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DETECHIP®: An Improved Molecular Sensing Array

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Abstract

DETECHIP® is a novel, highly selective and sensitive molecular sensor array producing color and fluorescence changes in the presence of many small molecules or analytes. This technology utilizes an array of eight sensors in two types of buffers that are dispensed in a 96-well plate. Color and fluorescent changes in the presence of analytes are recorded as a 32 digit binary code that is able to discriminate many substances. The current application is dedicated to testing narcotics such as cocaine, tetrahydrocannabinol (THC) from marijuana, as well as date-rape and club drugs such as flunitrazepam, gamma-hydroxybutyric acid (GHB), and methamphetamine, to name a few. Shown to be a contactless, portable, and inexpensive optical detection system, DETECHIP® can detect many substances and therefore can be used where a high degree of preliminary diagnostics is needed.Besides narcotics, DETECHIP® is able to detect and discriminate over-the-counter medications, trinitrotoluene (TNT), pesticides, food spoilage metabolites, and narcotics laced with cutting agents. DETECHIP® offers possibilities for a simple, sensitive, selective, and affordable alternative to costly immunoassays.

Keywords: Drugs of abuse; Narcotics detection; Testing cutting agents; Color changes; Fluorescent changes; Portability; Cocaine; Marijuana

Abbreviations: OTC: (over-the-counter); GC-MS: (gas chromatography-mass spectrometry); ELISA: (Enzyme-linked immunosorbent assay); THC: (tetrahydrocannibinol); HPLC: (high-performance liquid chromatography)

Introduction

Current detection methods for small molecules of interest

Many applications require a quick, sensitive and selective detection system, such as alerting security officers to the presence of explosives or their precursors, pre-incident monitoring/screening for homeland security purposes such as weapons of mass destruction, and detection and quantification of sports doping compounds. GC-MS is currently the most widely used method to detect these types of substances. However, sample introduction, miniaturization, and the need for skilled operators still remain prevalent challenges. Furthermore, in order to accurately discern drugs, metabolites, explosives, etc., high-resolution instruments are necessary and often require additional assays such as isotope ratio mass spectrometry (GC-IRMS). Current screening reagents for abused narcotics like flunitrazepam (often used for date rape, assault, or theft) lack selectivity, and are sensitive to many tertiary amines such as methylephedrine, caffeine, nicotine, and others. Similarly, there are commercial immunoassays that detect flunitrazepam and other abused amines in urine, but these require the use of expensive laboratory instruments, such as GC-MS [1], as well as highly trained personnel to run the tests. Other characterization methods of these compounds in urine [2,3], blood, serum, and hair samples include ion trap mobility spectrometry [3-5], fluorescence detection after solid-phase extraction [6], HPLC tandem mass spectrometry [7], micellarelectrokinetic chromatography (MEKC) [8], high performance thin-layer chromatography (HPTLC) [9], and immunoassays [4]. Rapid screening reagents, used in conjunction with thin-layer chromatography, include the Dragendorff reagent [9].

To date, modern instrumental methods [1,3-12] for drugs of abuse and other suspect materials have yet to replace wet chemical colorimetric assays [13-16] for rapid lab and field screening of analytes. These simple colorimetric assays (i.e. "spot tests") offer speed, simplicity of operation, portability, and affordability [13-16]. The stability and versatility of these spot tests enable lab scientists or other personnel to "triage" samples for additional characterization analysis, as well as providing quick answers to law enforcement, homeland security officers, or crime scene analysts in the field. A number of spot tests, e.g. Marquis [15], Duquenois-Levine [15], Scott Drug Testing Company drug tests (www.scottcompany.com) or the β-Glucuronidase Drug Analysis Bundle (Sigma-Aldrich), utilize an array of reagents with various handling requirements and procedures. These tests often use corrosive reagents, such as strong acids or bases, derivatization reagents, and special equipment such as purification columns. While demonstrating impressive analytical power, these spot tests are often characteristic for a class of compounds relying on the reactivity of a specific chemical functional group limiting the universal scope of the application. Traditional ELISA tests typically involve chromophore reporters that produce a color, fluorescent, or electro-chemiluminescent change to indicate the presence of antigen or analyte. Although these immunoassays offer high sensitivity and selectivity, they do suffer from high cost, quantifiable signals, and

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limited shelf life. In 2008, Royal Philips Electronics announced a hand held version of a roadside drug tester in which magnetic nanoparticles coated with ligands that adhere to a saliva sample for analysis are used [17]. The downfall of this device is that it tests for only 5 substances: cocaine, heroin, cannabis, amphetamine, and methamphetamine. Other portable test devices using antibody technology that allow for mobile screening of illicit drugs in saliva or detection of pathogens are being developed by Vantix Ltd [18]. Another potential small-molecule detection technology involves lateral flow devices such as functionalized silicon nanowires that have the potential for selective sensing of explosives [19]. Although promising and highly sensitive, nanowires have not yet reached a stage of commercial appeal in the industry, and the portable point of care sensors are mostly applicable to diagnostic medicine and health care services.

Original DETECHIP®

DETECHIP® (short for detection chip) is a spot test device for lab and potential field use. The term DETECHIP® combines the idea of small molecule detection with the use of an array of chemical indicators analogous to DNA microarray technology. DETECHIP® is a mix-and-measure assay providing a stable color and fluorescent signal for the rapid detection of commonly abused plant-derived and designer drugs. Unlike other color tests which proved a single "yes or no" response, DETECHIP® gives many simultaneous responses allowing users to quickly characterize suspect materials by assembling a binary code of "1" and "0". DETECHIP® also allows users to test controls alongside suspect materials, unlike other assays that only describe the control. The sensing elements for DETECHIP® were chosen based on their selectivity, clarity of color and fluorescence changes, solubility, price, ease of handling, and ease of disposal. DETECHIP® relies on mostly intermolecular interactions and uses non-toxic reagents that can be readily disposed after use, an advantage over current spot tests [13-16]. Other color tests [4] are based on immunoassays and only provide a "yes or no" response.

Improvement of Selectivity with DETECHIP®

Library of codes: Having only 5 sensors, the original DETECHIP® gave identical codes for some analytes, and the identity of the compound could not be clearly distinguished. For example, the synthetic opioid fentanyl rendered identical codes with multivitamins, while flunitrazepam, nicotine, and aspirin were also identical, as were hydromorphone and Tylenol® Cold. The new version of DETECHIP® alleviated this replication of codes for most of the analytes by the augmentation of the original array to eight sensing elements (DC1-DC8), resulting in an expansion of the binary code to 32 digits, thus reducing the statistical probability for false positives. To date, the 8 sensor DETECHIP® has been able to discriminate all tested analytes, with the exception of caffeine and cocaine. Another advantage of the expanded code is that a greater library of codes can be obtained for more analytes. Figure 1 shows the color and fluorescence changes in a typical DETECHIP® with 3 analytes (methamphetamine, hydrocodone, and hydromorphone) in the presence of two common buffers. These changes are recorded as a binary code. A "0" indicates no change while "1" denotes a change in the sample versus the control.

The use of cutting agents with DETECHIP®

Many illicit drugs are adulterated or diluted with "cutting agents", which are easily obtained substances generally selected based on their solubility and boiling and melting points. Cutting of illicit drugs leads to what appears to be a larger amount of product, which in turn results in a greater profit for the seller. Cutting agents typically include white powders such as aspirin, caffeine, and a variety of sugars [20-22]. The immediate on-site identification of impure street drugs still presents a challenge due to the occurrence of false positives and the need for further laboratory tests for confirmation. Samples of unknown origin are usually analyzed by chromatography (HPLC) followed by mass spectroscopy or infrared spectroscopy [23]. Raman spectroscopy has been reported for *in situ* identification of drugs and structural diagnostics of diluted or adulterated drugs [24,25]. The adulteration of illicit drugs with cutting agents requires drug identification methods to account for their presence so false negatives and positives are prevented. DETECHIP® is able to discriminate drugs in the presence of many adulterants. This improvement greatly increases the value of DETECHIP®, as suspect materials are rarely pure.

Materials and Methods

Standards and reagents

All standards and reagents were purchased from Sigma-Aldrich Co. (St. Louis, MO) unless otherwise noted. DC1-DC8 were prepared in our laboratories and their chemical composition remains proprietary.

DETECHIP® Design and Protocol

Fabrication of DETECHIP® is identical to that of original DETECHIP® [26], but the sensing elements have been expanded from five elements to eight. Stock solutions of the eight molecular sensors are dissolved in methanol at the 150μM concentration, and 150 μL of each sensor is pipetted into a 96 well optical bottom plate (Thermo Fisher Scientific, Rochester, NY). Each sensor occupies all 12 wells of its row, with DC1 corresponding to row A, DC2 to row B, and so on. After passive evaporation of the methanol (less than 16 hours) the sensors DC1-DC8 remain attached as solids in the bottom of the wells. Buffers used to re-suspend DC1-DC8 were prepared at 400 mM concentration in deionized water at pH 7. Buffer A is added in columns 1, 2, 5, 6, 9, and 10, while buffer B is added in column 3, 4, 7, 8, 11, and 12. Control wells are prepared by adding water (or if the analyte is insoluble in water; methanol or ethanol) to every odd column starting with column 1. The first dissolved analyte with a concentration of 25 mM in the appropriate solvent is then added to columns 2 and 4 for a final concentration of 12.5 mM. Similarly, analytes two and three are added to columns 6 and 8, and 10 and 12, respectively.

DETECHIP® analyte and cutting agent preparation

Procedures for preparation of drug samples, over the counter (OTC) samples, molecular sensors, and buffers remain consistent with those of the original DETECHIP® system [26]. Drug samples were prepared at 25 mM concentrations in one of three solvents; water, methanol, or ethanol. OTC's were passively extracted in water or ethanol. The coating on coated tablets was removed, and a single tablet was crushed and dissolved in 10mL of solvent. Samples were then centrifuged at 14k x g for 10 min to remove insoluble fragments, and the supernatant was used for analysis. Cutting agents were purchased from local grocery stores and prepared at 25 mM concentrations for testing alone. Illicit drugs were adulterated in mole-to-mole ratios with most cutting agents in 1:1 (25 mM drug: 25 mM cutting agent), 2:1(25 mM drug: 12.5 mM

cutting agent), and 1:2(25 mM drug: 50 mM cutting agent) ratios. For cutting agents where mole-to-mole ratios were impractical, illicit drugs were prepared with the cutting agent in gram equivalent ratios of 1:1, 1:2, and 2:1. For a complete listing of cutting agents tested see Table 1.

Analysis of plates was carried out by visually checking for color changes and fluorescence changes with the naked eye. Color changes were evaluated under typical fluorescent lighting. A 254nm UVLS-26 EL Series UV lamp was used to view the fluorescence. The resulting codes listed herein are based on visual analysis. Procedures and confirmation of the visual analysis for color and fluorescence changes are consistent with those of the original DETECHIP® methods. Figure 1 shows the assay of color changes (left) by eye, and fluorescence changes

Illicit Drugs	Cutting Agents	Over-the-Counter Drugs
1-(1-Phenylcyclohexyl)-piperidine	Baking soda	Equate® 24 hr. Allergy Relief D
Caffeine	Dextrose	Ibuprofen
Cocaine	Epsom salt	DHEA
d-Amphetamine sulfate	Glucose	Enteric coated aspirin
Fentanyl	Granulated sugar	Equate® Allergy Medication
Flunitrazepam*	Lactose	Equate® Night Time Sleep Aid
Hydrocodone	Lidocane	Tylenol® Cold Day
Hydromorphone	Mannitol	Tylenol® Cold Night
Ketamine	Methylsulfone	Jet-Alert™
Levoalphacetylmethadol	Powdered sugar	Equate® Naproxen Sodium
Methadone	Starch	Equate® SuphedrineSinus Headache
Methamphetamine	Talc	L-glutamine
Methylphenidate	Phenacetin	Multivitamin
Morphine	Quinine*	Glucosamine Chondroitin
Thebaine*	Powdered milk	

*Dissolved in Ethanol

Table 1: Analytes tested by DETECHIP®. Analytes are grouped by illicit drug, cutting agent, and over-the-counter drugs.

	CC	FC	CC	FC
DC1	1 [1]	1 [3]	1 [2]	1 [4]
DC2	1 [5]	1 [7]	1 [6]	1 [8]
DC3	1 [9]	0 [11]	1 [10]	0 [12]
DC4	1 [13]	1 [15]	1 [14]	1 [16]
DC5	1 [17]	0 [19]	1 [18]	0 [20]
DC6	1 [21]	1 [23]	1 [22]	1 [24]
DC7	0 [25]	1 [27]	0 [26]	1 [28]
DC8	1 [29]	1 [31]	1 [30]	1 [32]
Combined	11111111110011111100111100111111			

Table 2: Assembly of 32-digit binary code. The small numbers in the upper-right corner of each block represents the order in which the code is read**.** A representative assembled code is given at the bottom of the table. CC= color change FC = fluorescence change.

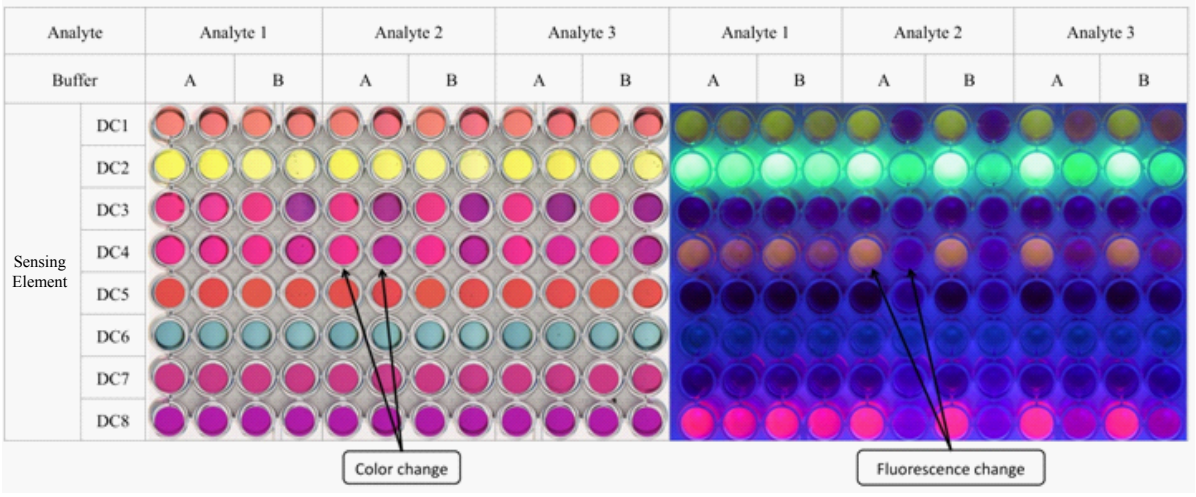

Figure 1: Setup of a typical DETECHIP®96-well plate. Each row contains a different molecular sensor. This plate has tests for three different analytes. Color (CC) and fluorescence (FC) changes in the sample well relative to the control well are noted (arrows). These changes are recorded as a binary code. A "0" indicates no change while "1" denotes a change in the sample versus the control.

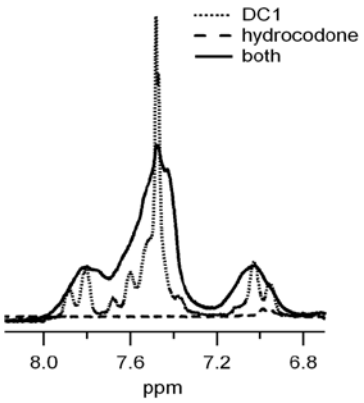

Figure 2: ^{1}H-NMR spectrum (90 MHz) of DC1 and hydrocodone. Line broadening (solid line) can be seen in the aromatic region upon mixing of DC1 and hydrocodone.

under UV light (right). The arrows on the left show a clear color change between a control well and an analyte well whereas the arrows on the right show a clear fluorescence change.

DETECHIP® code determination

To read the plate, control wells and analyte wells are compared to each other for color and fluorescence changes, such as control 1 versus methamphetamine 1. This involves a visual inspection for color and fluorescence changes between the sample and a control. Changes are assigned a "1", while no change is assigned a "0". The same is done for all control and analyte wells, giving a total of 32 responses for a single analyte. These responses are then assembled into a unique binary code (Table 2). Fluorescence was measured by visual comparison of the analyte well to the control well using a hand held 254 nm short wavelength UV lamp (Figure 1).

NMR sample preparation, Data acquisition, and analysis of analyte-DC1 interactions

^{1}H-NMR spectra of DC1, caffeine, and the mixture of the two (0.06M) were recorded in deuterated phosphate buffer at pH= 7 by using an Anasazi (90 MHz) spectrometer. Chemical shifts are reported in ppm. TLC analysis was carried out with silica gel plates. The chromatograms were visualized under ultraviolet light (254 nm). All solvents and chemicals were of analytical grade (Merck, Sigma-Aldrich).

Results and Discussion

Intermolecular Interactions of Molecular Sensors with Analytes

DETECHIP® produced remarkable selectivity for color and fluorescence changes because very few drugs or OTCs have identical codes. This suggested that changes in color and fluorescence are based on intermolecular interactions between molecular sensors and drugs, rather than chemical reactions that are functional group specific. Thin layer chromatography experiments using an array of analytes and molecular sensors supported this hypothesis. In most cases when the analytes and molecular sensors were spotted individually and as mixtures using a multitude of stationary and mobile phases, the retardation factors were identical for the analytes and molecular sensors before and after mixing and the analyte and molecular sensor separated on the plate. Thus, the DETECHIP® sensing methods based on color or fluorescent-changing molecular sensors must respond to a change in physical properties of its molecular environment. In this case, when a DETECHIP® sensing element is mixed with a selective analyte, the resulting supra molecular structure serves as the color or fluorescent reporter. This type of detection of non-covalent bonding using two-color fluorescent probes has been reported before [27]. ^{1}H-NMR screening of these noncovalent intermolecular interactions further elucidated the supra molecular reporter structures. For example, when DETECHIP® molecular sensor 1 (DC1) was mixed with hydrocodone, a dramatic line broadening occurred in the aliphatic and aromatic regions as seen in Figure 2, from 4.65ppm to 4.9ppm; and from 6.8ppm to 8.0ppm. Although most of our evidence pointed to the fact that the majority of the interactions between molecular sensors and analytes are of noncovalent nature, in some instances proton transfer reactions may be involved. Caffeine, for example, has a very labile proton on Carbon-8(C-8) and the mechanism of proton extraction on C-8 has been reported [28]. Figure 3 demonstrates a potential mechanism that would explain the color changes due to a proton transfer from caffeine to DC1. ^{1}H-NMR results (Figure 4) indicated that the negatively charged oxygen on DC1 may deprotonate C-8 of caffeine. This potentially created a negatively charged caffeine intermediate and the change of conjugation in DC1 led to a visible color change. This seems feasible as the pK_a of the proton on C8 in caffeine is 0.6 [29], and there is precedence of hydrogen exchange reactions in nucleic acids and similar heterocycles [30]. Figure 4 shows the ^{1}H-NMR spectra of caffeine, DC1, and a mixture of DC1 and caffeine in deuterated phosphate buffer. The proton of caffeine on C-8 (proton D) appears at 7.9ppm and the methyl protons (A,B,C) at 4.0, 3.4, and 3.3 ppm. When caffeine is added to DC1 at 1:1 ratio, proton D disappears and the methyl protons A, B, and C are up-field shifted to 3.7, 3.3, and 3.1 ppm suggesting an anionic form of caffeine. Similar results were observed in non-buffered D_2O (data not shown).

Selectivity and sensitivity

DETECHIP® exhibited a substantial increase in specificity from the original DETECHIP®. This new version can detect a wide variety

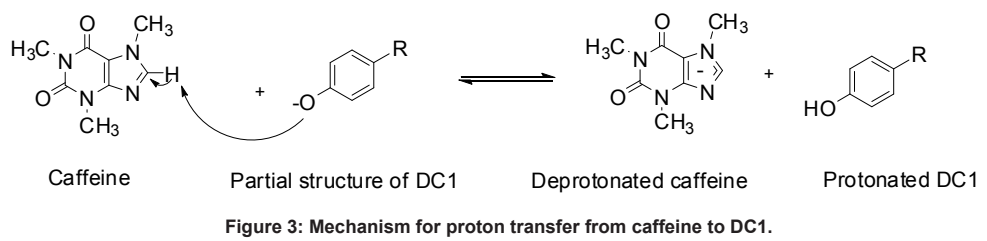

Figure 3: Mechanism for proton transfer from caffeine to DC1.

of substances, and here we report the detection of 15 narcotics in the presence of cutting agents, 14 OTC drugs, and one explosive agent (TNT) at a final concentration of 12.5mM. A complete list of analytes tested can be found in Table 1. The three additional sensing molecules were chosen for their ability to provide clear-cut discrimination

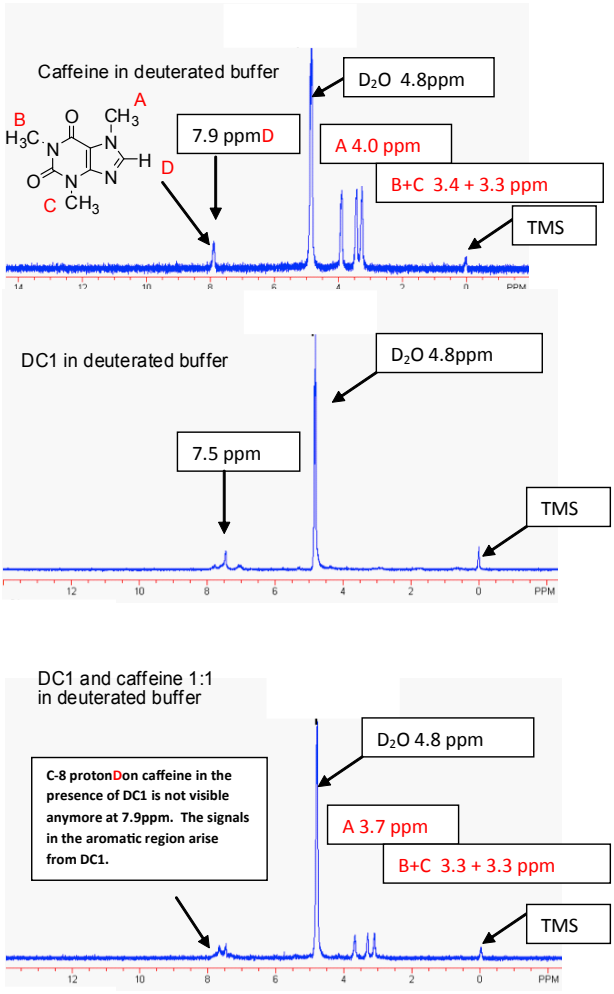

Figure 4: ^{1}H-NMR results of DC1 and caffeine. ^{1}H-NMR (90 MHz) was performed in D_2O and deuterated phosphate (pH7) buffer. The resulting spectra indicated that the C-8 proton in caffeine at 7.9 ppm disappeared when DC1 is added to the sample, suggesting that the proton has been involved in a transfer to DC1.

Reader	Methamphetamine & Baking Soda (1:2)
1	0011-0011-1100-1111-0000-1100-0000-0000
2	1111-0011-1100-1111-0100-1100-0000-0001
3	1111-0011-1100-1111-1000-1100-0000-0011
4	1111-1011-1100-1111-0000-1100-0000-0011
5	0111-1111-1100-1111-0000-1100-1000-0001
Combined	**1111-0011-1100-1111-0000-1100-0000-0001**

Table 3: Determination of combined code for methamphetamine adulterated with baking soda using five different readers. For each digit in the final combined code, the digit that prevailed was the one that the majority of readers reported.

A

Methamphetamine Alone		1111-0011-1100-1111-1100-1000-0000-0011	
Cutting Agents Alone		0000-0000-0000-0000-0000-0000-0000-0000	
Cutting Agent	Ratio	Code	Differences from metham-phetamine
Baking Soda	1:2	1111-0011-1100-1111-0000-1100-0000-0001	4/32
	1:1, 2:1	1111-0011-1100-1111-0000-1100-0000-0011	3/32
Dextrose	1:2, 1:1, 2:1	1111-0011-1100-1111-0000-1100-0000-0011	3/32
Epsom Salt	1:2, 1:1, 2:1	1111-0011-1100-1111-0000-1100-0000-0011	3/32
Granulated Sugar	1:2	1111-1011-1100-1111-0000-1100-0000-0011	4/32
	1:1, 2:1	1111-0011-1100-1111-0000-1100-0000-0011	3/32
Lactose	1:2, 1:1	1111-0011-1100-1111-0100-1100-0000-0011	2/32
	2:1	1111-0011-1100-1111-1100-1100-0000-0011	1/32
Mannitol	1:2, 1:1	1111-0011-1100-1111-1000-1100-0000-0011	2/32
	2:1	1111-0011-1100-1111-0100-1100-0000-0011	2/32
Methyl Sulfone	1:2, 1:1, 2:1	1111-0011-1100-1111-1100-1100-0000-0011	1/32
Powdered Sugar (gram equivalent)	1:2	1111-0011-1100-1111-1000-1100-0000-0011	2/32
	1:1	1111-0011-1100-1111-0000-1100-0000-0011	3/32
	2:1	1111-0011-1100-1111-1100-1100-0000-0011	1/32

B

Cocaine Alone		1111-1111-1100-1111-1100-1100-0000-0011	
Cutting Agents Alone		0000-0000-0000-0000-0000-0000-0000-0000	
Cutting Agent	Ratio	Code	Differences from cocaine
Baking Soda	1:2, 1:1, 2:1	1111-1111-1100-1111-1100-1100-0000-0011	0/32
Dextrose	1:2, 1:1	1111-1111-1100-1111-1100-1100-0000-0011	0/32
	2:1	1111-1111-1100-0111-1100-1100-0000-0011	1/32
Epsom Salt	1:2, 1:1, 2:1	1111-1111-1100-1111-1100-1100-0000-0011	0/32
Granulated Sugar	1:2, 1:1	1111-1111-1100-1111-1100-1100-0000-0011	0/32
	2:1	1111-1111-1100-0011-1100-1100-0000-0011	2/32
Lactose	1:2, 1:1, 2:1	1111-1111-1100-1111-1100-1100-0000-0011	0/32
Mannitol	1:2	1111-1111-1100-1111-1100-1100-1000-0011	1/32
	1:1, 2:1	1111-1111-1100-1111-1100-1100-0000-0011	0/32
Methyl Sulfone	1:2	1111-1111-1100-1111-1100-1100-1000-0011	1/32
	1:1, 2:1	1111-1111-1100-1111-1100-1100-0000-0011	0/32
Powdered Sugar (gram equivalent)	1:2, 2:1	1111-1111-1100-1111-1100-1100-0000-0011	0/32
	1:1	1111-1111-1100-1111-1100-1100-0100-0011	1/32

Table 4: Changes in Binary Code of Drugs Post Adulteration. Each code was determined as described previously using the same five readers in the same lighting conditions. (A) Methamphetamine codes with and without cutting agents. (B) Cocaine codes with and without cutting agents.

between an array of unknown molecules, to reduce false positives, and to reduce duplicate codes. Figure 1 shows the typical setup of the improved assay. In the original version, several groups of analytes had duplicate codes: caffeine and cocaine; fentanyl, a multivitamin (water and ethanol solvent), and Jet Alert™; hydromorphone and Tylenol® Cold Day; flunitrazepam, quinine, nicotine, Equate® Allergy Relief, codeine, and aspirin; and THC and L-glutamine (ethanol solvent). DETECHIP® is capable of discriminating all of these analytes with unique codes, with the exception of cocaine and caffeine, which remain identical.

Cutting agents

The effects of cutting agents on the codes of illicit drugs were investigated. Drugs were adulterated in 1:1, 1:2, and 2:1 molar ratios

with the following cutting agents: baking soda, dextrose, granulated sugar, lactose, Epsom salt, mannitol, and methyl sulfone. Powdered sugar was also tested but due to the presence of starch in powdered sugar, the drugs were adulterated in a 1:1, 1:2, and 2:1 gram-to-gram ratio. All of these cutting agents revealed no color or fluorescence changes and therefore a code of thirty-two zeros. To decrease impact of variations in the eyesight of individuals, 5 readers were selected to analyze each plate and the majority of overlap was used to assemble the combined binary code (Table 3). Codes with and without cutting agents for two drugs, methamphetamine and cocaine, are shown in Tables 4A and 4B. For each adulteration at different drug to cutting agent ratios, minimal differences were observed in the codes indicating high reproducibility (Tables 4A and 4B). The codes also varied minimally between cutting agents.

Methamphetamine (Table 4A) showed slightly less consistency in color changes than cocaine when adulterated with cutting agents. Only one change in fluorescence was noted with baking soda (1:1 ratio). Cocaine (Table 4B) showed very little variability in the code with any of the cutting agents tested; and all of the variability was seen in color changes only. Three out of the eight cutting agents did not change the cocaine code at any ratio. The largest change to the code occurred with a 2:1 ratio to granulated sugar, with only 2/32 digits changed from cocaine alone, but at the other ratios (1:2 and 1:1) no changes were seen. The DETECHIP® assay shows a unique color change pattern for each drug tested (data not shown) that may make it easy to identify drugs simply based on the types of color changes and pattern. Cocaine, for example, has unique color changes with DC2 and DC5 that even in the presence of the cutting agents are easily recognized.

Conclusions

DETECHIP® is a molecular sensor capable of yielding a unique 32 digit binary code corresponding to tested analytes of interest. A variety of analytes, including scheduled drugs (with and without cutting agents), OTCs, cutting agents, food spoilage metabolites and explosives have been successfully identified by the enhanced system. In the original DETECHIP, as the analyte pool was expanded from narcotics to OTC medications, some substances yielded identical binary codes, thus giving the first example of false positives. But enhancing the system by the addition of a sixth, then seventh, and finally eighth sensor provided a discernable binary code, which demonstrated the capability to engineer out false positives. Work is currently underway in our lab to expand DETECHIP® to 100 sensors, thus affording a 400-digit code. Concurrently, future research will focus on removing the human element in the code generation by developing bench-top and handheld scanners that would allow for field testing. Ultimately, the greatest advantages for DETECHIP® will be ease of use, low cost compared to industry alternatives, and the versatility to detect such a wide range of analytes. Because DETECHIP® is able to identify several different classes of compounds, e.g. abused narcotics, explosives, poisons, and metabolites, the applications for DETECHIP® will be broad.

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