol. 33, No. 3, May 1988, pp. 662-675.

ABSTRACT: A laboratory system of examination of illicit cocaine exhibits is described. Separation and identification of many of the components in exhibits are achieved by the use of capillary column gas chromatography and a Finnigan ion trap detector. Further examination and quantitation of the components of exhibits is achieved using two high performance liquid chromatographic (HPLC) systems. Both of these systems use identical reverse phase C_8 columns. System 1 employs a solvent composed of 40% acetonitrile, 10% tetrahydrofuran and 50% 0.1% v/v aqueous triethylamine. The eluant is monitored at 280 nm. This system is preferred for routine quantitative analysis of cocaine and related alkaloids in exhibits. System 2 employs a solvent composed of 30% acetonitrile and 70% 0.05*M* phosphate buffer (pH = 5.0). The eluant from this system is monitored at both 220 and 280 nm. This system offers advantages in sensitivity. The relative retention times of a number of relevant substances as determined with gas chromatography and the two HPLC systems are given. The utility of the methodology for the identification and comparison of exhibits is demonstrated.

KEYWORDS: toxicology, cocaine, chromatographic analysis, high performance liquid chromatography

The increase in recent years in the illicit use of cocaine in Canada is reflected both in the number of exhibits analyzed by the Health Protection Branch (4050 in 1983 to 1984, projected 8160 in 1986 to 1987) at the request of enforcement agencies and in the number of court convictions associated with cocaine [*1*]. The increase in cocaine related enforcement activity has resulted in a disproportionate increase in resource demand as, in addition to standard qualitative analyses, an increasing number of requests for quantitative analyses in respect of exhibits containing cocaine are received. In addition, increasingly more interest has been expressed by enforcement agencies in the relationship or linkage of exhibits.

For us to continue to provide the high level of service demanded by our client agencies in the face of this increased analytical demand, modifications to the analytical techniques employed in our laboratory were required.

Routine analytical procedures in our laboratory now comprise methodology involving a

Received for publication 23 May 1987; revised manuscript received 3 Sept. 1987; accepted for publication 8 Sept. 1987.

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spot test, two high performance liquid chromatography (HPLC) systems, and gas chromatography-mass spectrometry (GC-MS).

The two most common spot tests used for presumptive identification of cocaine are those described by Young [*2*] and Scott.[4] The merits of these tests and other tests have recently been reviewed [*3*]. The recent introduction of a free base form of cocaine, commonly referred to as "crack," has presented an additional problem in the application of these tests. Modifications to the Scott test have been described[5] that permit the identification of the base form of cocaine.

HPLC has been employed extensively in studies related to cocaine. Reports [*4–6*] have appeared describing the analysis of cocaine and its metabolites in biological fluids using octadecylsilyl (C_{18}) bonded reverse phase columns. Results of studies regarding the stability of cocaine [*7–10*], the separation of cocaine from possible isomers [*11–13*], and the determination of cocaine in plant material [*14*] have been reported. The application of HPLC to the examination of forensic science exhibits has resulted in reports of systems applicable to a variety of drugs including cocaine [*15–20*], as well as those designed specifically for the analysis of cocaine and related alkaloids and compounds [*21–26*]. These reports describe the use of varied columns, solvent systems, and detection methods. However, note that four investigators considered that the use of ultraviolet (UV) detection systems more elaborate than the single wavelength type were useful. Dual wavelength detection at 254 and 280 nm [*18,23,24*] as well as collection and UV spectrum recording [*25*] have been reported. The variety of possible compounds encountered in cocaine exhibits argues for the use of such detection methods.

Gas chromatography has similarly been employed extensively in the analysis of cocaine. Numerous reports have appeared describing the determination of cocaine, its metabolites, and related compounds in biological fluids [*27–45*], plant material [*46,47*], and illicit drugs [*48–53*]. All methods with the exception of one [*45*] used packed columns. However, the variety of related alkaloids and other compounds [*22–26,48–50,52*] which can be anticipated in illicit cocaine exhibits, makes the high resolution power and efficiency of capillary columns desirable for the routine examination of such materials.

Gas chromatography coupled with mass spectrometry has also been widely used in varied applications relative to the examination of cocaine containing materials. Extensive reports regarding the determination of cocaine and its metabolites in biological materials have appeared [*54–65*]. The utility of this method has also been demonstrated through a number of reports regarding its application to the examination of plant material [*66–69*] and illicit exhibits [*70–72*]. The resolution capabilities of open tubular capillary columns have been applied in some of these studies [*64,68,69*].

In developing an analytical regimen for the examination of cocaine exhibits, we considered a number of factors. From an operational position, the large majority of exhibits are complex mixtures, and in most cases a confirmation of the presence of cocaine would satisfy the enforcement agency's requirements. Second, quantitative results with respect to the cocaine content must be able to be generated, often with little advance notice. Third, capability must exist for the generation of data useful in identifying, to the enforcement agency, similarities or conclusive links between particular exhibits.

To meet these requirements, we have combined the individual advantages of the preceding technologies. A description of the GC-MS and HPLC systems employed in our laboratory follows.

[4]L. J. Scott, Drug Enforcement Administration, personal communication, 1973.

[5]J. Fasanello and P. Higgins, Drug Enforcement Administration, personal communication, 1986.

Experimental Procedure

Instrumentation

The two liquid chromatographs employed were Spectra Physics model 8100 units equipped with integral autosamplers and fitted with 10-μL injection loops. Chromatograph 1 was interfaced to a Kratos 773 detector operating at 280 nm and a Spectra Physics 4270 computing integrator. Chromatograph 2 was interfaced to a Spectra Physics 8440 detector and a Spectra Physics 4200 computing integrator. Chromatograph 2 was used for dual wavelength detection at 220 and 280 nm. Each sample was introduced in duplicate autosampler vials, and two chromatograms of each exhibit were recorded with the instrument set to perform wavelength selection automatically. The data systems of both units were interconnected using the Spectra Physics Labnet chromatography data system.

The gas chromatograph was a Carlo Erba Vega Series 6000 equipped with a Grob-type split/splitless injector and a capillary column. The detector was a Finnigan Mat 700 ion trap. The gas chromatograph's column effluent was introduced to the detector by direct attachment of the column; no splitting occurred between the gas chromatograph and the detector. The ion trap was set to acquire data at 1 scan/s over a mass range of 40 to 500 AMU.

Materials and Supplies

The HPLC columns employed in both liquid chromatographs were RP-8 Spheri 10, 250 by 4.6 mm (Brownlee Labs, Santa Clara, CA). The gas chromatography capillary column was a 15-m by 0.25-mm DB-5, 0.25-μm film thickness (J & W Scientific Inc., Rancho Cordova, CA). All chemical standards were available from our house collection and had been either obtained from various pharmaceutical manufacturers or synthesized in our laboratories. All solvents employed were HPLC grade.

Chromatographic Conditions

The liquid chromatographs were used to mix the solvent systems from solvent reservoirs. Both systems were operated at a flow rate of 1.0 mL/min; the columns were operated at ambient temperature. System 1 was operated using a solvent composed of 40% acetonitrile, 10% tetrahydrofuran, and 50%, 0.1% v/v aqueous triethylamine. System 2 was operated using a solvent composed of 30% acetonitrile and 70% 0.05*M* phosphate buffer (pH = 5.0).

The gas chromatographic column was operated at a head pressure of 40 kPa of helium (linear velocity = 60 cm/s). The injector was maintained at 275°C. The column oven was held at 100°C for 1 min and increased to 275°C at 20°C/min. One-microlitre injections were made at a split ratio of 60:1.

Sample Preparation

Samples for injection on HPLC System 1 were prepared by dissolving a sufficient quantity of the exhibit in methanol to yield a concentration of 2 mg/mL. Samples for injection on HPLC System 2 were prepared by dissolving 10 mg of exhibit in 10.0 mL of mobile phase. Approximately 1 mL of the resulting solution was added to each autosampler vial.

Samples were prepared for presentation to the GC-MS in two ways. To a culture tube approximately 70 by 10 mm in size was added 25 to 50 mg of sample followed by 1 mL of saturated aqueous sodium hydrogen carbonate and 3 mL of ethyl acetate. The tube was vigorously shaken, the contents allowed to settle, and the upper layer injected. To a culture tube was added approximately 25 mg or more of exhibit and 1 to 3 mL methanol. The tube

was shaken and any insoluble material allowed to settle. The clear methanolic solution was injected.

Results and Discussion

All exhibits submitted to our laboratory are contained in envelopes provided to enforcement agencies specifically for this purpose. There is an area on the envelope to permit the indication by the police officer of the suspected identity of the drug. This information is derived from the investigation surrounding the particular case and is useful operationally since it is the analyst's only information regarding the purported identity of the drug when commencing an analysis. A spot test is performed solely to confirm the suspicion regarding drug identity as indicated by the enforcement agency. Although spot tests are inherently inconclusive and are subject to interferences, the speed and ease with which they can be performed may provide an experienced analyst with useful information. We presently employ the Young [*2*] version of the cocaine test. It may indicate a confirmation of the indication by the enforcement agency, a negative result, or a weakly positive result. This information is useful in performing subsequent procedures leading to conclusive identification. For example, in the case of weakly positive results, the analyst is aware that significantly more material should be used or, in the case of negative tests, that the exhibit should be further examined by other standard spot tests for the presence of other drugs. It is not uncommon that enforcement agencies incorrectly identify a drug. Regardless of the spot test finding, the exhibit is examined by instrumental methods to confirm the conclusion.

As conclusive identification is fundamental to an illicit drug laboratory, all cocaine exhibits presented to our laboratory are now subjected to GC-MS examination.

The availability, in recent years, of simplified mass selective detectors of moderate cost has allowed for the introduction of these instruments to multi-user environments for the efficient performance of routine analysis. The Finnigan ion trap detector is one such instrument.

The ion trap delivers a mass spectrum characteristic of the instrument and sometimes significantly different from the common quadrupole instruments in use. An example of an ion trap spectrum of cocaine in comparison with that obtained on a Finnigan 4610B is shown in Fig. 1.

Although the sensitivity of the ion trap is not in the range of more expensive instruments, such as the Finnigan 4610B, for most purposes involving illicit drug work, sensitivity is not a limiting factor. In evaluating the limit of detection of this instrument for the task it performs, we employ a criterion that specifies that the background subtracted spectrum of a given amount of a substance contains all of the major fragment ions in the spectrum of that substance when determined with greater amounts. That is, the spectra are visually consistent. In the case of cocaine we have found the detection limit of the instrument to be 1.6 ng.

Since our acquisition of the ion trap, more than 500 cocaine exhibits have been examined. None has contained diluents or excipients which co-elute with cocaine. Table 1 lists substances which we have found to be incorporated in illicit cocaine, other related substances, and their respective relative retention times. Sugars which are normal constituents of exhibits are not detected. Two sample preparation techniques were used: the bicarbonate extraction for routine analysis and the simpler methanol dissolution when a more comprehensive analytical examination of the exhibit is desired. The bicarbonate extraction has the advantage of eliminating acidic and polar aqueous soluble components such as benzoyl ecgonine and sugars and thereby presenting a cleaner sample to the chromatograph. We prefer this method because at present we do not use a guard column.

The routine use of GC-MS for the identification of cocaine exhibits provides simultaneous, useful, ancillary information. Enforcement agencies are interested in the similarities between two or more exhibits. Although other methods are available (including those HPLC

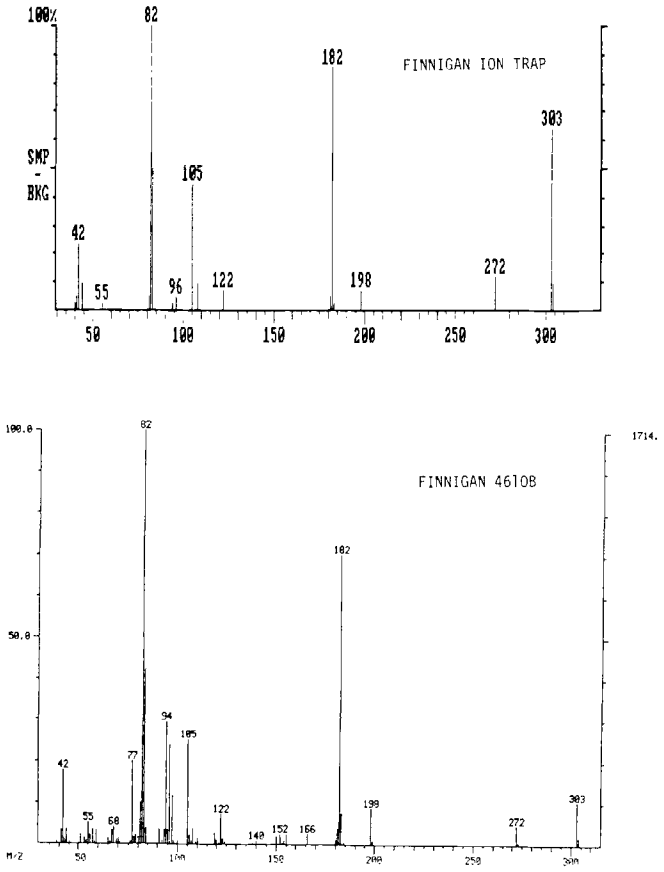

FIG. 1—*Comparison of mass spectra of cocaine between a Finnegan 4610B quadrupole instrument and a Finnegan Mat 700 ion trap.*

methods described below) that are applicable in carrying out such determinations, the use of the GC-MS system described here may often be sufficient at least to determine nonsimilarity of exhibits. For example, the detection of cis- and trans-cinnamoylmethylecgonines in one exhibit and not in another is certainly sufficient to determine that the exhibits are derived from different sources. Similarly, the detection of ephedrine or lidocaine in one exhibit and not in another at least is indicative that the materials are not identical. The temperature range employed in the column ramp program is sufficient to elute effectively the most commonly found compounds in cocaine exhibits.

A liquid chromatographic system for the routine quantitation of illicit drug exhibits must be both dependable and durable. System failure is unacceptable in an environment requiring emergency quantitations. Liquid chromatography System 1 is employed for this purpose. It offers the advantages over System 2 of simplicity of solvent preparation, ability to store the column in the solvent, fast column equilibration, and extended column life. The reproducibility at a cocaine concentration of 2 mg/mL (coefficient of variation of peak areas = 0.7%, 9 injections) and linearity (coefficient of correlation = 0.999, 0.5 to 6.0 mg/mL) of this system are excellent. Table 2 gives the relative retention times for a number of related materials that have been found in cocaine exhibits.

It may be seen from Table 2 that not all related substances are resolved from each other and that lidocaine, a common adulterant in exhibits, is only marginally resolved from co-

TABLE 1—*Relative retention times of substances by gas chromatography.*[a]

Substance	Relative Retention Time
Methyl benzoate	0.19
Benzoic acid	0.23
Acetylsalicylic acid	0.26
Phenylpropanolamine	0.39
Methylecgonidine	0.41
Nicotinamide	0.41
Ephedrine	0.42
Methylecgonine	0.49
P-aminobenzoic acid	0.55
Benzocaine	0.56
Acetaminophen	0.66
Dyclonine	0.67
Caffeine	0.75
Prilocaine	0.76
Lidocaine	0.79
Tropacocaine	0.84
Procaine	0.89
Cocaine	1.00[b]
Tetracaine	1.02
Cis-cinnamoylmethylecgonine	1.11
Trans-cinnamoylmethylecgonine	1.18
Benzoyl ecgonine	1.22

[a]For chromatographic conditions see Experimental Procedure section.

[b]Retention time of cocaine = 8.2 min.

TABLE 2—*Relative retention times of substances by HPLC System 1.*[a]

Substance	Relative Retention Time
Acetaminophen	0.38
Acetylsalicylic acid	0.22
Benzocaine	0.66
Benzoyl ecgonine	0.42
Caffeine	0.42
Cocaine	1.00[b]
Ephedrine[c]	2.34
Lidocaine[c]	0.99
Nicotinamide[c]	0.42
Phenylpropanolamine[c]	0.66
Prilocaine	0.84
Procaine	0.86
Tetracaine	2.09
Trans-cinnamoylmethylecgonine	1.26
Cis-cinnamoylmethylecgonine	1.13

[a]See Experimental Procedure section for a complete description of the system.

[b]Retention time of cocaine approximately 8.5 min.

[c]Substances not detectable at 280 nm.

caine. This lack of resolution dictates the use of 280 nm as the detection wavelength. Lidocaine is almost transparent to light of this wavelength. Experimentally, the nullification of any effective interference from lidocaine was verified by the injection of mixed cocaine-lidocaine standards under the described experimental conditions. Even at a concentration of 1.5 mg/mL of lidocaine in 2 mg/mL of cocaine, no effect could be observed.

The detection of other exhibit adjuvants may be beneficial but is unnecessary when developing quantitative data. Not all substances were detected at the wavelength used (280 nm); the relative retention times of the other substances indicated by an asterisk were determined using a detection wavelength of 254 nm.

A routine method of analysis of cocaine exhibits should be able both to detect and to separate the related coca alkaloids cis- and trans-cinnamoylmethylecgonines. These components are frequently encountered in exhibits; if they are present, their detection provides gratuitous information regarding exhibits. Liquid chromatography System 1 both detects and separates these alkaloids. It can be seen from Table 2 that none of the other related substances co-elute with these alkaloids. In the course of examining hundreds of exhibits over a number of years, no exhibit ingredient has interfered in the quantitation of the cocaine.

Moreover, at a detection wavelength of 280 nm the cis- and trans-cinnamoylmethylecgonines are approximately 8 and 19 times more absorbent than cocaine. Therefore, although these alkaloids frequently constitute only a small percentage of an exhibit, they may be readily detected, and their area counts in relation to that for the cocaine peak may be used to develop useful sample linking information. The generation of this data is of course incidental to that required to develop quantitative estimates of the amount of cocaine present in a sample.

Where a more comprehensive examination of exhibits is required, System 2 is employed. The 220-nm detection wavelength provides for greater sensitivity in relation to most substances and the dual detection wavelengths provide for the calculation and use of response ratios for particular substances. This methodology has been applied previously using 254 and 280 nm [*17,23,24*] in the examination of cocaine exhibits. It is invaluable in providing evidence, in addition to retention time, regarding the identity of substances because the retention times of the various components are similar due to the large number of materials that may be incorporated into exhibits. We have used 220 nm as the lower of the wavelengths because many of the compounds of interest, in particular benzoyl ecgonine, absorb more strongly in this region, thereby permitting the detection of smaller amounts of each component.

Table 3 lists the relative retention times of these substances, their relative responses at 220 versus 280 nm, and their minimum detectabilities. The system, moreover, yields quantitative results in which an analyst may have more confidence because the correspondence of the quantitative determinations at the two wavelengths is further confirmation of the integrity of the peak due to cocaine. The linearity of the system was confirmed over the concentration range of 0.25 to 2 mg/mL for cocaine at both 220 nm (coefficient of correlation = 0.999) and at 280 nm (coefficient of correlation = 0.999).

During routine analytical screening of cocaine exhibits using this system, we found it convenient to prepare three standard solutions each containing cocaine and four or five of the other components listed in Table 3. The routine injection of these standard mixtures ensured adequate system resolution and reproducibility of the dual wavelength response ratios.

To illustrate more clearly the usefulness of each of these systems, some actual exhibit examinations are presented below.

The practical advantages of employing GC-MS systems for routine analysis are readily recognized. Lukaszewski [*71*] in particular was able to demonstrate the utility of this method when applied to illicit exhibits. An example of the ability of the system to differentiate exhibits easily is illustrated in Fig. 2. Exhibits A, B, and C were recent submissions to our

TABLE 3—*HPLC data: cocaine and related substances using HPLC System 2.*[a]

Substance	Relative Retention time	A220 / A280	Minimum Detectability (ng on column)
Acetaminophen	0.39	2.54	15
Acetylsalicylic acid	0.34	21.20	15
Benzocaine	1.50	0.48	10
Benzoylecgonine	0.56	12.07	10
Caffeine	0.45	0.97	10
Cocaine	1.00[b]	8.50	[c]
Ephedrine	0.41	large	200
Lidocaine	0.74	large	20
Nicotinamide	0.35	14.76	10
Phenylpropanolamine	0.32	6.01	15
Prilocaine	0.62	27.10	20
Procaine	0.52	0.51	15
Tetracaine	2.13	0.64	30
Cis-cinnamoylmethylecgonine	1.78	0.81	[c]
Trans-cinnamoylmethylecgonine	2.05	0.50	15

[a] See Experimental Procedure section for a complete description of the system.
[b] Retention time of cocaine approximately 12.5 min.
[c] Not determined.

laboratory. The total ion chromatogram resulting from the injection of the ethyl acetate extract of each is shown in Fig. 2. The identity of each of the components as determined from their respective mass spectra is indicated. Exhibit A is not typical of cocaine exhibits analyzed in our laboratory. The presence of tropacocaine is not particularly common (less than 2% of the exhibits). However, this particular example illustrates the detection of other coca derived alkaloids such as methylecgonine which may be useful in linking exhibits. Exhibits B and C are more typical of our exhibits especially since they contained lidocaine which we and others [*21,22,24-26,52,69,71*] have found to be one of the most common adulterants in cocaine, undoubtedly because of its ability to mock the local anaesthetic effect of cocaine. The presence of the other coca unrelated adjuvants in these latter two examples is not uncommon.

Of course not all exhibits are as easily differentiated. However, the utility of HPLC System 1 in the linking of exhibits was demonstrated in a recent case where a number of exhibits were submitted. Eight identical white powders suspected of being cocaine were received. GC-MS analysis indicated that only Exhibits 1 to 7 contained cocaine; Exhibit 8 was shown to contain ephedrine and dyclonine. Exhibits 5 to 7 contained cocaine, ephedrine, and dyclonine. This evidence alone implied a manufacturing operation to cut the cocaine may have existed. Quantitation using System 1 of the seven cocaine containing exhibits yielded cocaine hydrochloride contents of 98, 91, 89, 91, 61, 70, and 71%, respectively. It appeared from this data that Exhibits 1, 2, 3, and 4 were high quality cocaine; Exhibits 2, 3, and 4 may have been identical; Exhibits 5, 6, and 7 had been adulterated (as the GC-MS had indicated); Exhibits 6 and 7 may have been identical; and these latter exhibits were different from Exhibit 5. Analysis of the ratios of the area counts of the cocaine peak to that of the area of the cis- and trans-cinnamoylmethylecgonines present in each exhibit was able to indicate more clearly the relationship of the various exhibits. Table 4 shows the "alkaloid ratios" for each exhibit. These results indicate that of the four high quality cocaine exhibits, only Numbers 2 and 3 were identical and that the three "cut" cocaine exhibits, Numbers 5 to 7, had been prepared from cocaine identical to Exhibits 2 and 3. Since the percentage of cocaine differed in Exhibits 5, 6, and 7, the cocaine had been "cut" at least on two occasions.

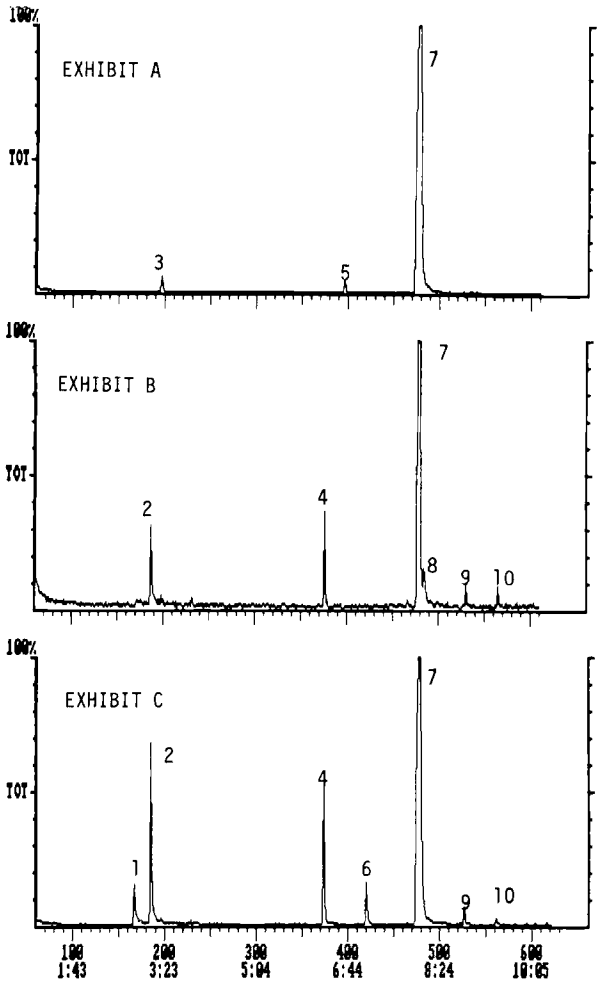

FIG. 2—*Total ion chromatograms of three exhibits. Peak identification:* 1 = *phenylpropanolamine;* 2 = *ephedrine;* 3 = *methylecgonine;* 4 = *lidocaine;* 5 = *tropacocaine;* 6 = *procaine;* 7 = *cocaine;* 8 = *tetracaine;* 9 = *cis-cinnamoylmethylecgonine;* 10 = *trans-cinnamoylmethylecgonine.*

TABLE 4—*Data used in the comparison of seven exhibits containing cocaine.*

Exhibit	Drug Content (GC-MS)	% Cocaine (as HCl)	Alkaloid Ratios	
			Cocaine/Cis-	Cocaine/Trans-
1	cocaine	98	32.7	26.4
2	cocaine	91	1.48	0.78
3	cocaine	89	1.51	0.78
4	cocaine	91	2.00	1.06
5	cocaine^{+a}	61	1.51	0.78
6	cocaine^{+}	70	1.51	0.78
7	cocaine^{+}	71	1.50	0.79

^{a} + indicates ephedrine and dyclonine also present.

Not all cocaine exhibits contain significant amounts of these alkaloids. They may be removed oxidatively during the preparation of cocaine from the coca leaves. A random sample of 100 cocaine exhibits from our laboratory indicated that 30% of these exhibits contained the cinnamoyl alkaloids. However, we have found the presence of these substances in cocaine to have varied from month to month, which may be a reflection of the variability of sources of illicit materials seized in our area.

The absence of these coca alkaloids generally precludes the use of HPLC System 1 for the generation of definitive sample linking information. When such a situation arises, HPLC System 2 may be useful in developing conclusions in this regard. Although a number of substances have been chromatographed on this system (Table 3), it is not always possible to identify positively all of the chromatographic peaks. Figure 3 shows the chromatograms of two exhibits at both 280 and 220 nm. At 280 nm, the chromatogram of Exhibit D indicates the presence of procaine, cocaine, benzocaine and cis- and trans-cinnamoylmethylecgonines. However, at 220 nm, the chromatogram indicates the further presence of both ephedrine and benzoylecgonine. Both chromatograms of Exhibit E indicate the presence of caffeine, procaine, cocaine, and benzocaine. An unknown component eluting at approxi-

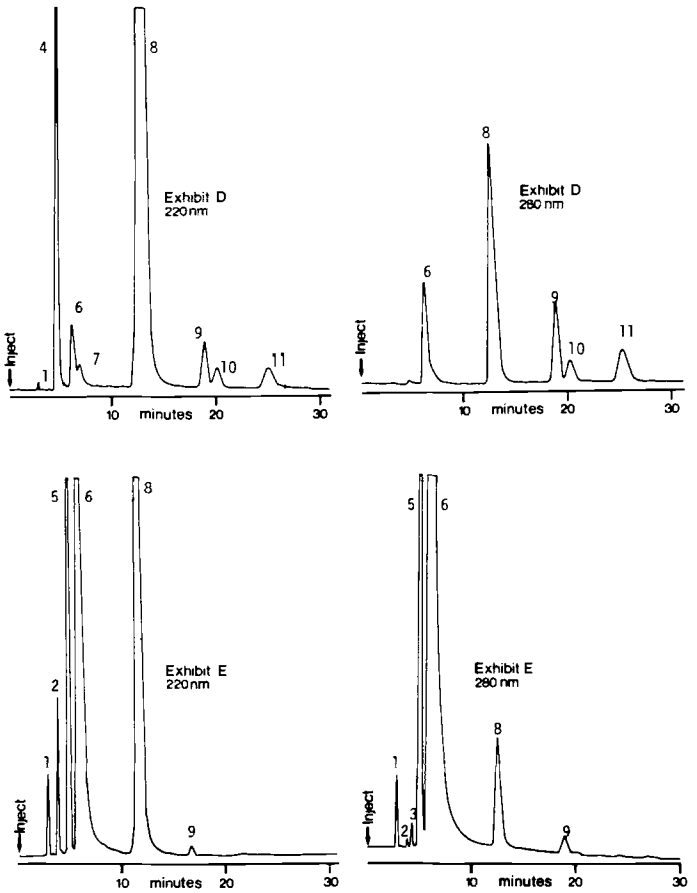

FIG. 3—*HPLC chromatograms of two exhibits,* D *and* E *at 220 and 280 nm. Peak identification:* 1,3 = *unknown;* 2 = *acetylsalicylic acid;* 4 = *ephedrine;* 5 = *caffeine;* 6 = *procaine;* 7 = *benzoylecgonine;* 8 = *cocaine;* 9 = *benzocaine;* 10 = *cis-cinnamoylmethylecgonine;* 11 = *trans-cinnamoylmethylecgonine.*

mately 3 min is also detected at both wavelengths as well as one at 4.5 min at 280 nm. Acetylsalicylic acid also appears to be contained in the exhibit, as evidenced by the peaks at approximately 4 min in both chromatograms. The positive identification of all substances in any of these chromatograms, of course, is not necessary for the effective comparison of exhibits.

Conclusion

The analytical method presented herein forms the foundation of a solid analytical system. Requirements for identification, quantitation, and sample linking are encompassed. The efficient use of GC-MS for the separation and identification of illicit cocaine exhibit components has been described. The usefulness of a routine quantitative HPLC system for the examination of such exhibits which may also provide ancillary analytical data has been demonstrated. The use of a HPLC system providing superior sensitivity for sample linking data has also been described.

References

[1] Katz, S., "The Rising Popularity of Cocaine: How Serious a Problem?," *Canadian Medical Association Journal,* Vol. 133, Oct. 1985, pp. 682–685.

[2] Young, J. L., "The Detection of Cocaine in the Presence of Novocaine by Means of Cobalt Thiocyanate," *American Journal of Pharmacy,* Dec. 1931, pp. 709–710.

[3] Schlesinger, H. L., "Topics in the Chemistry of Cocaine," *Bulletin on Narcotics,* Vol. 37, No. 1, 1985, pp. 63–78.

[4] Masoud, A. N. and Krupski, D. M., "High-Performance Liquid Chromatographic Analysis of Cocaine in Human Plasma," *Journal of Analytical Toxicology,* Vol. 4, Nov./Dec. 1980, pp. 305–310.

[5] Evans, M. A. and Morarity, T., "Analysis of Cocaine Metabolites by High Pressure Liquid Chromatography," *Journal of Analytical Toxicology,* Vol. 4, Jan./Feb. 1980, pp. 19–22.

[6] Jatlow, P. I., Van Dyke, C., Barash, P., and Byck, R., "Measurement of Benzoylecgonine and Cocaine in Urine, Separation of Various Cocaine Metabolites Using Reversed-Phase High-Performance Liquid Chromatography," *Journal of Chromatography,* Vol. 152, 1978, pp. 115–121.

[7] Garrett, E. R. and Seyda, K., "Prediction of Stability in Pharmaceutical Preparations XX: Stability Evaluation and Bioanalysis of Cocaine and Benzoylecgonine by High-Performance Liquid Chromatography," *Journal of Pharmaceutical Sciences,* Vol. 72, No. 3, March 1983, pp. 258–271.

[8] Das Gupta, V., "Stability of Cocaine Hydrochloride Solutions at Various pH Values as Determined by High-Pressure Liquid Chromatography," *International Journal of Pharmaceutics,* Vol. 10, 1982, pp. 249–257.

[9] Fletcher, S. M. and Hancock, V. S., "Potential Errors in Benzoylecgonine and Cocaine Analysis," *Journal of Chromatography,* Vol. 206, 1981, pp. 193–195.

[10] Poochikian, G. K. and Cradock, J. C., "Stability of Brompton Mixtures: Determination of Heroin (Diacetylmorphine) and Cocaine in Presence of Their Hydrolysis Products," *Journal of Pharmaceutical Sciences,* Vol. 69, No. 6, June 1980, pp. 637–639.

[11] Allen, A. C., Cooper, D. A., Kiser, W. O., and Cottrell, R. C., "The Cocaine Diastereoisomers," *Journal of Forensic Sciences,* Vol. 26, No. 1, Jan. 1981, pp. 12–26.

[12] Lewin, A. H., Parker, S. R., and Carroll, F. I., "Positive Identification and Quantitation of Isomeric Cocaines by High-Performance Liquid Chromatography," *Journal of Chromatography,* Vol. 193, 1980, pp. 371–380.

[13] Olieman, C., Maat, L., and Beyerman, H. C., "Analysis of Cocaine, Pseudococaine, Allococaine and Allopseudococaine by Ion-Pair Reverse-Phase High-Performance Liquid Chromatography," *Recueil des Travaux Chimiques des Pays-Bas,* Vol. 98, 1979, pp. 501–522.

[14] Da Rocha, A. I., "A Presença de Alcaloides em Espécies Botânicas da Amazônia V. Determinaçao de Cocaina em Erythroxylum Através de Cromatografia de Alta Pressao," *Acta Amazonica,* Vol. 11, No. 3, 1981, pp. 661–663.

[15] Jane, I., "The Separation of a Wide Range of Drugs of Abuse by High-Pressure Liquid Chromatography," *Journal of Chromatography,* Vol. 111, 1975, pp. 227–233.

[16] Lurie, I., "Application of Reverse Phase Ion-Pair Partition Chromatography to Drugs of Forensic Interest," *Journal of the Association of Official Analytical Chemists,* Vol. 60, No. 5, 1977, pp. 1035–1040.

[17] Baker, J. K., Skelton, R. E., and Ma, C.-Y., "Identification of Drugs by High-Pressure Liquid Chromatography with Dual Wavelength Ultraviolet Detection," *Journal of Chromatography*, Vol. 168, 1979, pp. 417-427.

[18] Lurie, I. S., "Improved Isocratic Mobile Phases for the Reverse Phase Ion-Pair Chromatographic Analysis of Drugs of Forensic Interest," *Journal of Liquid Chromatography*, Vol. 4, No. 3, 1981, pp. 399-408.

[19] Lurie, I. S. and Demchuck, S. M., "Optimization of a Reverse Phase Ion-Pair Chromatographic Separation for Drugs of Forensic Interest Part II—Factors Effecting Selectivity," *Journal of Liquid Chromatography*, Vol. 4, No. 2, 1981, pp. 357-374.

[20] Jane, I., McKinnon, A., and Flanagan, R. J., "High-Performance Liquid Chromatographic Analysis of Basic Drugs on Silica Columns Using Non-Aqueous Ionic Eluents," *Journal of Chromatography*, Vol. 323, 1985, pp. 191-225.

[21] Trinler, W. A. and Reuland, D. J., "Unequivocal Determination of Cocaine in Simulated Street Drugs by a Combination of High Performance Liquid Chromatography and Infrared Spectrophotometry," *Journal of Forensic Sciences*, Vol. 23, No. 1, Jan. 1978, pp. 37-43.

[22] Jane, I., Scott, A., Sharpe, R. W. L., and White, P. C., "Quantitation of Cocaine in a Variety of Matrices by High-Performance Liquid Chromatography," *Journal of Chromatography*, Vol. 214, 1981, pp. 243-248.

[23] Noggle, F. T., Jr. and Clark, C. R., "Liquid Chromatographic Identification of cis- and trans-Cinnamoylcocaine in Illicit Cocaine," *Journal of the Association of Official Analytical Chemists*, Vol. 65, No. 3, 1982, pp. 756-761.

[24] Noggle, F. T., Jr. and Clark, C. R., "Liquid Chromatographic Analysis of Samples Containing Cocaine, Local Anesthetics, and Other Amines," *Journal of the Association of Official Analytical Chemists*, Vol. 66, No. 1, 1983, pp. 151-157.

[25] Gill, R., Abbott, R. W., and Moffat, A. C., "High-Performance Liquid Chromatography Systems for the Separation of Local Anaesthetic Drugs with Applicability to the Analysis of Illicit Cocaine Samples," *Journal of Chromatography*, Vol. 301, 1984, pp. 155-163.

[26] Selavka, C. M., Krull, I. S., and Lurie, I. S., "An Improved Method for the Rapid Screening of Illicit Cocaine Preparations Using High Performance Liquid Chromatography with Electrochemical Detection," *Forensic Science International*, Vol. 31, 1986, pp. 103-117.

[27] Fish, F. and Wilson, W. D. C., "Excretion of Cocaine and its Metabolites in Man," *Journal of Pharmacy and Pharmacology*, Vol. 21, 1969, Suppl. 135S-138S.

[28] Fish, F. and Wilson, W. D. C., "Gas Chromatographic Determination of Morphine and Cocaine in Urine," *Journal of Chromatography*, Vol. 40, 1969, pp. 164-168.

[29] Koontz, S., Besemer, D., Mackey, N., and Phillips, R., "Detection of Benzoyl Ecgonine (Cocaine Metabolite) in Urine by Gas Chromatography," *Journal of Chromatography*, Vol. 85, 1973, pp. 75-79.

[30] Sine, H. E., Kubasik, N. P., and Woytash, J., "Simple Gas-Liquid Chromatographic Method for Confirming the Presence of Alkaloids in Urine," *Clinical Chemistry*, Vol. 19, No. 3, 1973, pp. 340-341.

[31] Bastos, M. L. and Hoffman, D. B., "Comparison of Methods for Detection of Amphetamines, Cocaine and Metabolites," *Journal of Chromatographic Science*, Vol. 12, May 1974, pp. 269-280.

[32] Javaid, J. I., Dekirmenjian, H., Brunngraber, E. G., and Davis, J. M., "Quantitative Determination of Cocaine and its Metabolites Benzoylecgonine and Ecgonine by Gas-Liquid Chromatography," *Journal of Chromatography*, Vol. 110, 1975, pp. 141-149.

[33] Jatlow, P. I. and Bailey, D. N., "Gas-Chromatographic Analysis for Cocaine in Human Plasma, with Use of a Nitrogen Detector," *Clinical Chemistry*, Vol. 21, No. 13, 1975, pp. 1918-1921.

[34] Van Dyke, C., Barash, P. G., Jatlow, P., and Byck, R., "Cocaine: Plasma Concentrations After Intranasal Application in Man," *Science*, Vol. 191, Feb. 1976, pp. 859-861.

[35] Wallace, J. E., Hamilton, H. E., King, D. E., Bason, D. J., Schwertner, H. A., and Harris, S., "Gas-Liquid Chromatographic Determination of Cocaine and Benzoylecgonine in Urine," *Analytical Chemistry*, Vol. 48, No. 1, Jan. 1976, pp. 34-38.

[36] Kogan, M. J., Verebey, K. G., DePace, A. C., Resnick, R. B., and Mule, S. J., "Quantitative Determination of Benzoylecgonine and Cocaine in Human Biofluids by Gas-Liquid Chromatography," *Analytical Chemistry*, Vol. 49, No. 13, Nov. 1977, pp. 1965-1969.

[37] Wallace, J. E., Hamilton, H. E., Christenson, J. G., Shimek, E. L., Land, P., and Harris, S., "An Evaluation of Selected Methods for Determining Cocaine and Benzoylecgonine in Urine," *Journal of Analytical Toxicology*, Vol. 1, Jan./Feb. 1977, pp. 20-26.

[38] Jain, N. C., Chinn, D. M., Budd, R. D., Sneath, T. S., and Leung, W. J., "Simultaneous Determination of Cocaine and Benzoyl Ecgonine in Urine by Gas Chromatography with On-Column Alkylation," *Journal of Forensic Sciences*, Vol. 22, No. 1, Jan. 1977, pp. 7-16.

[39] Dvorchik, B. H., Miller, S. H., and Graham, W. P., "Gas Chromatographic Determination of Cocaine in Whole Blood and Plasma Using a Nitrogen-Sensitive Flame Ionization Detector," *Journal of Chromatography*, Vol. 135, 1977, pp. 141-148.

[40] Minden von, D. L. and D'Amato, N. A., "Simultaneous Determination of Cocaine and Benzoylecgonine in Urine by Gas-Liquid Chromatography," *Analytical Chemistry*, Vol. 49, No. 13, Nov. 1977, pp. 1974-1977.

[41] Javaid, J. I., Dekirmenjian, H., Davis, J. M., and Schuster, C. R., "Determination of Cocaine in Human Urine, Plasma and Red Blood Cells by Gas-Liquid Chromatography," *Journal of Chromatography*, Vol. 152, 1978, pp. 105-113.

[42] Valentour, J. C., Aggarwal, V., McGee, and Goza, S. W., "Cocaine and Benzoylecgonine Determinations in Postmortem Samples by Gas Chromatography," *Journal of Analytical Toxicology*, Vol. 2, July/Aug. 1978, pp. 134-137.

[43] McCurdy, H. H., "Quantitation of Cocaine and Benzoylecognine After JETUBE Extraction and Derivatization," *Journal of Analytical Toxicology*, Vol. 4, March/April 1980, pp. 82-85.

[44] Baselt, R. C., "Stability of Cocaine in Biological Fluids," *Journal of Chromatography*, Vol. 268, 1983, pp. 502-505.

[45] Froldi, R., Gambaro, V., Mariani, R., Pisoni, F., and Procaccianti, P., "Rapid Quantitation of Cocaine and Benzoylecgonine in Urine by 'On Column' Capillary Gas Chromatography After 'Extrelut' Extraction," *Il Farmaco*, Vol. 39, No. 12, Dec. 1984, pp. 417-423.

[46] Aynilian, G. H., Duke, J. A., Gentner, W. A., and Farnsworth, N. R., "Cocaine Content of Erythroxylum Species," *Journal of Pharmaceutical Sciences*, Vol. 63, No. 12, Dec. 1974, pp. 1938-1939.

[47] Turner, C. E., Ma, C. Y., and Elsohly, A., "Constituents in Erythroxylum Coca I: Gas Chromatographic Analysis of Cocaine from Three Locations in Peru," *Bulletin on Narcotics*, Vol. 31, No. 1, Jan./March 1979, pp. 71-76.

[48] Moore, J. M., "Identification of cis- and trans-Cinnamoylcocaine in Illicit Cocaine Seizures," *Journal of the Association of Official Analytical Chemists*, Vol. 56, No. 5, 1973, pp. 1199-1205.

[49] Moore, J. M., "Gas Chromatographic Detection of Ecgonine and Benzoylecgonine in Cocaine," *Journal of Chromatography*, Vol. 101, 1974, pp. 215-218.

[50] Clark, C. C., "Gas-Liquid Chromatographic Quantitation of Cocaine. HCl in Powders and Tablets: Collaborative Study," *Journal of the Association of Official Analytical Chemists*, Vol. 61, No. 3, 1978, pp. 683-686.

[51] Prager, M. J., Harrington, S. M., and Governo, T. F., "Gas-Liquid Chromatographic Determination of Morphine, Heroin, and Cocaine," *Journal of the Association of Official Analytical Chemists*, Vol. 62, No. 2, 1979, pp. 304-307.

[52] Baker, P. B. and Gough, T. A., "The Rapid Determination of Cocaine and Other Local Anesthetics Using Field Tests and Chromatography," *Journal of Forensic Sciences*, Vol. 24, No. 4, Oct. 1979, pp. 847-855.

[53] Kratochvil, B. and Brown, B., "Sampling Errors in the Determination of Cocaine in Seized Drugs," *Journal of Forensic Sciences*, Vol. 29, No. 2, April 1984, pp. 493-499.

[54] Jindal, S. P. and Vestergaard, P., "Quantitation of Cocaine and Its Principal Metabolite, Benzoylecgonine, by GLC-Mass Spectrometry Using Stable Isotope Labeled Analogs as Internal Standards," *Journal of Pharmaceutical Sciences*, Vol. 67, No. 6, June 1978, pp. 811-814.

[55] Rafia, F. K. and Epstein, R. L., "Identification of Cocaine and Its Metabolites in Human Urine in the Presence of Ethyl Alcohol," *Journal of Analytical Toxicology*, Vol. 3, March/April 1979, pp. 59-63.

[56] Chinn, D. M., Crouch, D. J., Peat, M. A., Finkle, B. S., and Jennison, T. A., "Gas Chromatography-Chemical Ionization Mass Spectrometry of Cocaine and Its Metabolites in Biological Fluids," *Journal of Analytical Toxicology*, Vol. 4, Jan./Feb. 1980, pp. 37-42.

[57] Ambre, J. J., Ruo, T.-I., Smith, G. L., Backes, D., and Smith, C., "Ecgonine Methyl Ester, A Major Metabolite of Cocaine," *Journal of Analytical Toxicology*, Vol. 6, Jan./Feb. 1982, pp. 26-29.

[58] Liu, Y., Budd, R. D., and Griesemer, E. C., "Study of the Stability of Cocaine and Benzoylecgonine, its Major Metabolite, in Blood Samples," *Journal of Chromatography*, Vol. 248, 1982, pp. 318-320.

[59] Griesemer, E. C., Liu, Y., Budd, R. D., Raftogianis, L., and Noguchi, T. T., "The Determination of Cocaine and Its Major Metabolite, Benzoylecgonine, in Postmortem Fluids and Tissues by Computerized Gas Chromatography/Mass Spectrometry," *Journal of Forensic Sciences*, Vol. 28, No. 4, Oct. 1983, pp. 894-900.

[60] Poquette, M. A. and Smith, P. J., "Hydroxymethoxybenzoylmethylecgonines: New Metabolites of Cocaine From Human Urine," *Journal of Analytical Toxicology*, Vol. 8, Jan./Feb. 1984, pp. 29-34.

[61] Ambre, J., Fishman, M., and Ruo, T.-I., "Urinary Excretion of Ecgonine Methyl Ester, a Major Metabolite of Cocaine in Humans," *Journal of Analytical Toxicology*, Vol. 8, Jan./Feb. 1984, pp. 23-25.

[62] Smith, R. M., "Arylhydroxy Metabolites of Cocaine in the Urine of Cocaine Users," *Journal of Analytical Toxicology*, Vol. 8, Jan./Feb. 1984, pp. 35-37.

[63] Matsubara, K., Maseda, C., and Fukui, Y., "Quantitation of Cocaine, Benzoylecgonine and Ecgonine Methyl Ester by GC-CI-SIM After Extrelut Extraction," *Forensic Science International,* Vol. 26, 1984, pp. 181-192.

[64] Spiehler, V. R. and Reed, D., "Brain Concentrations of Cocaine and Benzoylecgonine in Fatal Cases," *Journal of Forensic Sciences,* Vol. 30, No. 4, Oct. 1985, pp. 1003-1011.

[65] Goenechea, S., Rucker, G., Neugebauer, M., and Zerell, U., "Extraction, Quantitative Gas Chromatographic Determination and Gas Chromatographic/Mass Spectrometric Detection of Ecgonine for Identification of Cocaine and its Metabolites in Urine," *Fresenius's Zeitschrift für Analytische Chemie,* Vol. 323, 1986, pp. 326-329.

[66] Holmstedt, B., Jaatmaa, E., Leander, K., and Plowman, T., "Determination of Cocaine in Some South American Species of Erythroxylum Using Mass Fragmentography," *Phytochemistry,* Vol. 16, 1977, pp. 1753-1755.

[67] Turner, C. E., Ma, C. Y., and Elsohly, A., "Constituents of Erythroxylon Coca II. Gas-Chromatographic Analysis of Cocaine and Other Alkaloids in Coca Leaves," *Journal of Ethnopharmacology,* Vol. 3, 1981, pp. 293-298.

[68] Rivier, L., "Analysis of Alkaloids in Leaves of Cultivated Erythroxylum and Characterization of Alkaline Substances Used During Coca Chewing," *Journal of Ethnopharmacology,* Vol. 3, 1981, pp. 313-335.

[69] Plowman, T. and Rivier, L., "Cocaine and Cinnamoylcocaine Content of Erythroxylum Species," *Annals of Botany,* Vol. 51, 1983, pp. 641-659.

[70] Jindal, S. P., Lutz, T., and Vestergaard, P., "Gas-Liquid Chromatographic-Mass Spectrometric Determination of Lidocaine in an Illicit Sample of Cocaine," *Journal of Chromatography,* Vol. 179, 1979, pp. 357-360.

[71] Lukaszewski, T. and Jeffery, W. K., "Impurities and Artifacts of Illicit Cocaine," *Journal of Forensic Sciences,* Vol. 25, No. 3, July 1980, pp. 499-507.

[72] Clark, C. C., "Mass Spectral Quantitation of Cocaine HCl in Powders," *Journal of the Association of Official Analytical Chemists,* Vol. 64, No. 4, 1981, pp. 884-888.

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