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A multi-laboratory investigation of drug background levels

Edward Sisco*, Marcela Najarro

National Institute of Standards and Technology, Gaithersburg, MD 20899, United States

HIGHLIGHTS

- Drug background levels have been measured across twenty laboratories.
- Quantitative and non-targeted qualitative analyses were completed.
- Background levels were highest within the drug chemistry unit.
- Cocaine was found on 82% of surfaces at an average concentration of 14.48 ng cm^{-2}.

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ABSTRACT

Identifying and quantifying the drug background in operational environments such as forensic laboratories is an emerging body of research. Knowing these levels is crucial to addressing issues like occupational exposure risk – due to the emergence of potent novel psychoactive substances and synthetic opioids – and data integrity – due to improvements in instrument sensitivity. The work presented here builds upon a prior study to provide a broader representation of the average drug background levels found on surfaces in forensic laboratories. Over 700 samples from 20 laboratories were collected, extracted, and analyzed quantitatively using LC–MS/MS, and qualitatively using TD-DART-MS. Quantitative analysis by LC–MS/MS included a panel of 18 drugs while the non-targeted qualitative analysis by TD-DART-MS screened for over three hundred drugs and excipients. The study focused primarily on surfaces within the drug unit and evidence receiving area of the laboratories, but also investigated other operational units (crime scene, drug interdiction, latent prints, and toxicology) as well as report writing. Background levels were highest within the drug unit of the laboratory, though detectable (tens of nanograms) levels were observed in nearly all sampled areas. The data from this expanded study plays a critical role in addressing laboratory concerns such as establishing drug identification reporting limits for new instrumentation and establishing new workflow or cleaning protocols while also providing a more comprehensive dataset for general environmental background studies.

1. Introduction

Drug residues can be transferred readily to surfaces through touch or through the deposition of airborne drug particulate. Urban environments with a high population density tend to have elevated levels of environmental contamination on a variety of surfaces; trace amounts of drugs have been found in a variety of surfaces including paper currency [1–4] and grocery store shopping carts [4]. These environmental exposures lead to measurable amounts of drugs on the fingertips of non-drug users [5]. A recent review of the literature established that 67% to 100% of U.S. currency is contaminated with cocaine ranging from a few nanograms to over one milligram per bill [6]. As drug residues become ubiquitous to most environments, it is likely that the general public is exposed to low-levels of drugs while carrying out routine daily tasks. The growing interest in measuring the trace drug contamination of various environments is starting to provide more data that is available for interpretation of its significance. For instance, factors such as whether the levels found have a potential implication on public safety [7,8] or whether they can predict drug-related activities are being considered. To assess the utility of non-invasive drug testing, one study showed that sampling an individual's hands (after hand-washing) was able to identify 87.5% of cocaine and 100% of heroin users [5]. This data was critical to establish the environmental cutoff level of drugs found in non-users versus the elevated levels found in the drug user population tested. Smith and McGrath showed that paper currency containing drug levels 50 to 100 times that of background levels were likely directly involved in large-scale drug activity [4]. This type of predictive analysis is not possible unless average background levels

* Corresponding author.
E-mail address: edward.sisco@nist.gov (E. Sisco).

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have been established for a given surface or environment.

Manufacturers pushing the sensitivity of analytical instruments are also interested in characterizing operational environments for improved detection algorithms capable of discriminating background. In the field of forensics, drug chemists need instruments capable of identifying synthetic opioids found in low-weight percentages in samples. Therefore, as instrument sensitivity improves, routine background monitoring should be considered best practice to ensure data integrity. Additionally, as the potency of drugs continues to increase, the workplace exposure of drug chemists working in forensic laboratories is of concern. A recent study by our laboratory measured the drug background of surfaces in three laboratories (one central and two satellite labs) comprising a state laboratory system. Samples were primarily collected in the drug unit, however additional spaces such as the adjacent toxicology unit and evidence receiving were also sampled. A sample collection and quantitation method were developed to identify what and how much background was present. Results showed that workspace surfaces within the drug units have measurable amounts of drugs. The three most abundant drugs found were cocaine, heroin, and methamphetamine at an average amount of 5.2 ng cm^{-2}, 7.8 ng cm^{-2} and 1.3 ng cm^{-2}, respectively. The study also provided insight as to which analytical processes most contribute to elevated levels of background such as pouring out drug evidence to take net weights and loading samples for analysis by Fourier-transform infrared spectroscopy (FTIR).

While this study provided valuable data, the levels reported were limited to three laboratories. Since they are part of one laboratory system and share analytical protocols and cleaning practices, results may differ from other drug units around the country. To determine how these levels compare to amounts found in a larger population, we expanded the number of laboratories sampled. A larger data set provides laboratories with a basis for comparison and establishes an average amount of background expected in drug units. This paper describes a study where the drug background was measured for 20 forensic laboratories implementing the protocols discussed in the earlier publication [9]. It is important to note that the laboratories for this study participated on a voluntary basis and were not selected or controlled to represent forensic drug units as a population. They did however vary in size, geographical location, and included a mix of state and local laboratories.

The compilation of background drug levels presented in this study will 1) allow laboratories performing background monitoring to identify elevated drug levels as compared to the average levels measured for each drug reported here, 2) provide a reference data set to determine whether improved cleaning practices and procedures yield lower than average background levels, 3) provide quality managers with a starting point for setting reasonable standard cleaning levels for drug contamination in their workspace, 4) allow occupational health experts to make exposure and risk determinations, and 5) provide background levels relevant to implementation of new and more sensitive instrumentation for casework.

2. Materials and methods

2.1. Sample collection and extraction

The goal of this project was to expand upon previous work to provide a larger dataset of drug background levels to gain a broader understanding of levels across multiple laboratories. Samples from 20 forensic laboratories were taken by wiping surfaces using dry meta-aramid wipes (DSA Detection, North Andover, MA). Samples were collected from various areas within the laboratories and included: analyst specific space within the drug unit, general-use space within the drug unit, evidence receiving, report writing area for the drug unit, and other units within the laboratories. Specific surfaces tested included: balances, benchtops, keyboards, analytical instruments, and other relevant surfaces. A total of 726 samples were collected over the course of the study. All samples were collected by the same individual to reduce variability. Additional details on the collection of samples can be found elsewhere [9].

Collected samples were stored individually in manila envelopes and were transported back to NIST for extraction and analysis. Prior to extraction, the bottom half of the wipe was removed to leave only the portion of the wipe that contacted the surface. While the specifics of the extraction process have been previously reported [9], a brief summary of the process is: the wipe was placed in a 10 mL amber vial and extracted with 4 mL of Chromasolv-grade methanol (Sigma-Aldrich, St. Louis, MO). This extract was then split into two aliquots – one 2 mL aliquot for quantitative liquid chromatography tandem mass spectrometry (LC–MS/MS) analysis and the remaining, approximately 2 mL, aliquot for qualitative non-targeted screening analysis by thermal desorption direct analysis in real time mass spectrometry (TD-DART-MS). Both aliquots were evaporated to dryness and reconstituted. The aliquot for quantitative analysis was reconstituted in 500 μL of methanol containing deuterated cocaine, fentanyl, heroin, methamphetamine, and Δ-9-tetrahydrocannabinol (THC) (Cerilliant, Round Rock, TX) as internal standards. The aliquot for non-targeted screening by TD-DART-MS was reconstituted in 200 μL methanol, 10 μL of which was then pipetted onto a PTFE-coated wipe (DSA Detection, North Andover, MA) for analysis.

2.2. Chemicals

An 18 drug panel was used for quantitative analysis by LC–MS/MS, and included: acryl fentanyl, carfentanil, cocaine, fentanyl, furanyl fentanyl, heroin, JWH-203, levamisole, 3,4-methylenedioxyamphetamine (MDA), 3,4-methylenedioxymethamphetamine (MDMA), methadone, methamphetamine, methylone, oxycodone, pentylone, phentermine, THC, and U-47700. To create the appropriate calibration curves, 1 mg mL^{-1} standards of these compounds were purchased from Cerilliant, Sigma-Aldrich, or Cayman Chemical (Ann Arbor, MI). For those not available as 1 mg mL^{-1} solutions, solids were purchased and dissolved in methanol. Chromasolv-grade methanol was used for all sample and standard preparation. For the LC mobile phase, Chromasolv-grade methanol and water were used, with the addition of 0.1% v/v formic acid (Sigma-Aldrich).

2.3. Instrumental methods

Quantitation of the drugs was completed using LC–MS/MS (Thermo Ulti-Mate 3000 liquid chromatography system coupled to a Sciex Q-Trap 4000 mass spectrometer) and operated in multiple reaction monitoring (MRM) mode, targeting two transitions per analyte – one for quantitation and one for confirmation. The method used for analysis was identical to that used in previous work [9]. The drugs that were quantified, their detection limits, and MRM transitions are listed in Table 1.

Qualitative, non-targeted, screening of samples for additional drugs and cutting agents was completed using TD-DART-MS, comprised of an in-house built system [10] coupled with a JEOL AccuTOF JMS T100-LP mass spectrometer (JEOL USA, Peabody, MA). The method used for the qualitative screen has also been discussed in detail elsewhere [9].

3. Results and discussion

3.1. Overview of the collected samples

For this study, a total of 726 samples were collected from 20 forensic laboratories across the country. In addition to the 726 samples, at least one process blank was collected from each laboratory. The number of samples collected from each laboratory varied between 13 and 70 depending on the size of the laboratory, available surfaces to sample

Table 1
Drugs quantified by LC–MS/MS as well as their retention time, transitions, limits of quantitation, and measurement uncertainty. Bolded MS/MS transitions represent the transition used for quantitation, and the non-bolded transition was used for confirmation. The value under measurement uncertainty is the deviation between the known concentrations of the calibration curve verification (CCV) samples and their measured concentrations across the calibration range. This table is reproduced from [9].

Analyte	Retention Time (min)	MS Transitions		LOQ (μg wipe^{-1})	Measurement Uncertainty	Internal Standard
		Q1	Q3			
Acryl Fentanyl	8.5	**335**	**188**	0.01	± 13.7%	Fentanyl-d_5
		335	105			
Carfentanil	8.6	**395**	**113**	0.01	± 9.6%	Fentanyl-d_5
		395	134			
Cocaine	7.6	**304**	**182**	0.01	± 11.4%	Cocaine-d_3
		304	105			
Fentanyl	8.5	**337**	**188**	0.05	± 11.9%	Fentanyl-d_5
		337	105			
Furanyl Fentanyl	8.8	**375**	**188**	0.01	± 12.3%	Fentanyl-d_5
		375	105			
Heroin	7.3	**370**	**328**	0.025	± 7.1%	Heroin-d_9
		370	310			
JWH-203	12.8	**340**	**125**	0.025	± 10.9%	THC-d_9
		340	214			
Levamisole	6.5	**205**	**128**	0.1	± 10.2%	Cocaine-d_3
		205	91			
MDA	5.9	**180**	**135**	0.05	± 9.8%	Meth-d_5
		180	77			
MDMA	6.3	**194**	**77**	0.025	± 11.4%	Meth-d_5
		194	135			
Methadone	10.0	**310**	**265**	0.01	± 10.1%	THC-d_9
		310	105			
Methamphetamine	6.1	**150**	**119**	0.1	± 13.6%	Meth-d_5
		150	91			
Methylone	6.1	**208**	**117**	0.05	± 8.4%	Cocaine-d_3
		208	132			
Oxycodone	6.1	**316**	**241**	0.01	± 9.3%	Cocaine-d_3
		216	212			
Pentylone	7.2	**236**	**131**	0.01	± 7.1%	Cocaine-d_3
		236	174			
Phentermine	6.1	**150**	**133**	0.1	± 9.3%	Meth-d_5
		150	91			
THC	12.3	**315**	**193**	0.025	± 10.0%	THC-d_9
		315	123			
U-47700	8.1	**329**	**173**	0.025	± 7.1%	Fentanyl-d_5
		329	81			

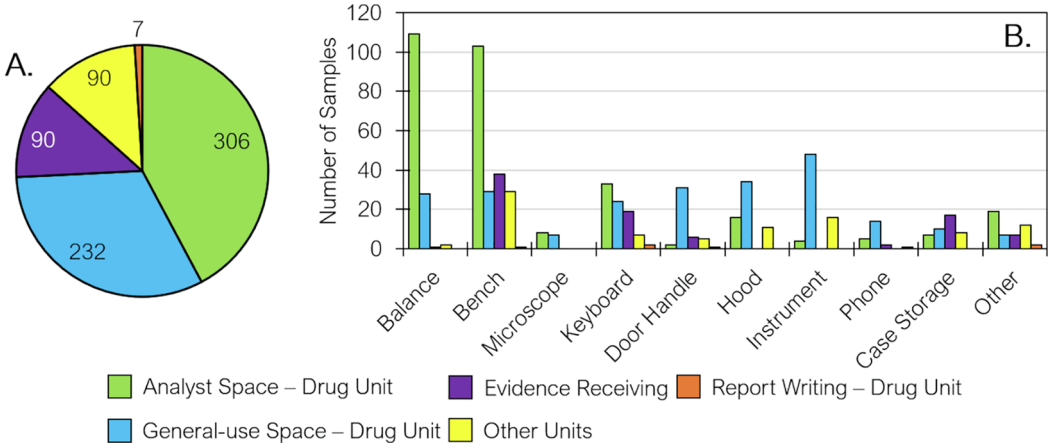

Fig. 1. Breakdown of the locations (A.) and surfaces (B.) that were sampled throughout the study. The numbers in (A.) correspond to the number of samples taken from that location.

that minimized interruption of workflow, and specific requests from laboratory management. The location from which each sample was taken was denoted as either: analyst specific space within the drug unit, general-use space within the drug unit, report writing for the drug unit, evidence receiving, or other unit. Analyst space was used to denote areas within the drug unit (*i.e.* a specific balance or bench) where an analyst completes casework, while general-use space referred to common areas within the drug unit (*i.e.* instrument rooms, chemical hoods, etc.). These two locations accounted for roughly 75% of the samples collected, as shown in Fig. 1A. Only seven samples were collected from surfaces within the report writing section for the drug units. Samples taken outside of the drug unit were broken down into either

the evidence receiving section or other laboratory units. The other units are represented by samples taken from crime scene / drug interdiction task force, latent print, and toxicology. A total of 90 surfaces were sampled across both the evidence receiving areas and other units.

Along with the broad location of where each sample was taken, the specific surface that was sampled was also recorded. Fig. 1B highlights the major classifications of surfaces that were sampled. Balances and benches represented the two most frequently sampled surfaces in this study, accounting for 340 of the samples taken. These two surfaces were targeted as they represented the main areas where bulk drugs are handled. Other types of surfaces that were sampled included frequently touched surfaces such as keyboards, door handles, telephones, microscopes, and case storage containers, as well as surfaces where elevated background levels may be observed (chemical hoods and instruments such as gas chromatograph mass spectrometry (GC–MS) or Fourier-transform infrared spectroscopy (FTIR)). Surfaces that did not fit into this category where denoted as an "other" category.

3.2. Overview of the measured drug concentrations

Out of the 18 drugs that were targeted 17 were detectable in at least one of the 726 samples. The only drug not detected was acryl fentanyl, and therefore is not discussed or reported further in this paper.

A composite of the results from the study is presented in Fig. 2. In this plot, the percentage (left axis), or number (right axis) of samples indicates how frequently each drug from the LC–MS/MS panel was encountered, while the size of the bubble indicates the magnitude of the overall average background (a larger bubble indicates a higher level). In agreement with previous work [9], the two most frequently detected drugs were cocaine (596 of 726 samples, 82.0%) and heroin (542 of 726 samples, 74.6%). The average surface concentration of heroin, however, was three times larger than that of cocaine (47 ng cm^{-2} versus 15 ng cm^{-2}, respectively). Methamphetamine was present at nearly the same concentration (17 ng cm^{-2}) as cocaine, though the frequency of encountering methamphetamine was approximately half (352 of 726 samples). The presence of these three drugs as the most commonly encountered drugs agrees with other studies [9,11–13] that have shown detectable levels of these drugs in other operational environments (*i.e.* police stations), and public spaces.

When considering the presence of synthetic opioids and other novel psychoactive substances (NPSs), fentanyl was found to be the most prevalent drug in the laboratories. Approximately 39% of surfaces (280 of 726) sampled had detectable levels of the drug. While this number is lower than that reported in previous work [9], this data represents a more geographically diverse dataset that includes areas where fentanyls are less prevalent in casework. The other synthetic opioids were recovered from 5 to 100 surfaces across multiple laboratories. All the NPSs that were investigated were present on a small number of surfaces and at low concentrations. The presence of THC on surfaces was relatively low and may be attributed to this evidence typically being plant material (compared to powder and pills) which does not spread as easily as powder.

A more in-depth look at the relative amounts of material recovered from surfaces is shown in Table 2, Fig. 3, and Fig. S1. For all drugs examined the mean recovered concentration is higher than the median recovered concentration (Table 2). This highlights the fact that most of the surfaces had background levels on the lower end of the concentration range with the exception of a few samples containing significantly higher levels of background leading to a higher mean. For the frequently encountered drugs, like heroin and methamphetamine, the range of concentrations recovered spanned up to six orders of magnitude while NPSs and some synthetic opioids spanned only three or four orders of magnitude at the low end of the range.

For most of the figures in this paper, data for six of the 17 drugs will be presented (carfentanil, cocaine, fentanyl, furanyl fentanyl, heroin, and methamphetamine) as they represent the three most commonly encountered drugs and three main synthetic opioids. The concentration distributions for these drugs are presented in Fig. 3 and the remaining drugs in Fig. S1. For cocaine and heroin, Fig. 3A, the distribution of concentrations is skewed toward the higher concentrations (above 1 ng cm^{-2}). This trend is unique to these two drugs and may be due to the higher prevalence of these two drugs in casework, compared to others examined in this work [14]. The remaining drugs either presented an even distribution (*i.e.* methamphetamine or fentanyl) or, more frequently, a skewed right distribution – indicating that majority of samples had low-level surface concentrations.

While looking at the data in its composite form can be useful, additional information can be obtained by considering the locations from which they were collected: drug unit, evidence receiving, etc. A breakdown of the samples as a function of their location within the laboratories is presented in Fig. 4 (data for additional drugs can be found in Fig. S2). The plots in this figure, and subsequent figures, provide information on both the frequency of occurrence (% of samples containing a drug, y-axis) and average surface concentration (x-axis, log

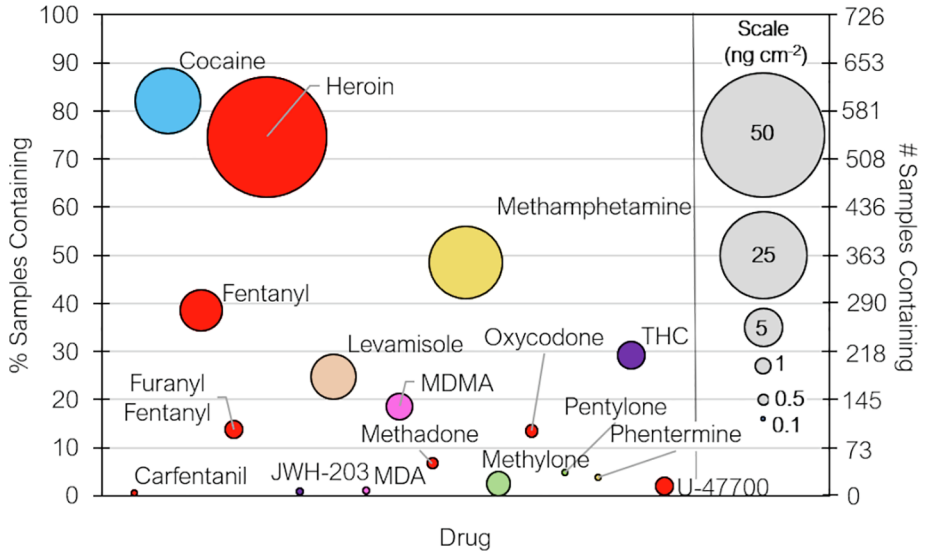

Fig. 2. Bubble chart showing the relationship between the percentage (left axis) or number (right axis) of samples which contain a drug (x-axis) versus the average amount collected (bubble size). Drugs are listed in alphabetical order. Drugs of similar class are colored the same.

Table 2
Overall summary of the concentration (ng cm^{-2}) and mass (μg wipe^{-1}) of drugs recovered from all samples.

Drug	% Samples Containing Drug	Mean Concentration (ng cm^{-2})	Median Concentration (ng cm^{-2})	Concentration Range (ng cm^{-2})	Mass Range (μg wipe^{-1})
Carfentanil	< 1%	0.20	0.07	0.002–0.80	0.01–0.51
Cocaine	82%	14.48	2.00	0.002–412.40	0.01–56.51
Fentanyl	39%	6.11	0.52	0.004–264.21	0.01–47.08
Furanyl Fentanyl	14%	1.31	0.10	0.004–46.31	0.01–11.32
Heroin	75%	47.07	3.24	0.01–2,542.78	0.02–455.71
JWH-203	< 1%	0.25	0.22	0.02–0.59	0.08–0.64
Levamisole	25%	6.94	1.01	0.01–153.75	0.06–38.24
MDA	1%	0.24	0.12	0.02–0.96	0.06–1.28
MDMA	19%	2.60	0.28	0.004–90.18	0.02–74.73
Methadone	7%	0.560	0.080	0.002–5.77	0.01–1.86
Methamphetamine	48%	17.78	0.81	0.004–1,387.45	0.003–190.99
Methylone	2%	2.13	0.17	0.003–30.50	0.02–3.28
Oxycodone	13%	0.61	0.17	0.003–7.57	0.02–9.66
Pentylone	5%	0.19	0.04	0.004–1.57	0.01–1.32
Phentermine	4%	0.23	0.03	0.003–3.60	0.02–0.36
THC	29%	2.81	0.42	0.004–79.56	0.01–12.81
U-47700	2%	1.24	0.05	0.001–16.54	0.003–1.65

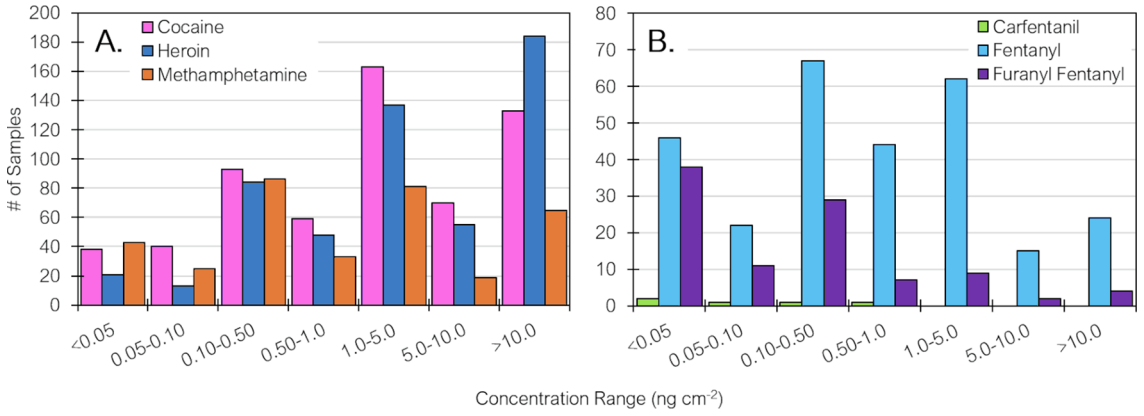

Fig. 3. The distributions of surface concentrations of six drugs of interest. The distributions for the remaining drugs analyzed can be found in Fig. S1.

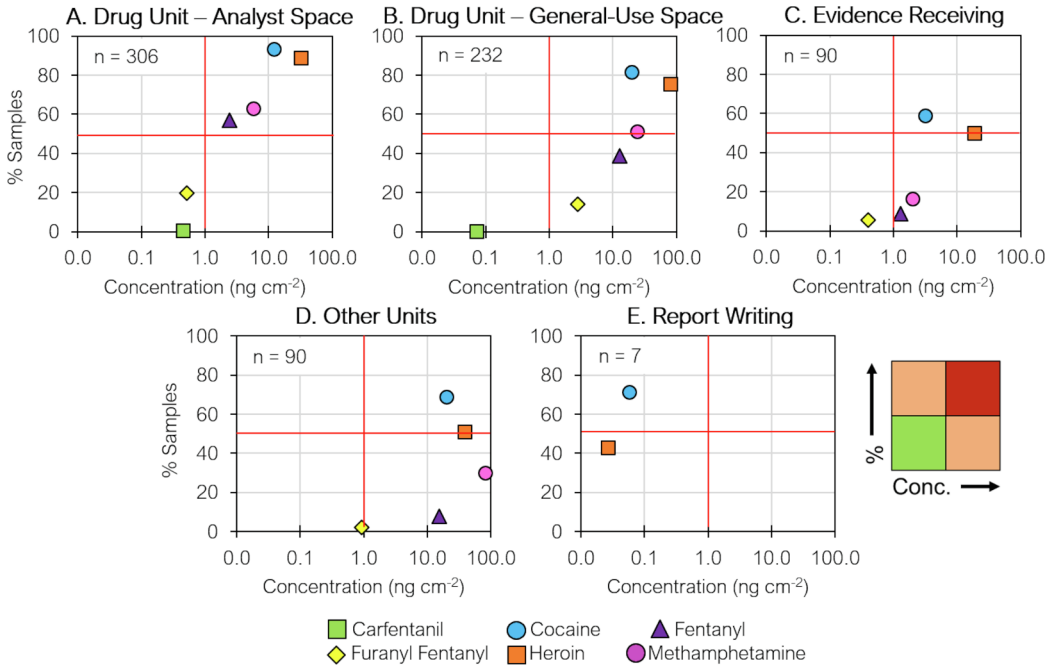

Fig. 4. Comparison of average drug concentrations (x-axis) and percentages of samples containing the drug (y-axis) from surfaces within the different sections of the laboratories. Note the x-axis is log scale. Only 2 spaces contained all 6 drugs.

scale) to provide a more insightful picture of the prevalence of different drugs in the same location and the same drug in different locations. For these plots, data points located in the lower left quadrant are considered most desirable, as it represents low level (< 1 ng cm^{-2}) background in a minority of the samples, whereas data points in the upper right quadrant indicates higher level (> 1 ng cm^{-2}) background in a majority of the samples. As expected, similar trends are observed for the analyst specific space and general-use space within the drug unit (Fig. 4A and 4B), though the frequency of occurrence is slightly lower in the general-use space. Background levels in evidence receiving were found to be lower (typically by about an order of magnitude) and at least 20% less likely to be encountered compared to drug unit levels. The report writing section had the lowest background in terms of number of drugs detected, average surface concentration, and frequency of occurrence. The other unit data, shown below (Fig. 4D), is more nuanced due to the data being collected from three different units within the laboratories. A further discussion of the other unit data is presented later in the text. The following sections discusses each of these different locations in greater detail.

3.3. Drug unit – analyst specific surfaces/items

A delineation between analyst specific surfaces and general-use surfaces within the drug unit was made to identify if areas where bulk drug evidence was handled (analyst benches, balances, etc.) presented different drug profiles or surface concentrations than areas where bulk evidence was less likely to be handled. Within the analyst specific space, benches and balances were the main surfaces sampled, though samples from microscopes, keyboards, hoods, phones, instruments, and storage containers were also collected. Fig. 5 provides a breakdown of select surfaces that were sampled. Of note, surface concentration levels and the probability of recovering a particular drug was similar for balances, benches, and keyboards. This observation differs from the data obtained in previous work [9], which found higher levels on balances. While that dataset focused on one laboratory system, as opposed to the 20 labs here, this dataset highlights the need to evaluate cleaning protocols of all surfaces including balances.

The relative prevalence and abundance of drugs in the analyst space, was, however, consistent with previous work. Cocaine and heroin represented the most abundant and pervasive drugs on all surfaces within the drug unit, with methamphetamine and fentanyl the third and fourth most frequently encountered drugs. Carfentanil was only detected on the surfaces of two analyst workspaces (in different laboratories), at levels around 1 ng cm^{-2}. As with previous work, microscopes had detectable residue, possibly because they are often overlooked during the cleaning process, as the average concentration levels of heroin and cocaine were approximately the same on the microscopes as they were on the benches.

A more detailed analysis of individual analyst spaces was completed to determine whether there was a correlation between an analyst's practices and drug levels (*i.e.* does an analyst with a higher level of cocaine also mean they will have a higher level of heroin or does a high background on one surface predict elevated levels on all surfaces). Correlation between different surfaces was investigated by plotting analyst specific data in ranked order of increasing surface concentration on the balance, and identifying what, if any, trend existed in the bench or keyboard data. The data for cocaine, heroin, fentanyl, and methamphetamine (Fig. S3) all show that there is no positive correlation between surface concentration levels on the balances to those on other surfaces, indicating background levels of one surface cannot be used as an accurate predictor for other surfaces. It also indicates that differences in cleaning frequency (of each surface) and cleaning procedure or technique may affect surface background levels. Looking at the relative levels of different drugs for all analysts (Fig. S4), shows that there is no obvious correlation that a higher surface concentration of one drug predicts a higher surface concentration of other drugs. Interestingly, there was no apparent trend between background levels of heroin and fentanyl or heroin and furanyl fentanyl, as one might expect given that they are often found in combination. Correlation between different drugs was not expected, as the types of drugs received by analysts can vary greatly.

3.4. Drug unit – general-use surfaces/items

A delineation between analyst specific space and general-use space within the drug unit was made to better understand whether significant

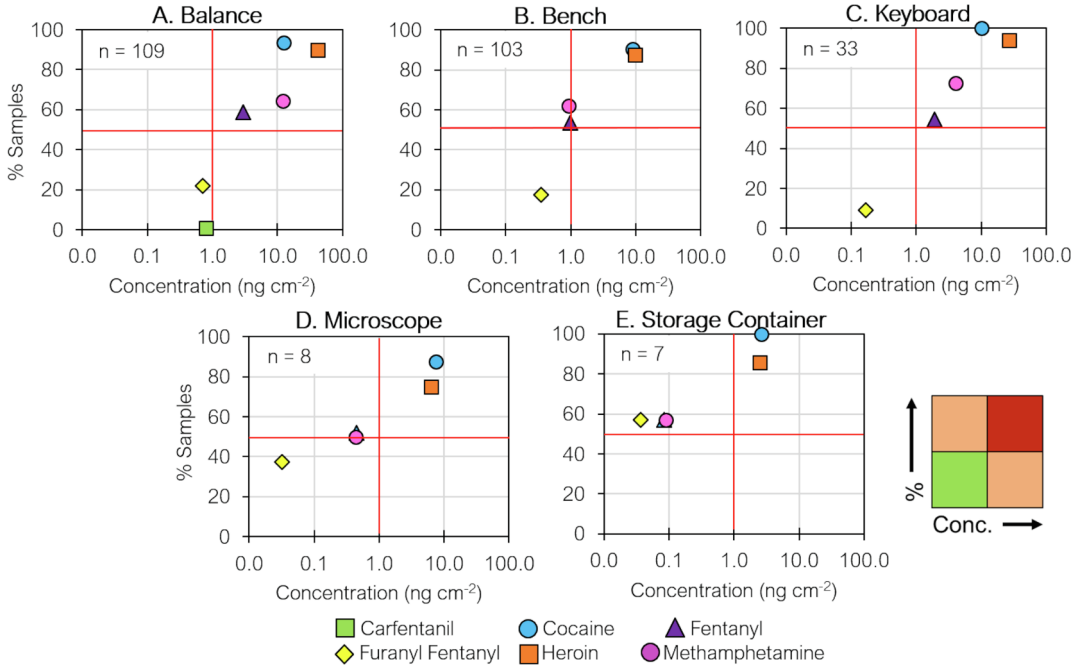

Fig. 5. Comparison of average drug concentrations (x-axis) and percentages of samples containing the drug (y-axis) from analyst specific surfaces within the drug unit. Note the x-axis is log scale. Only 1 surface contained all 6 drugs.

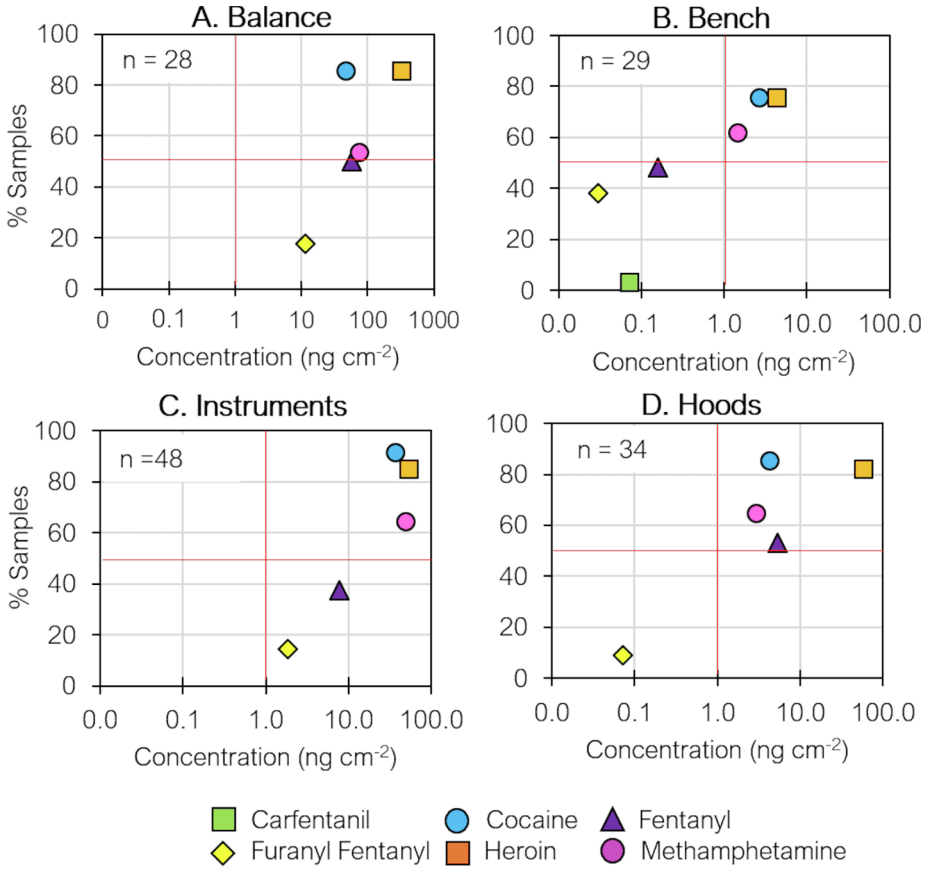

Fig. 6. Comparison of average drug concentrations (x-axis) and percentages of samples containing the drug (y-axis) from general-use surfaces within the drug unit. Note the x-axis is log scale. Plots with missing points mean that no samples contained that drug.

differences in surface concentrations existed in areas where bulk drugs were handled versus where they are not commonly handled. Samples collected from the general-use were primarily comprised of balances (mostly 5-place balances or bulk weight balances), benchtops, instruments, and safety hoods. These all represent areas where drug evidence is typically handled. The make-up of surface concentrations from these surfaces is shown in Fig. 6. The concentration of drugs on benches (Fig. 6B) was similar to that of the analyst specific space (Fig. 5B). The balances in the general-use space, however, had a significantly higher level of five of the six drugs highlighted (except carfentanil) than the balances found at most analyst desks. This is likely a function of the bulk weight balances found in general-use spaces versus the 3-place or 4-place balances found at an analysts' bench. Analytical instruments (Fig. 6C) also had elevated surface levels of drugs. The high background levels were primarily due to samples collected from FTIR instruments, since they were typically one to two orders of magnitude higher than what was observed on GC–MS systems – likely due, again, to the presence of bulk powdered drugs required for FTIR analysis.

Detectable levels of several drugs were found on surfaces personnel touch while not wearing personal protective equipment (PPE) such as gloves, namely door handles and telephones. Cocaine and heroin were the only two drugs present in greater than 30% of the samples (64.5% and 42.9% of door handles and telephones had cocaine present and 48.4% and 35.7% of door handles and telephones had heroin present). Surface concentrations for the door handles and telephones were under 10 ng cm^{-2} for all but two door handles. One door handle and two telephones (out of the 31 and 14 tested, respectively) contained a detectable level of fentanyl while methamphetamine was present on about one quarter of all samples, at a similar concentration to cocaine. For all drugs, the concentration recovered from the telephones was lower than that recovered from the door handles.

3.5. Evidence receiving and report writing

Outside of the drug unit, evidence receiving was the other area where sample collection was focused because it is where drug evidence is exchanged (between law enforcement and the lab, and between the evidence vault custodian and drug chemists) and represents an area where little to no PPE is worn. Given that the primary function in this unit is the exchange of evidence, sampling was primarily focused on benchtops or desktops (surfaces where evidence would be placed), keyboards, and a select number of evidence storage containers. Fig. 7 shows that background levels on benches and keyboards were about an order of magnitude lower than the levels measured within the drug unit. A higher heroin data point is observed in Fig. 7A due to a single bench which contained 686.0 ng cm^{-2} of the drug. The background profiles were also substantially different, where the presence of drugs other than cocaine and heroin were substantially lower, or non-existent, when compared to the drug unit. Only one bench and two keyboards sampled contained detectable levels of synthetic opioids (fentanyl and furanyl fentanyl) – all at less than 0.25 ng cm^{-2}. The storage containers, used to store evidence pre-analysis and/or post-analysis had higher levels, and prevalence, of background which was not unexpected. Within the storage containers there is a high concentration of evidence, and any particulate on the exterior of these packages can be transferred to the container itself. These containers also are not routinely cleaned, so the background that is present was accrued over a much longer timeframe than on other surfaces which are routinely cleaned.

Only a small number of samples (7) were collected from the report writing sections within the laboratories. Low levels (less than 0.75 ng cm^{-2}) of cocaine and heroin were measured on desks and keyboards within this area. No other drugs, including opioids, were recovered from the report writing section. One practice, however, that

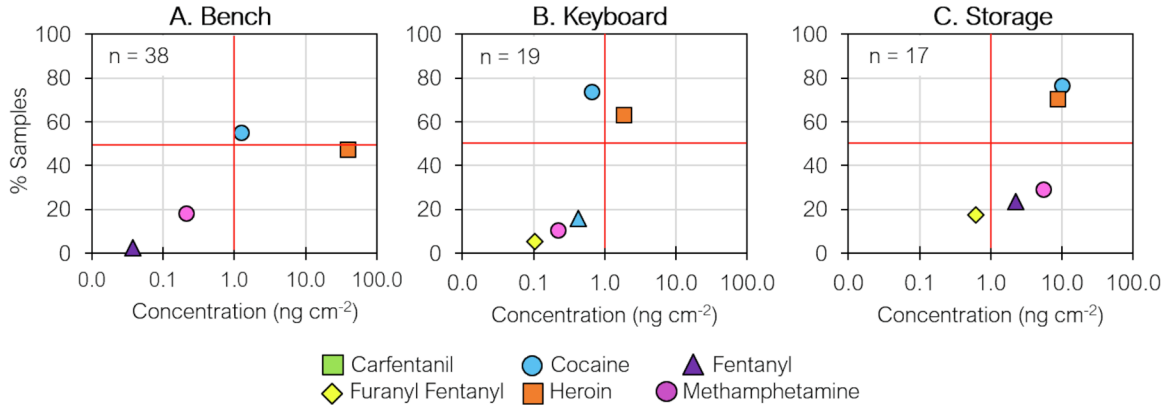

Fig. 7. Comparison of average drug concentrations (x-axis) and percentages of samples containing the drug (y-axis) from surfaces within evidence receiving. Note the x-axis is log scale. All six drugs were not found on any surface.

may lead to the presence of background in this area is the transference of laptops (which were coded as keyboards in the analyst-specific space) between laboratory and report writing areas.

3.6. Other units

A portion of this study also focused on collecting samples from other operational units within the laboratory. Sampling was completed from one of three additional units, when available, including the crime scene or drug interdiction task force unit, the latent print unit, and the toxicology unit. Crime scene or drug interdiction task force and latent print units were chosen because these units handle drug evidence as it passes through either for collection or processing, and therefore represent an area where elevated background levels may be observed. These also represent areas where personnel may be less aware of the hazards associated with drugs and where PPE requirement levels may be lower than within the drug unit. The toxicology unit was chosen for the opposite reason – bulk drugs are never handled in this area of the laboratory. While this unit utilizes drug standards, they are commonly low amounts (sub-milligram) in a solution. Approximately thirty samples were collected in each of these three units.

Breakdown plots of the three units, shown in Fig. 8, highlight the stark difference in background levels between the areas where drug evidence in encountered (crime scene and latent print) and areas where drug evidence is not handled (toxicology). Few surfaces (8 of 24) in the toxicology units had measurable levels of compounds of interest on them, and half of those surfaces were related to areas where standards preparation is done – one of the few processes that involves handling powdered drugs or drug solutions. Low levels were also found on or near analytical instrumentation, the other area where drug standards would be used. There was only one surface (standards prep bench) where a detectable level of an opioid was found.

The latent prints units that were sampled had background levels of cocaine and heroin that were similar to those observed in the drug unit. Within the latent print unit there were three main areas where higher levels were observed – hoods or processing chambers, heat sealers, and evidence storage containers. Elevated background levels in hood and processing chambers are logical given that this is where evidence, presumably containing drugs, would be cyanoacrylate fumed or developed otherwise. Heat sealers, as with the drug unit, present a unique and often overlooked surface where elevated background was measured. Background on this surface is likely due to a slow build-up or accumulation of particulate from opened casework being sealed. Additionally, the temperature of the heat sealer is likely not hot enough to thermally degrade these compounds – allowing a cumulative build-up over time.

Samples collected in the crime scene and drug interdiction task force units had more sporadic measurements than those observed in other units. The elevated level of heroin, for instance, was driven by a balance and a storage container with higher than average levels (171.1 and 77.0 ng cm^{-2} respectively), methamphetamine was influenced by a single storage container (1,387.4 ng cm^{-2}), and cocaine by a balance and storage container both just above 100 ng cm^{-2}. Most surfaces in the crime scene and drug interdiction task force units had levels that

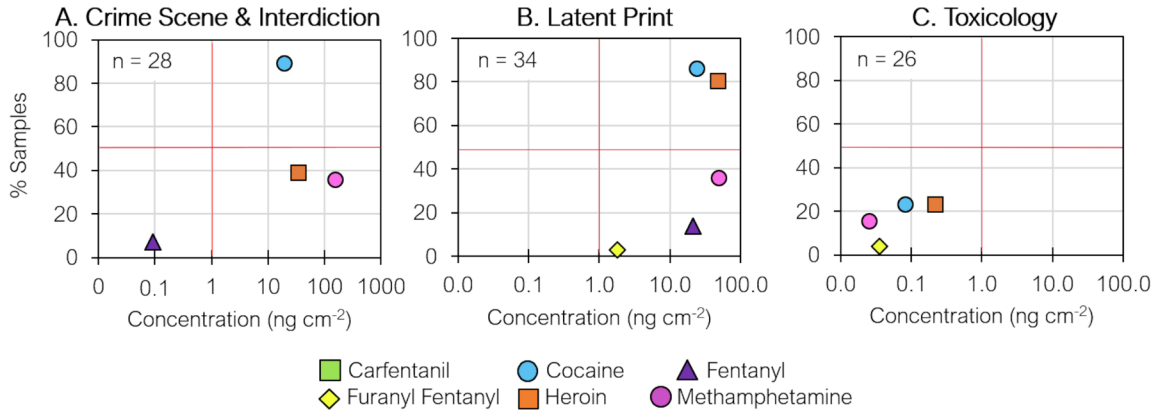

Fig. 8. Comparison of average drug concentrations (x-axis) and percentages of samples containing the drug (y-axis) from surfaces within other laboratory units. Note the x-axis is log scale. Plots with missing points mean that no samples contained that drug.

Table 3
Ranked list of compounds presumptively identified on the TD-DART-MS non-targeted screen. AS = analyst specific space within the drug unit, GS = general-use space within the drug unit, ER = evidence receiving, OU = other units, and RW = report writing.

Drug	Total	AS	GS	ER	OU	RW
Quinine	67	32	27	4	4	0
Acetaminophen	39	21	16	1	1	0
Mannitol	34	22	12	0	0	0
Procaine	32	18	12	2	0	0
Lidocaine	29	8	14	7	0	0
Phenacetine	21	12	7	2	0	0
Caffeine	20	9	10	0	1	0
PCP	18	4	10	2	2	0
Ephedrine/Pseudoephedrine	14	5	5	2	1	1
JWH (All Variants)	12	7	5	0	0	0
Mescaline	11	5	5	0	1	0
Cannabinol	9	4	4	0	0	1
2-MMC/4-MMC/Mephedrone	8	5	2	1	0	0
Acetyl or Benzyl Fentanyl	8	4	4	0	0	0
2C-E	7	4	2	0	0	1
AMB-FUBINACA	7	4	1	1	1	0
Amphetamine	7	1	5	1	0	0
Methyl Phenidate	7	0	7	0	0	0
Acetylsalicylic Acid	6	4	2	0	0	0
Naphyrone	6	2	2	1	1	0
Butylone	5	2	2	1	0	0
Dextromethorphan	5	2	1	1	0	0
MDPV	5	2	2	1	0	0
Codeine	4	0	1	0	3	0
Ketamine	4	4	0	0	0	0
Alprazolam	3	1	2	0	0	0
FIBF	3	2	1	0	0	0
HU-331	3	2	1	0	0	0
Methoxybutyryl Fentanyl	3	1	1	1	0	0
Despropionyl Fentanyl	2	1	1	0	0	0
Hydroxythiol Fentanyl	2	0	2	0	0	0
Benzocaine	1	0	0	1	0	0
Butyryl Fentanyl	1	0	0	1	0	0
Cyclopropyl Fentanyl	1	0	1	0	0	0
Etizolam	1	1	0	0	0	0
Propofol	1	0	0	0	1	0
Temazepam	1	1	0	0	0	0

were equivalent to those observed in the evidence receiving areas.

4. Using TD-DART-MS for non-targeted screening of other compounds

In addition to quantitative analysis, an aliquot of all samples was also run by TD-DART-MS for a non-targeted qualitative screen of other drugs and excipients. Of the 726 samples, 240 were found to also contain at least one other compound present in our library. A total of 37 additional compounds were detected, accounting for 406 individual identifications (some samples had multiple additional compounds). Table 3 lists the additional compounds detected, in ranked order, as well as the number of occurrences in the individual sections of the laboratories. Most identifications (87.9%) occurred from samples collected within the drug unit. Common cutting agents were encountered, accounting for the top 7 compounds and 59.6% of identifications. An additional seven fentanyls were detected on at least one surface that was sampled, with 3 of the 20 occurrences from surfaces outside of the drug unit. It should be noted that these identifications are presumptive as they are based solely on DART-MS data. DART-MS provides data of the entire chemical profile in a single mass spectrum, typically producing molecular ions. Because there is no separation of compounds, or individual compound fragmentation, only presumptive identifications can be made. This full chemical profile information, however, can prove useful for further data-mining of compounds of interest.

5. Conclusion

Background levels of drugs were detected on surfaces throughout forensic laboratories. Cocaine and heroin were the two most frequently encountered drugs and typically represented the drugs with the highest surface concentrations. Drug levels were highest in the drug chemistry unit, which was expected given the fact that this is where bulk drugs are handled. The evidence receiving, and toxicology units had the lowest level of drug background. For most drugs, the majority of surfaces had low background concentrations and averages were skewed by a few surfaces with high concentration levels. These hotspots are the areas where greater care and frequency in cleaning or the implementation of mitigation measures (*i.e.*, bench paper or weigh boats) would be warranted.

From this dataset a number of other important takeaways were discovered. In the drug chemistry unit, care should be taken to periodically clean surfaces that are often overlooked. Microscopes, heat sealers, and evidence storage containers are areas where accumulation may occur over time. Transferring of laptops and report folders between the laboratory and report writing spaces should be done cautiously as this may lead to transfer of drug residue between the two spaces and an increase in the drug background of the report writing spaces. This could also be true for clothing and personal objects such as cell phones. Changing gloves between samples, and removing after handling of evidence, could also aid in reducing transfer. Evidence receiving, which is considered an administrative function in most labs, should consider implementing protocols so evidence technicians wear gloves when handling evidence to protect personnel from exposure. In toxicology units, special care should be taken to clean areas or use mitigation measures where drug standards are prepared.

The background level of drugs in this work were not dissimilar to background levels found in other studies. Work by Doran *et al* [12] found levels of cocaine and methamphetamine in police stations that exceeded the levels recovered in this study while Jenkins [15] found higher levels of cocaine and heroin on currency than on surfaces in the laboratory (Table 4). Other studies have also shown that greater than 80% of public surfaces have a trace background of cocaine.

The work in this study aimed to characterize average surface levels of drugs in forensic laboratories by providing an expanding sample set compared to previous work. Now that these levels have been established, additional work can be completed to evaluate their context in areas such as data integrity or personnel health and safety. Current work is focused on addressing data quality from the perspective of existing and next-generation technologies. A simple, implementable, strategy to ensure data integrity would be the incorporation of quality control measures such as process blanks prepared alongside casework. A multi-agency collaboration is also ongoing to address the personnel health and safety aspect. By combining this reference data set with past work on background levels [9], cleaning protocols [16] and future work, laboratories should have the necessary data and methods to implement a robust background self-monitoring program as best practice.

Table 4
Comparison of background levels to those reported in literature.

	Cocaine	Heroin	Meth
Range of Levels (μg wipe^{-1})	0.01–56.51	0.63–62.25	0.10–22.71
Forensic Lab – Spain (μg 100 cm^{-2}) [15]	3.1–105		
Police Stations (μg wipe^{-1}) [12]	71.43		326.16
Money (μg bill^{-1}) [14]	0.01–922.72	0.02–168.50	0.50–1.00
Public Surfaces (% > 50 ng) [3]	80%		
Cocaine in City Air (pg m^{-3}) [16]	7–304		

6. Disclaimer

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forc.2019.100184.

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