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Computational Design and Fabrication of Optical Fibre Fluorescent Chemical Probes for the Detection of Cocaine

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Abstract—A rationally designed fluorophore has been developed and has been incorporated into molecularly imprinted polymers, as the basis of the design of a sensor. Its use has allowed the fabrication of two different designs of fibre-optic chemical probes using an approach based on the change of the emitted fluorescence being related to the concentration of the desired species that was present. A high sensitivity to the drug Cocaine was achieved with each of the probes, showing positive changes in the fluorescence signal achieved in response to 1–100 μM solutions of the drug, in solution in aqueous acetonitrile. High sensitivity for Cocaine over a range of compounds was demonstrated for one of the probes (probe X) and detection of the drug is possible even in the presence of strong fluorescence interference. The work has also shown that probes of this type do not need to be discarded when used: re-use of probe X is possible using a straightforward washing procedure and the calibration performance was maintained.

Index Terms—Chemical probe, Cocaine probe, fluorescence, molecular imprinted polymer (MIP), optical fibre.

I. INTRODUCTION

CONTRABAND detection is an ongoing worldwide challenge and the need for easy means to detect and measure the quantity of such substances is thus becoming increasingly important. Further, the market for illicit Cocaine continues to expand from the Americas and Europe towards the emerging economies in Asia [1]. This is supported by estimates published recently by the United Nations Office on Drugs and Crime which show that 17 million people world-wide used Cocaine at least once in 2012–13. The significance of this figure is evident from it being equivalent to 0.37% of the global population aged 15–64 years (as of 2011). This has major consequences for the health of those users of Cocaine, as this long-term exposure cause problems such as irregular heartbeat, heart attack and stroke. This emphasises the importance of developing new and convenient detection methods which can be readily used by security and border services in the course of their work.

Efforts to develop suitable sensors have centred on aptamer-based biosensors using electrochemical detection [2], [3], electrogenerated chemiluminescence [4] and piezoresistive, microcantilever-based sensing [5] as there are relatively few reports in the literature of new sensor designs. Rapid, *in situ* detection of Cocaine residues is possible using paper spray ionization coupling with ion mobility spectrometry [6]. Portability of the equipment is a key issue for security services and police forces and many current systems are relatively non-portable, for example floor-standing X-ray machines, Raman spectrometry and gas chromatography-mass spectrometry. [7] In addition, there are problems with low detection rates and false alarms with other methods such as manual handling, sniffer dogs, and Fourier transform infrared spectroscopy. An interesting approach is based on molecular imprinting technology which has enabled skilled practitioners to generate polymers that are tailor-made and thus designed to recognize selectively an extensive range of chemical and biological materials [8]. These operate by a process in which the desired template interacts with functional monomers and the structure of the resultant complex is preserved by co-polymerization using excess cross-linker. In the fabrication process, the template may be washed out of the molecular imprinted polymer (MIP) to leave specific binding sites. Apart from presenting a low cost method, other advantages in designing probes using MIPs are their excellent durability and stability.

Optical fibres have been coated with MIPs and important examples are the low nM detection of the herbicide 2,4-dichlorophenoxyacetic acid [9] and other carboxyl-containing molecules [10]. Extraction MIPs [11] for Cocaine are known and some of the authors have developed high affinity MIP nanoparticles [12]. To optimise the design of MIPs, computational methods are available and have been explored by the authors and others in designing new MIPs [13], [14]. Research published by Holdsworth employed the semi-empirical AM1 method to calculate binding energies of complexes between Cocaine and

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monomer molecules. This was done in a study to optimise the template-functional monomer ratio in the polymerization mixture [15].

An exciting feature of this approach is that it couples well to optical fibre sensors (OFSs) which routinely offer many advantages over other methods of measurement for this application. Such devices are ideally suited to exploiting the benefits of their lightweight nature, small size, low cost, and remote sensing capability for use 'in-the-field'. OFSs fit well to being multiplexed along a single fibre optic cable, creating potentially a 'smart sensor' network when coupled to an intelligent system. Above all, for use outside the laboratory, they are physically robust and chemically stable—making them suitable for use in harsh environments or where there are high levels of electromagnetic interference, to which they are inherently immune. The major advance that this work puts forward is both the effective computational design of a fluorophore and its incorporation into a MIP for coating on the distal end of an optical fibre to create the sensing element. This approach has allowed the creation of two optical fibre based Cocaine probes. The advance over the prior work by some of the authors lies in the improved Cocaine sensitivity [16]–[18]. Thus the work has been a critical step in designing and developing the first compact, hand-held Cocaine probe, based around stable synthetic molecular receptors, and thus a device which meets the requirements of security forces.

To address this, enhancing probe sensitivity and selectivity, over what has been seen with previous Cocaine probes [16]–[18], is critical and this has involved systematic, computational monomer design. Leading from that is the fabrication of highly sensitive sensors derived from MIPs incorporating what has been described in this work as acrylamide monomer **3**. Two different probe designs, labelled **X** and **Y**, are discussed and their performance has been evaluated and extended from our prior work. [19] A detailed evaluation of the selectivity of probe **X** is also reported.

II. EXPERIMENTAL SECTIONS

A. Fluorescence Spectroscopic Measurements

In the evaluation of the probes produced, fluorescence emission spectra were obtained and recorded. Light from a LED (375 nm centre wavelength) was coupled through a multimode fibre with good UV/visible spectral transmittance and having a hard polymer cladding. [18] The fibre was of much larger diameter than "standard" communications fibre—at 1000 μm for the silica core—with a numerical aperture (NA) of 0.37. Further optical components such as collimation and focusing lenses were used, to couple light via a 2×1 Y fibre coupler, as can be seen from the diagram. The distal end of the coupler which was fabricated using two multimode UV/visible fibres (of NA 0.37) with hard polymer cladding and in this case a smaller, 600 μm silica core. This arrangement was connected to the probe. For convenience of use, the active sensing region lies at the distal end of the fibre. When exposed to Cocaine, enough of the light emitted from the sensing layer was guided by that fibre bundle to the other branch of the fibre coupler. The spectral nature of the signal produced is obtained by analysis using an Ocean Optics USB2000 spectrometer. For convenience of use by more inexperienced operators, SpectraSuite software was used to create a
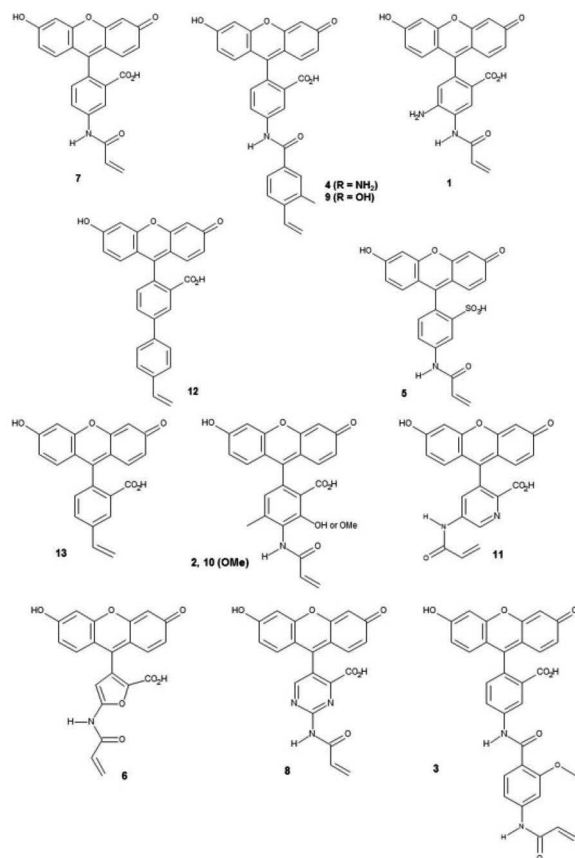

Fig. 1. Chemical structures of monomers **1–13** considered in this work.

display to allow the performance of the senor to be measured. Data for the software are as follows: 100 ms integration time, 23 scans being taken and an average obtained and 10 point boxcar width. Setting these values has been effective for the detector to monitor the incoming photon signal for a relatively prolonged period with a signal-to-noise ratio that has allowed measurements to be made effectively.

A 1000 μM stock solution of Cocaine in distilled water:acetonitrile (9:1) was used in the performance evaluation in which acetonitrile was diluted appropriately to provide a series of stock solutions of various concentrations for evaluation; examples were 1 in 40 (25 μM), 1 in 20 (50 μM), 1 in 10 (100 μM), 1 in 4 (250 μM).

B. Computational Design

The design of the monomer is described next, showing the advance from work reported as earlier studies [16]–[18]. A critical aim has been to maximize the interactions between the drug and the chosen fluorescent monomer used as starting material for polymer synthesis. A computer-aided rational design strategy pioneered by Piletsky *et al.* [20] was used in this part of the work. The protocol involved the simulation of a complex formation between a virtual library of functional monomers selected as binders to Cocaine (see Fig. 1) and the template (Cocaine) in a monomer mixture. The design simulation was performed on a PC running CentOS 5 GNU/Linux operating system and SYBYL 7.3 software suite (Tripos, Inc., St. Louis,

Monomer	Binding Energy (kcal · mol^{-1})	Comment
1	−39.24	Low synthetic tractability
2	−31.02	Lengthy synthesis
3	−25.42	**Optimised Monomer**
4	−23.07	
5	−22.99	
6	−22.82	Less synthetic tractability
7	−22.73	Previous acrylamidofluorescein (Ref. 16)
8	−21.97	Deprioritised
9	−21.66	Deprioritised
10	−21.76	Deprioritised
11	−21.6	Deprioritised
12	−21.24	Deprioritised
13	−19.01	Deprioritised

Fig. 2.   Synthesis of Monomer **3**.

MO, USA). The LEAPFROG algorithm was applied to the monomers for their possible interactions with Cocaine, resulting in a ranked order of monomers according to their binding scores (in kcal · mol^{-1}; see Table I).

Many possible monomer structures exist but our purpose here was to use our previously reported technique [20] to identify functional monomers on a small, focussed library. In the design, the energies calculated were a combination of typical monomer-template complexation and additionally a system of scoring the complementarities between the monomer and template where the template is defined by LEAPFROG as the receptor binding site (using additional site-point matching scores, a system of scoring the receptor and ligand interactions) was used. A sense of regionality was offered by this scoring method, thereby rewarding complementary sites which are nearby in the hope the highest binding energy (in kcal · mol^{-1}) and ideally the "best fit" would occur. The monomers contained functional groups which are commonly used in molecular imprinting and possessed polymerizable residues. This allowed attachment to suitably treated optical fibres, and residues able to interact with a template through ionic and hydrogen bonds, van der Waals' and dipole–dipole interactions [14]. The amine motifs present in some of the monomer structures (**1** and **4**, Fig. 1) may be involved in fluorescence quenching. The monomers were also found to have varied in terms of their synthetic accessibility.

The charges for each atom were calculated using the Powell method in combination with Gasteiger–Huckel charges and Tripos Force Field. This method was applied to refine the structures of the monomers using the gradient minimisation method: this is stopped when the energy gradient is lower than 0.001 kcal · mol^{-1}. The molecular structure of Cocaine was also drawn and minimised to a value of 0.001 kcal · mol^{-1} with a dielectric constant for acetonitrile (36.6), the polar solvent use in the polymerisation mixtures. The monomer library was screened against the minimised structure of Cocaine (30 000 iterations). Undertaking such screening allowed the generation of a table ranking the monomers according to their binding scores (kcal mol^{-1}) identifying the best candidates for sensing Cocaine. In this way those monomers with the lowest binding energies, **1** and **2**, were not progressed due to the relatively challenging nature of the chemistry required to synthesise the compounds. After taking into consideration these chemical viability restrictions,
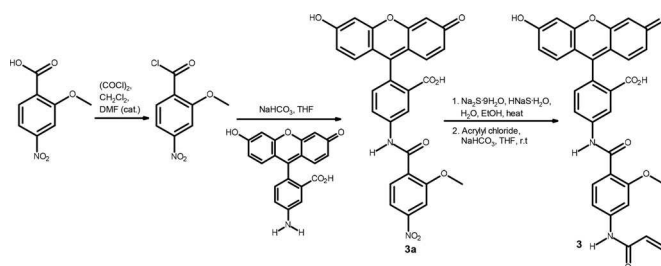
monomer **3**, with a binding energy of –25.42 kcal · mol^{-1}, was identified as the optimum candidate from those considered for incorporation into the probe design. Minimised conformations of **3** and Cocaine are depicted in the Supporting Information. By way of comparison, monomer **7**, an acrylamidofluorescein [17] previously shown to confer slightly reduced sensitivity to Cocaine, was predicted to bind less favourably to the drug (binding energy of –22.73 kcal · mol^{-1}; Table I).

C. Apparatus and Reagents

An analysis using mass spectrometry was performed to evaluate the sample. This was carried out using a Waters LCT Premier Xe electrospray ionization Time of Flight machine. ^{1}H NMR spectra were recorded on a Bruker Avance instrument operating at 500 MHz. The optical fibre hardware was used as follows: the optical fibre itself, the connectors and the polishing pads used were purchased from Thorlabs. All chemicals were of analytical grade, obtained from Sigma–Aldrich or Acros Organics and were used without further purification except for ethylene glycol dimethacrylate which was distilled under reduced pressure. The solvents used for syntheses and purifications were either of HPLC grade (from Fisher Scientific) or anhydrous (from Sigma–Aldrich). Dry ethanol and dry acetonitrile for probe fabrication were taken from sealed bottles under argon. All aqueous solutions were prepared using distilled water.

D. Preparation of Fluorophore 3

Synthesis of the chosen fluorophore, labelled **3,** was achieved in four steps as outlined in Fig. 2. To do this, the acyl chloride derivative of 2-methoxy4-nitrobenzoic acid was coupled with fluoresceinamine, under standard conditions, to create amide **3a**. Subsequent sodium sulphide-mediated reduction of the nitro group [21] was followed by conversion to **3** by reaction of the intermediate aniline and acrylyl chloride. Careful purification of the target compound by flash chromatography was required to furnish material ready for optical studies. Experimental details are outlined in the Supporting Information. Fluorophore **3** was then used to fabricate probes **X** and **Y**.

E. Polymerization and Probe Fabrication

It is evident from the foregoing that the design and fabrication of the Cocaine probes has the required the use of a multi-step process. In each case, the distal end of a 1000 μm diameter UV multimode fibre was polished (with polishing pads) and washed with acetone. Subsequent treatment with 10% KOH in isopropanol for 30 min, then rinsing with distilled water and

drying using compressed argon, was followed by treatment with 3:7 (v/v) 30% hydrogen peroxide:concentrated sulphuric acid (Piranha solution) for 30 min. After rinsing in distilled water and drying in an oven at 100 °C for 30 min, the fibres were modified by silanization, in a 10% solution of 3-(trimethoxysilyl)propyl methacrylate in dry ethanol, for 2 h. The fibres were then washed with ethanol repeatedly in an ultrasonic bath to ensure cleanness and oven-dried overnight at 70 °C.

The mixture used for the polymerization step in the fabrication of probe **X** was prepared by dissolving Cocaine (4 mg, 2 equivalents), **3** (3.6 mg, 1 equivalent), ethylene glycol dimethacrylate cross linker (103.8 mg, 80 equivalents), methacrylic acid co-monomer (7.9 mg, 14 equivalents) and AIBN initiator (0.7 mg) in dry acetonitrile (150 μL). This solution was left standing for 2 h then purged thoroughly with argon for 5 min and a small volume of the mixture was placed into a capillary tube and the distal end of the fibre was inserted. This arrangement was sealed quickly with melted plastic and polymerized was performed at 70 °C for 2.75 h, then at 50 °C for 23 h. A MIP layer formed on both the cylindrical surface and the distal end surface of the fibre. However, only the MIP on the distal end surface is responsible for sensing because it is the only part of the sensor material that is excited by light transmitted by the fibre. The sensor tip was washed repeatedly for 8 h (methanol:acetic acid (4:1, v/v) for 3 h 55 min followed by methanol alone for the remainder of the time) using intermittent ultrasonication. A control probe (non-imprinted polymer, NIP) version of probe **X** was prepared, under identical conditions, using the same protocol but without the addition of Cocaine.

An analogue of probe **X** was fabricated using trimethylolpropane trimethacrylate, TRIM, as the cross-linker (in place of ethylene glycol dimethacrylate), termed probe **Y**. The following reagent quantities were used to prepare probe **Y**'s prepolymerization mixture as described above; Cocaine (4.5 mg, 2 equivalents), fluorophore **3** (4.05 mg, 1 equivalent), TRIM (199.3 mg, 80 equivalents), methacrylic acid co-monomer (8.9 mg, 14 equivalents) and AIBN initiator (0.8 mg) in dry acetonitrile (165 μL). The fabrication of probe **Y** was completed by purging this solution with argon for 4.5 min and a small volume of this mixture was sealed onto the distal end of a treated fibre, as described for **X**. Polymerization occurred at 70 °C (this process was carried out overnight), following which the sensor tip was washed repeatedly for 7 h 47 min (methanol:acetic acid (4:1, v/v) for 3 h 47 min followed by methanol alone for 4 h), using intermittent ultrasonication, prior to use.

F. Setup for the Measurement System

This can be described as follows. A 375 nm LED was chosen as the light source as this provided an output in a region of the spectrum in which output signals from the sensor were expected and because it is relatively high power, compact and rugged, operating using a low voltage power supply. All this makes it ideal for 'in-the-field' measurements. The output from the LED was then coupled through a multimode UV/visible fibre (with hard polymer cladding, 1000 μm silica core and numerical aperture (NA) of 0.37 and as discussed earlier), using collimation and focusing lenses, into a 2 × 1 Y fibre coupler. The far end of the coupler, made using two multimode UV/visible fibres with

hard polymer cladding, 600 μm silica core and 0.37 NA, was connected to each probe with the active sensing region being located at the distal end of the fibre. Following the interaction of the Cocaine sample with the active sensing region, a portion of the total light emitted was collected and guided through the same fibre bundle to the other branch of the fibre coupler. This is connected to an Ocean Optics USB2000 spectrometer to allow for the analysis of the signal obtained through the display on a computer screen using SpectraSuite software.

III. RESULTS AND DISCUSSION

A. Sensing Mechanism

Imprinting and drug detection is achieved due to formation of a complex between the carboxyl group on fluorophore **3** and the amine group present in Cocaine. The complex was copolymerized with cross-linking monomer on the end surface of the fibre, which has been functionalized with polymerizable groups. After extraction of Cocaine from the polymer, the resultant MIPs contained recognition sites incorporating **3** and thus exhibited an increase of fluorescence intensity selectively in the presence of the drug. Consequently, the high selectivity described for probe **X** arose from the functional nature of **3** and from the shape of the MIP cavities. The sensing principle depends on changes in the frontier orbitals of **3**, which occur when it is deprotonated by Cocaine, leading to an increase in the observed fluorescence intensity.

B. Response of the Probes to Cocaine

Probe calibration measurements were performed using the preferred distilled water:acetonitrile (9:1) solvent system [16] over 15 min, a response time found to be suitable from our related work [16]. The probes were rinsed with methanol after each measurement (progressing from low to high concentrations of Cocaine). The performance characteristics of two probes were evaluated as follows.

Probe **X** was the first to be evaluated and it was shown to exhibit good sensitivity and responded to a range of concentrations of between 25 and 100 μM to which it was exposed, giving a Cocaine response (shown in Fig. 3(a)). The probe appeared to be saturated using 250 μM Cocaine; short-term washing gave a fluorescence response below background peak (when zero cocaine present). The response of the control/NIP probe to Cocaine was also studied and no increase in fluorescence (rather a 1.4% decrease) was observed upon addition of 25 μM Cocaine (at 523.6 nM) relative to when zero Cocaine was present. Conversely, the MIP probe exhibited a 6.1% increase in fluorescence at this wavelength. These results suggest that the analyte bound to the MIP more strongly than to the NIP and confirming the existence of effective MIP recognition.

After this initial study, the probe was washed for a further 3 h 40 min with methanol:acetic acid (4:1) followed by methanol (3 h 45 min), with periodic insertion into an ultrasonic bath. It is possible that a shorter time remove bound Cocaine just as effectively but the precise requirement for cleaning was not fully explored. Next, we generated the data shown in Fig. 3(b). Here, the probe became saturated (500 μM measurement gave lower signal) so once again appeared to have a maximum detection limit.
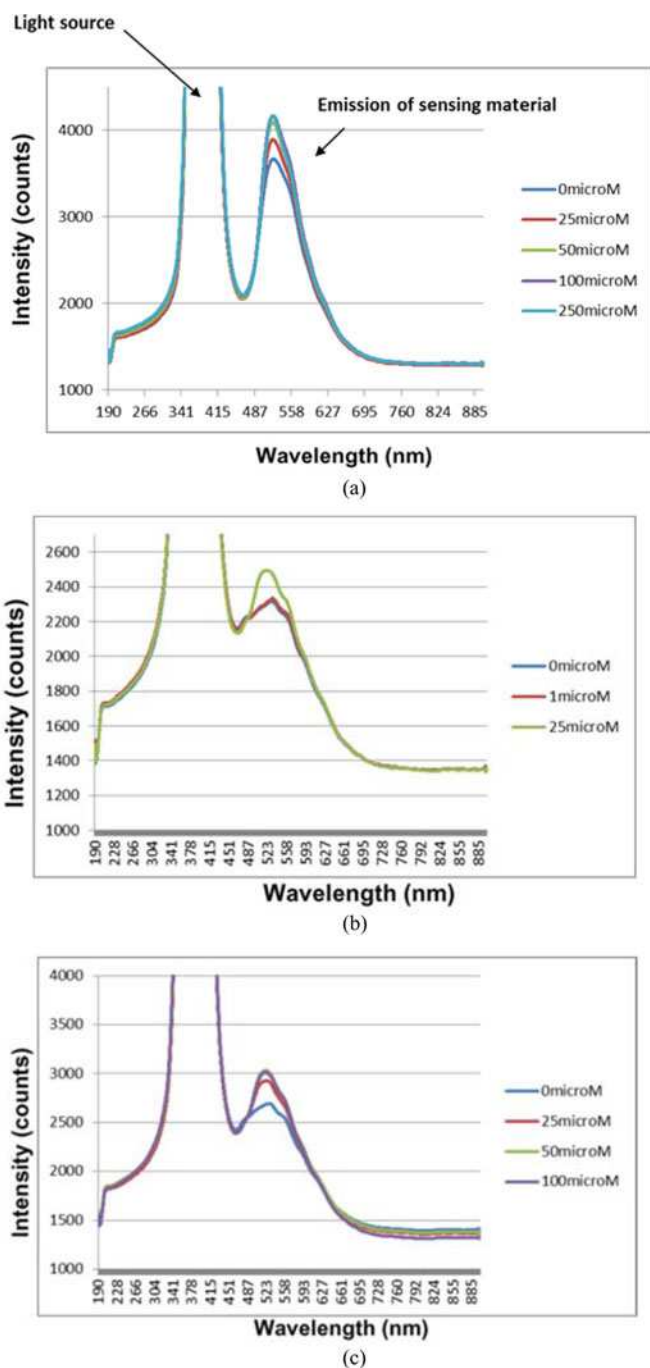
Fig. 3. Summary of probe performance characteristics (all in water:acetonitrile 9:1). (a) Probe **X** response to Cocaine. (b) Response of probe **X** to low Cocaine concentrations (after second wash). (c) Probe **Y** response to Cocaine.

Although the background (no Cocaine) peak was 'lowered' the sensor regenerated and still functioned (see 25 μM trace). Positively, the lowest concentration of Cocaine that caused a distinguishable change in fluorescence intensity was 1 μM and this low detection limit provided an advantage over previous probes [16]–[18] of this type (2–500 μM).

Probe **Y** was next the subject of experiments and the probe was seen to respond to 25 μM Cocaine and showed similar emission spectra in the presence of concentrations of 50 and

100 μM of the drug (see Fig. 3(c)). These results, reveal the advantage indicated that the probe appeared to be better for detecting low concentrations before becoming saturated as the levels of Cocaine rise. Also, after ultrasonication in methanol for 24 min, the response to 1000 μM Cocaine was measured. This experiment gave an output spectrum with a peak intensity value at a level between that for the original blank (0 μM) and 25 μM traces. Thus, the use of TRIM as the cross-linker did not offer any significant advantage over ethylene glycol dimethacrylate (probe **X**).

Plots of fluorescence intensity versus Cocaine concentration (and not wavelength), using results from Fig 3(a) and (c), are shown in the Supplementary Information.

These results compare well with respect to the desirable dynamic range for a Cocaine probe to be useful in contraband detection and border security enforcement. Standards depend on whether trace detection is required (probably in the μM or even nM range). However, if a detector is needed to work as a dipstick system testing for large quantities of Cocaine dissolved in rum, for example, then detection in the molar region or greater is the goal. Other reports describe a microfluidic affinity sensor [22] and electrochemical detection [23] of Cocaine in the 10 pM and nM range respectively.

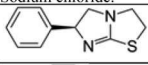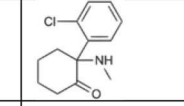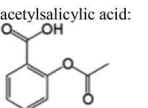### C. Assessment of the Selectivity of Probe X

Cocaine is frequently combined with other substances on the street in order to increase criminal profit. Inert substances with similar physical properties can be used to increase weight and compounds with similar chemical properties may be used because they are less expensive, or easier to obtain. There is a paucity of literature on the subject of precise compositions of street Cocaine and this represents an intelligence problem for law enforcement agencies and from a health perspective. However, Legleye's extensive study [24] in France included acetylsalicylic acid as an example adulterant present as "cutting agent", as reported by drug users. Levamisole [25] has increasingly been used as a cutting agent in Cocaine sold in the United States and Canada. Evaluation of the composition of street Cocaine seized in two regions of Brazil has also been recently reported. [26] In addition, attenuated total reflection infrared spectra of saliva samples have been recorded [27] with a particular interest in detecting Cocaine and measuring spectral interferences of selected diluents, masking agents, common medication, and soft drinks.

The common drug adulterants listed in Table II were selected for our probe selectivity studies. Specifically, Levamisole (entry 6) was chosen because of its importance to the criminal drug world; the Drug Enforcement Administration reported the compound was found in 82% of seizures by April 2011. Fructose (entry 4) is an example of a sugar and ketamine (entry 6) bears a secondary amine motif which is also present in Cocaine. The rationale for inclusion of bicarbonate of soda[1] and salt[2] (entries

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[1]Fifteen samples found by HMRC (Customs) out of total of 214 (all figures relate to seizures made from October to December 2008 (Source: Serious Organised Crime Agency).

[2]Five samples found by U.K. police out of a total of 459 (all figures relate to seizures made from October to December 2008 (Source: Serious Organised Crime Agency).

TABLE II
SET OF INTERFERANTS USED FOR SELECTIVITY SCREEN

| Entry	Interferant	Brand name/Supplier	Constituents/Chemical Structure
1	Biological washing powder	Persil	5 to 15% anionic surfactants, oxygen-based bleaching agents; Less than 5% soap, perfume, brighteners, enzymes, phosphonates
2	Baby teething powder	Teetha^{TM}/Nelsons	Homeopathic Chamomilla, lactose, xylitol and starch
3	Bicarbonate of soda		Sodium hydrogen carbonate.
4	D(-)-fructose	Sigma	
5	Salt		Sodium chloride.
6	Levamisole hydrochloride	Acros Organics	
7	Ketamine hydrochloride		
8	Aspirin		Main component is acetylsalicylic acid:
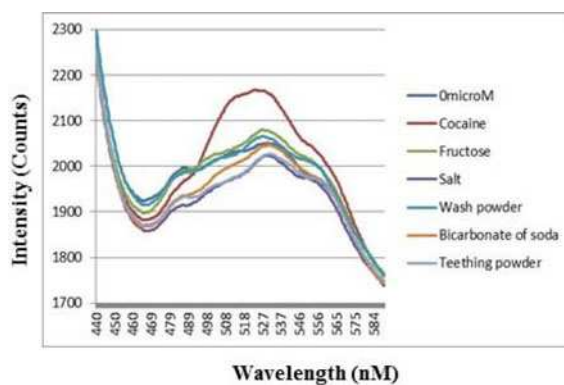
Fig. 4. Expansion of fluorescence emission spectra from initial interferant screen using probe **X** (25 μM).
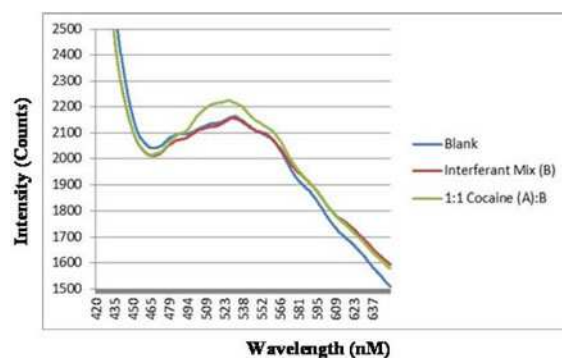

Fig. 5. Expanded Fluorescence emission spectra from extended selectivity studies with Sensor **X.**
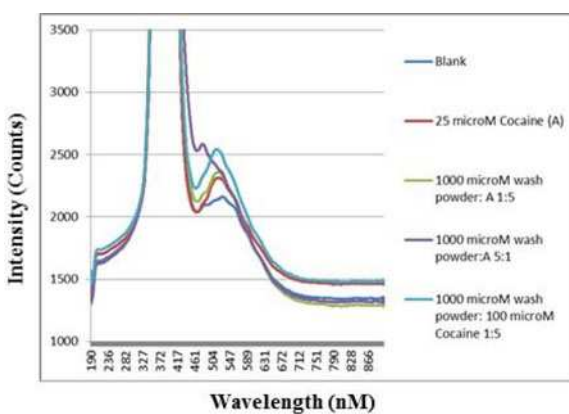

Fig. 6. Additional fluorescence profiling of probe **X.**

3 and 5) involved their frequent presence in samples from drug seizures.

Selectivity studies were initiated by preparing the following 25 μM solutions. Solutions of 0.30 mg/mL concentration (equivalent to 1000 μM Cocaine in weight) for substances listed in entries 1–5 of Table II were prepared using a 9:1 mixture of distilled water:acetonitrile. These 1000 μM stock solutions were then diluted appropriately; 1 in 40 (giving concentrations of 25 μM). A stock solution of Levamisole hydrochloride (664 μM) in 9:1 distilled water:acetonitrile was diluted appropriately giving a concentration of 25 μM. A stock solution of ketamine (2847 μM) in 9:1 distilled water:acetonitrile was diluted appropriately giving a concentration of 25 μM. Based on a concentration of 0.30 mg/mL (equivalent to 1000 μM Cocaine in weight) in 9:1 distilled water:acetonitrile, a 3800 μM stock solution of Aspirin was prepared and then diluted appropriately to 25 μM. It should be noted that some of the substances tested (see entries 6 and 7, Table II) existed in their hydrochloride salt forms, not free bases, which might affect the test results obtained.

Firstly, probe **X** was immersed in 4:1 methanol:acetic acid (for 4 h) then methanol alone (for three further hours) in order to remove bound Cocaine and excess polymerisation reagents. Fig. 4 shows our initial fluorescence results; an equilibration time of 10 min was used for each interferant test solution and methanol was used to rinse the probe after each measurement. The sensor showed good selectivity because it responded less to fructose, salt, biological washing powder, bicarbonate of soda and baby teething powder compared to Cocaine (at 25 μM).

Fig. 5 summarizes an extension of the selectivity test whereby measurements were taken for the solvent 'blank', 25 μM solutions of Cocaine (**A**), a solution comprising an equal mixture of 25 μM salt/fructose/Persil/baby teething powder/bicarbonate of soda (**B**) and, finally, a 1:1 mixture of **A**:**B**. These results clearly demonstrate that Cocaine can still be detected when combined with other agents.

Profiling of probe **X** continued with a comparison of the fluorescence spectra arising from its interaction with the aforementioned solution **A**, a 1:5 mixture of 1000 μM washing powder:**A**, a 5:1 mixture of 1000 μM washing powder: **A** and a 1:5 mixture of 1000 μM washing powder:100 μM Cocaine (see Fig. 7). It was observed that the high concentration (1000 μM) of
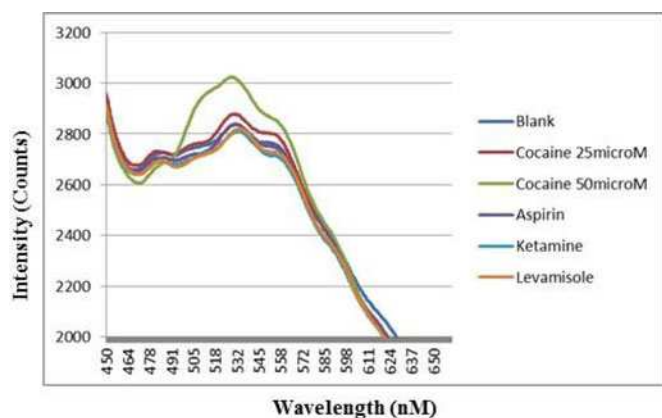
Fig. 7. Expanded fluorescence emission spectra (probe **X**) for Cocaine and other agents.

washing powder effectively swamps the fluorescence signal; an effect that is probably caused by brighteners. Importantly, however, the fluorescence spectra for 1:5 combinations of 1000 μM washing powder: 25 and 100 μM Cocaine suggests drug detection may be possible even in the presence of such strong interference. This is shown by the emission maximum, at 523.6 nM wavelength, in the light blue curve (see Fig. 6) having a larger intensity than the one arising from the purple line at the same wavelength. This offers a potentially valuable detection tool at the particular concentrations used here.

At this point, probe **X** was washed for a further 7.5 h (methanol:acetic acid 4:1 followed by methanol alone) before use in the selectivity studies summarised in Fig. 7. The probe was immersed in each solution for 15 min, to allow for equilibration, and rinsed with methanol after each measurement. Essentially no fluorescence response was observed using Aspirin, Ketamine and Levamisole (all 25 μM). The sensor lost some sensitivity to Cocaine; the 25 μM response appeared to be less significant than previously observed. However, the 50 μM Cocaine trace indicated that the probe was still functional despite the probe having been washed for 22 h in total prior to multiple measurement cycles.

IV. Conclusion

This research has been carried out to advance knowledge in the field of optical fibre sensor based probes. In the course of the work several achievements were seen. Rational design studies have allowed the engineering of two probes discussed, derived from **3**, that display enhanced sensitivity for the detection of Cocaine, over that seen in earlier generation of probes. [16]–[18] This work builds on but develops in a new direction from that reported earlier by the authors [19] by outlining a rapid method that helps to distinguish between the drug and illicit substances and legal impurities. It has been shown that detection of Cocaine is possible even in the presence of strong fluorescence interference. Further evaluation of parameters such as repeatability, temperature variation and photostability as well as the study of new probe designs is underway in our laboratory. A key conclusion is that this technology offers an inexpensive, easy-to-use method that may benefit the world of border security. On-going

research is focused on further enhancements of the performance and capability of the probes developed.

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