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Determination of amphetamine-type stimulants (ATs) and synthetic cathinones in urine using solid phase micro-extraction fibre tips and gas chromatography-mass spectrometry

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In recent years, an increasing number of stimulant drugs and new psychoactive substances (NPSs) have caused concern in scientific communities and therefore innovative methods to extract compounds from complex biological samples are required. This work is aimed at developing and validating a clean, convenient and straightforward extraction procedure with microliter amounts of organic solvent using Solid Phase Micro-Extraction tips (SPME tips) and analysis using Gas Chromatography-Mass Spectrometry (GC-MS) in human urine samples. Another aim is to evaluate three different types of SPME fibre tips C18, C18-SCX (mixed mode) and PDMS-DVB. The quantification method examined the different classes of stimulant compounds included Amphetamine-Type Stimulants (ATs) (amphetamine, methamphetamine, *para*-methoxyamphetamine (PMA), and ($\pm$)-3,4-methylenedioxymethamphetamine (MDMA)) and synthetic cathinones (mephedrone, buphedrine (buphedrone ephedrine metabolite), 4-methylephedrine (mephedrone metabolite), and pentylone). The method was developed with respect to several areas of the experimental design including pH, ionic strength, addition of salts, vial dimensions, analytes and derivatisation, type of solvents, solvent volume, extraction and desorption time, agitation speeds in the extraction and desorption steps and matrix volume. The optimised method was validated for eight compounds using the SPME PDMS/DVB fibre tips with satisfactory linearity and selectivity ranging between 50 and 2000 ng mL⁻¹, and limits of detection (LODs) and low limits of quantification (LLOQs) ranging between (5–25) and (25–100) ng mL⁻¹ respectively. Within-run and between-run accuracy and precision were <15%. The method was applied to real human urine samples indicating its suitability for common stimulant drugs and provided clean chromatograms with no interfering peaks. The assessment of green analytical chemistry for the method used was discussed and compared with Solid Phase Extraction (SPE). According to the results obtained we recommend the method for use in routine laboratories carrying out drug/forensic analysis for confirmation tests of the studied compounds.

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Introduction

Over the past few years, approximately one compound has entered the recreational drug market on a weekly basis within the category of new psychoactive substances (NPSs). These are synthesised to bypass regulations and laws, and to have similar or stronger effects than existing drugs. Throughout the world, amphetamine-type stimulants (ATs) are the second most commonly used drugs and often exceed heroin and cocaine use.^{1–3}

Synthetic cathinones covered approximately 23% of the global trends of individual NPSs reported in the Early Warning

Advisory (EWA) from 2008 to 2015.³ Cathinone is found in the plant *Catha edulis* (khat) and synthesized derivatives have a varied range of β -ketoamphetamines and have been sold as alternatives to ATs. Fatalities and toxicity related to the abuse of stimulant drugs and synthetic cathinones are of international concern with several deaths reported.^{4–11}

Consequently, the proof of identity of ATs and synthetic cathinones in biological specimens is vital in the clinical, forensic and toxicology fields since most of the NPSs are not fully detected using routine immunoassay screening methods. This may be a result of cost-ineffectiveness or unavailability of reagents. Moreover, the confirmation of positive results in chromatographic and mass spectrometric techniques is required for accurate molecule identification and to distinguish between isomers and structures.

Biological samples contain various components with urine and blood which are not compatible with complex instrumentation.

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1 : 10 dilution in methanol. A mixture of the working solution of each standard was prepared by the dilution of the $100\ \mu\text{g mL}^{-1}$ stock solutions *via* 1 : 50 dilution in Drug-Free Urine (DFU) to reach a concentration of $2\ \mu\text{g mL}^{-1}$.

Working internal standards (ISDs) of the deuterated standards were prepared by the dilution of purchased internal standards *via* 1 : 10 dilution in methanol to reach $10\ \mu\text{g mL}^{-1}$. The mixture of the 8 drugs in urine and ISDs were stored at $-20\ ^\circ\text{C}$ until use.

Optimised procedure

The optimised procedure was applied to assess the parameters of the method validation work.

Initially, the SPME tips (PDMS-DVB fibre) were conditioned between 10 and 20 minutes in MeOH : distilled water (50 : 50).

1 mL of the drug mixture in urine (for example $2\ \mu\text{g mL}^{-1}$) and 100 μL of ISDs of amphetamine d11 and pentylone d5 ($1\ \mu\text{g mL}^{-1}$) with 0.5 g NaCl and 100 μL of 10% NaOH (pH 12.6) were added to 1.5 mL microcentrifuge Eppendorf tubes. The Eppendorf tubes were pierced before inserting the SPME tips.

The samples including tips were placed in a shaker (IKA VIBRAX VXR) for agitation at a speed of 2000 rpm. They were left for at least 1 hour so that equilibrium between the analytes and stationary phase was reached.

The SPME tips were transferred to 0.3 mL vials with the addition of 65 μL of MeOH and left for 10 minutes at an agitation speed of 2000 rpm. 10 μL of acidified methanol (1 : 9) was added, and the vials were evaporated under a stream of nitrogen at room temperature (RT) until fully dry.

The vials were then derivatised by adding 50 μL PFPA and EtOAc (2 : 1). The samples were capped and vortexed immediately for 3–5 seconds and then incubated for 10–15 minutes at $60\ ^\circ\text{C}$. The samples were evaporated under a stream of nitrogen at RT. The time required until fully dried in the evaporation steps was 2–5 minutes only. The samples were reconstituted in 50 μL of ethyl acetate before 1 μL was injected into the GCMS for analysis (see Fig. 1).

Method development preparation

The method development of SPME tips was assessed based on the following criteria: the pH of buffer, ionic strength, addition of salts, size of vials, analyte and derivatisation, type of solvents, solvent volume, extraction time, agitation speed in the extraction step, desorption time, agitation speed in the desorption step and matrix volume. Each criterion was evaluated as a single factor keeping the other factors constant.

The parameters were assessed based on the absolute recovery¹⁴ by adding 1 mL urine containing the mixture of the 8 drugs ($1\ \mu\text{g mL}^{-1}$). A 50 μL ISD ($0.5\ \mu\text{g mL}^{-1}$) of amphetamine d11 was added prior to the evaporation step.

100 μL of a duplicate unextracted mixture of the 8 drug samples ($1\ \mu\text{g mL}^{-1}$) and a 50 μL ISD of amphetamine d11 ($0.5\ \mu\text{g mL}^{-1}$) were added on each evaluation day.

The response of extracted (response of extracted analyte – response of ISD)/response of unextracted (response of unextracted analyte – response of ISD) ratio (%) is calculated as the recovery rate on each day of the method development process.

The pH buffering of urine was evaluated on the three fibres and adjusted to pH 3, 5, 7, 9 and 11 by adding small drops of formic acid, HCl for acidity products, 25% NaOH for alkaline products and phosphate buffer for pH 7.

The ionic strength and the additive of NaOH and KOH salts (5%, 10% and 25% (w/v)) with and without NaCl (0.1, 0.25, 0.5, 0.75 and 1 g; 5%, 10% and 25% (w/v)) were examined in duplicate samples. The experiments were repeated three times on three different days for NaOH (5%, 10% and 25%) with NaCl (0.1, 0.25, 0.5, 0.75 and 1 g) to confirm the results.

The evaluation of the sample volume was performed in triplicate vials at volumes of 1000, 500 and 100 μL at a concentration of $1\ \mu\text{g mL}^{-1}$.

The derivatisation agent was evaluated by the application of the duplicate samples of PFPA derivatives added pre-, during and post-extraction and after the first evaporation step.

The solvents MeOH, acetonitrile, EtOAc, ($\text{NH}_4\text{OH} : \text{MeOH}$; 2 : 98), ($\text{NH}_4\text{OH} : \text{MeOH}$; 0.5 : 99.5), ($\text{DCM} : \text{IPA} : \text{NaOH}_4$;

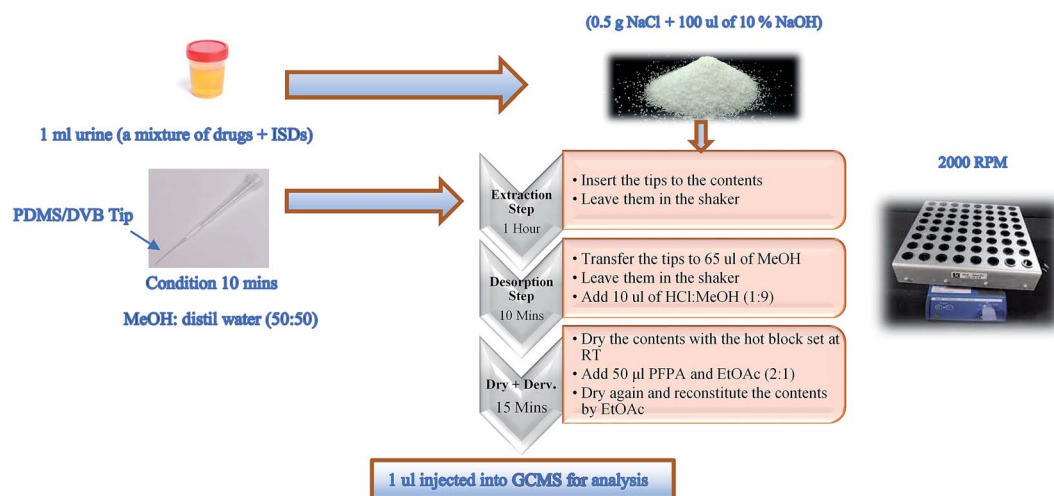


Fig. 1 Illustration of the optimum condition procedure applied to SPME PDMS/DVB fibre tips in the mixture of drugs in urine samples.



The evaluation of two types of vials, Eppendorf vials (1.5 mL) and kit vials (1.2 mL), was performed by applying the optimum procedure in duplicate samples. They were examined once more to evaluate the linearity at concentrations of 50, 100, 250, 500, 750, 1000, and 2000 ng mL⁻¹ (duplicate samples at each point). All the developed method parameters were tested in the spiked urine containing the 8 stimulant drugs at a concentration of 1 µg mL⁻¹.

The interference study was performed by analysing ten different individual blank urine samples for verifying the absence of the peaks interfering with the analytes of interest *via* SIM mode.

The method was carried out with Gas Chromatography-Mass Spectrometry (GC-MS) using a 7890A GC/5975C MSD, a split/splitless inlet and a DB-5ms (5% phenyl/95% methylpolysiloxane; 30 m $\times$ 0.25 mm, 0.25 μ m film thickness) separation column (all from Agilent Technologies, Waldbronn, Germany). Helium was used as a carrier gas (99.99% purity). Splitless injection at 225 $^{\circ}$ C was employed. The column temperature programme was initially started at 70 $^{\circ}$ C and then raised to 200 $^{\circ}$ C at a rate of 11 $^{\circ}$ C min $^{-1}$ (held for 4 minutes), and 200 $^{\circ}$ C to 280 $^{\circ}$ C at a rate of 10 $^{\circ}$ C min $^{-1}$ (held for 1 minute). The total time was 25 minutes. The MS transfer line temperature was kept at 250 $^{\circ}$ C. The MS was operated in the electron impact ionisation mode (70 eV). The ion source was maintained at 200 $^{\circ}$ C. MS data acquisition was initiated at 7 minutes and was performed in the selected ion monitoring (SIM) mode. The method was developed to provide an excellent separation and response. All data acquisition and processing steps were performed using GC/MSD ChemStation Software Version 6.5.

Results and discussion

SPME tip extraction and GC-MS methods

GC MS was initially developed until the desired responses were achieved along with separation and detection by applying the mixture of the 8 stimulant drugs. Each standard of the mixture compounds was prepared alone by running unextracted samples with PFPA derivatives. The separation, t_R and fragmentation patterns with the ion intensity ratio% were considered and recorded. The random procedure of SPME tips was initially applied to the optimised conditions of the GC MS. The responses of the SMPE tips were compared with unextracted

sample responses (ISD was involved in the calculation). This process showed an initial successful separation and detection in the chromatogram through the procedure of SPME tips (see Fig. 2 and Table 2).

Method development

The presence of an efficient, convenient, clean and reliable method for the sample preparation of stimulant drugs such as ATs and synthetic cathinones and other related compounds of NPSs is important in forensic toxicology laboratories, specifically for confirmation tests. The final products of the method development processes enabled the detection of ATs and

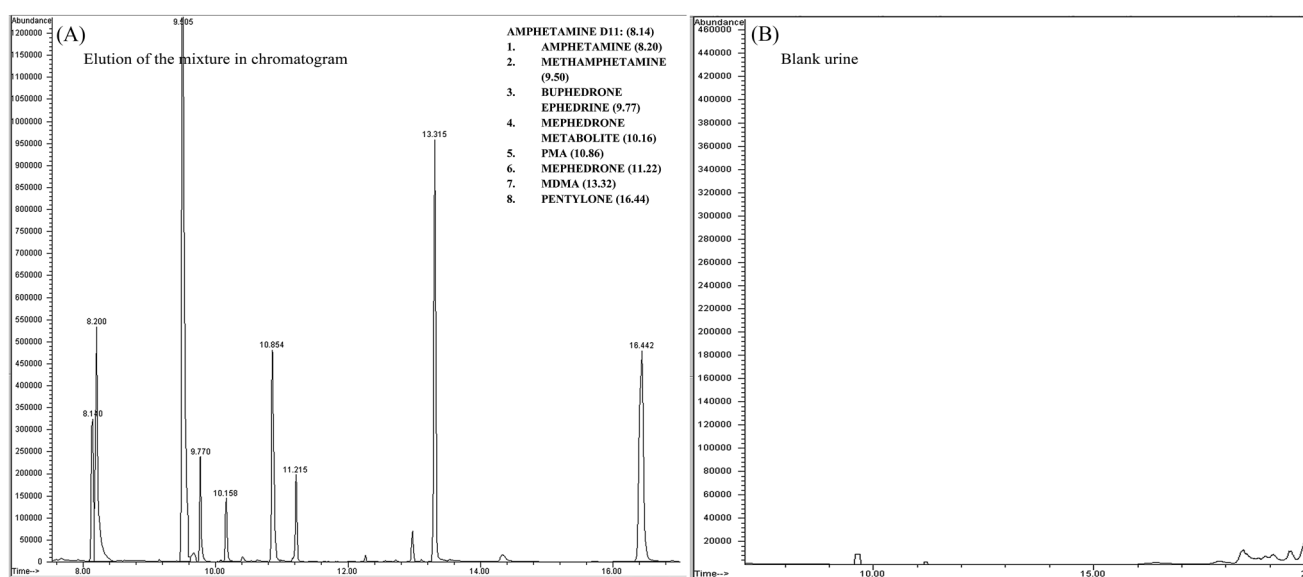


Fig. 2 (A) SIM chromatogram for the eight stimulant drugs (SPME tips and PFPA derivative; optimum conditions were applied) at a concentration of $1 \mu\text{g mL}^{-1}$ in a urine sample. (B) Chromatogram (SIM) for a blank urine sample.

Table 2 SIM fragmentation patterns (m/z) and relative ion intensities (ratio%) with the retention time (t_R). Quantification ions in bold. The remaining ions were used as qualifier ions with the ratio (%)

Target compounds	t_R	m/z	Ratio (%)	Target compounds	t_R	m/z	Ratio (%)
Amphetamine d11	8.422	194	100	4-Methylephedrine (mephedrone metabolite)	10.158	204	100
		128	72			119	13
		98	33			160	20
						308	3
Amphetamine	8.486	190	100	PMA	10.854	121	100
		118	79			148	42
		91	36			190	5
		65	9			311	7
Methamphetamine	9.505	204	100	Mephedrone	11.215	119	100
		160	31			204	25
		118	24			91	20
		91	14			160	14
Pentylone d5	16.339	193	100	MDMA	13.315	204	100
		235	86			162	73
		148	380			135	43
						339	12
Buphedrine (buphedrone metabolite)	9.770	218	100	Pentylone	16.442	149	100
		119	12			190	22
		308	3			232	19
		160	18			381	5



The extraction products can be optimised by altering the sample conditions.¹⁵ Therefore, several parameters of



Table 4 Method evaluation applied to SPME tip and SPE procedures for green analytical chemistry assessment. Both extraction procedures met the method validation parameters for similar compounds tested (quantification method)

Chemicals used/sample										
Method & criteria	Chemicals amount/ sample	NFBA health rating	NFBA flammability rating	NFBA reactivity rating	Energy rate ^a (kW h)	Waste rate ^b	Health rate ^c	Safety rate ^d	Environmental rate ^e	
SPME tips procedure used in this paper	● 100 μL of 10% NaOH	3	0	0	3	1	3	0 (F*)	1	
	● 0.5 g NaCl	1	0	0	● The time required for evaporation was roughly 5 min and the volume was 75 μL per sample. ● Agitation speed was 2000 rpm and total time was 70 min. ● GC-MS	The volume of waste per sample was 1.6 mL (urine and chemicals)				
	● 65 μL of MeOH	1	3	0						
	● 10 μL of acidified methanol (1 : 9)	3	0	0						
	● 50 μL of PFPA and EtOAc (2 : 1)	3 : 2	0 : 3	0 : 0						
	Total score	13	6	0	Total amount of chemicals used = 725 μL per sample					
	SPE procedure ¹⁶	● 4 mL of 0.10 M phosphate buffer – pH 6	1	0	0	3	1	3	0 (F)	1
● 1 mL of 100 mM acetic acid		3	2	0	● The time required for evaporation was (30–40 min) and the volume was 2.6 mL per sample. ● SPE vacuum was used for 5 min. ● Centrifuged for 10 min at 3000 rpm. ● GC-MS	The volume of waste per sample was 18 mL (urine and chemicals)				
● 5 mL of MeOH		1	3	0						
● 3 mL of DCM : IPA : NH ₄ OH (78 : 20 : 2)		2 : 2 : 3	1 : 3 : 0	0 : 0 : 0						
● 10 μL of acidified methanol (1 : 9)		3	0	0						
● 50 μL of PFPA and EtOAc (2 : 1)		3 : 2	0 : 3	0 : 0	The variation and uncertainty values may be very high					
Total score		20	12	0	Total amount of chemicals used = 13.6 mL per sample					
Overall	The total amount of chemicals consumed per sample using the SPME tip procedure decreased by approximately 95% compared to the total amount of chemicals consumed by SPE per sample				The method of SPME tips decreased the waste by 91% compared to the SPE procedure per sample		The method of SPME tips decreased the flammability compared to SPE by 50%		The above data obtained should be considered as estimation only	

^a Energy rating: 1 = wet chemistry and very little solvent in the evaporation step; 2 = GC and moderate solvent used in the evaporation step; 3 = GC-MS and high volume of solvent used in the evaporation step. ^b Waste rating: 1 = full waste per sample ≤50 g; 2 = full waste ≤250 g; 3 = full waste >250 g. ^c Health rating: NFPA (National Fire Protection Association) score is 0 or 1 = slightly toxic and irritant; NFPA 2 or 3 = moderately toxic and temporary incapacitation; NFPA = 4 serious injury and exposure. ^d Safety rating: NFPA score 0 or 1 = instability score, no special hazards, flammable; 2 or 3 = instability score, a special hazard is used, flammable; 4 = instability score, flammable. ^e Environmental rating: 1 = <50 g; 2 = ≥50 g and ≤250 g; 3 = >250 g. *Flammable.

experimental design were considered in the process of the method development (the pH of buffer, ionic strength, addition of salts, size of vials, analyte and derivatisation, type of solvent, solvent volume, extraction time, agitation speed in the extraction step, desorption time, agitation speed in the desorption step and matrix volume). The work was carried out to study three different fibre tips (C18, C18-SCX and PDMS/DVB) *via* method development processes. The stationary phase of PDMS/DVB fibre tips provided the maximum recovery (2–80%) compared to C18 (0.1–10%) and C18-SCX (0.1–10%). The recovery was calculated through all the method development parameter processes.

The results of the developed method are summarised in Table 3. In summary, the PDMS/DVB fibre tips proved to reach the maximum equilibrium in the reaction for all stimulant drugs tested. An example of pH buffering results and addition of salts is shown in Fig. 3.

Green analytical chemistry

The assessment of green analytical chemistry is complex and has several criteria and variations that need to be checked. In many cases it is difficult to meet the ideal green analytical methodology in the procedure, because method validation is difficult to achieve without the use of hazardous substances. In our procedure, we minimise the use of solvents, chemicals and reagents to meet the lowest effects or hazards with the consideration of the criteria of assessment and method validation.

The five criteria for the evaluation of green analytical chemistry are health, safety, environment, energy and waste. Based on the above criteria, we compared the SPME tip procedure with the SPE method¹⁶ in the stage of sample preparation only, *i.e.* when they were applied for ATSS and synthetic cathinone compounds. Both extraction methods have similar compounds that meet the requirements of method validation.^{17–19} The tool of assessment was recently discussed in a paper by Plotka-Wasyłka.²⁰ For the results and overall discussion see Table 4.

Method validation

The results for all obtained validation parameters were successful for the observed analytes.

The method was linear demonstrated by R^2 which was always higher than 0.992 in the range of the LLOQ (at least ≥ 100 ng mL⁻¹) for all compounds of interest.

The LODs ranged from 5 to 25 ng mL⁻¹ for all the drugs investigated.

The LLOQ ranged from 25 to 100 ng mL⁻¹ for all the substances tested.

Both the within and between run precision and accuracy were satisfactory with results in an acceptable range giving values lower than 15%.

No carryover was recognised for any of the stimulant analytes. No peak was observed from endogenous urine compounds in the blank for the interference study or from the 20 drugs tested in the selectivity study that affected the interpretation

Table 5 Linearity (R^2), LOD (ng mL⁻¹), LLOQ (ng mL⁻¹), accuracy and precision. The concentration of analytes was calculated in the unit of ng mL⁻¹

Compound name	(R^2)	LOD S/N	LLOQ S/N	Conc. of the analyte	Within-run		Between-run	
					RSD%	Bias%	RSD%	Bias%
Amphetamine	0.999	5	25	250	3.78%	1.17%	2.34%	1.33%
				750	6.3%	0.91%	2.20%	-0.93%
Methamphetamine	0.997	5	25	1500	2.61%	-0.66%	1.97%	-0.70%
				250	7.9%	-0.08%	3.40%	0.87%
				750	10%	2.77%	3.48%	1.34%
Buphedrine (buphedrone metabolite)	0.994	5	25	1500	8.7%	-0.30%	4.16%	-0.30%
				250	13%	6.2%	5.7%	6.5%
				750	7.9%	-1.82%	4.30%	-2.21%
4-Methylephedrine (mephedrone metabolite)	0.992	10	100	1500	9.7%	-2.30%	5.8%	-1.61%
				250	13%	2.95%	11%	2.17%
				750	9.9%	-4.16%	3.56%	-5.6%
				1500	12%	-5.4%	7.0%	-4.45%
PMA	0.997	5	25	250	13%	-0.34%	4.28%	0.03%
				750	9.8%	3.04%	1.65%	1.24%
Mephedrone	0.994	25	100	1500	8.3%	-1.56%	3.52%	-1.49%
				250	11%	6.6%	6.1%	5.8%
				750	13%	-3.72%	2.62%	-2.03%
MDMA	0.995	10	50	1500	15%	-6.9%	2.73%	-4.11%
				250	12%	-2.15%	6.3%	-0.57%
				750	12%	-1.10%	4.30%	-2.59%
Pentylone	0.999	5	25	1500	9.4%	-0.25%	5.6%	-0.01%
				250	5.8%	2.78%	5.5%	3.59%
				750	7.4%	-0.24%	2.20%	-2.34%
				1500	2.70%	-0.99%	1.35%	-1.30%



Serial & extraction method type	The average conc. for the validated method of SPE with $\pm$ SD	The average conc. for the new trends of SPME PDMS/DVB fibre tips with $\pm$ SD
Sample number 1	802 $\pm$ 32	806 $\pm$ 76
Sample number 2	1209 $\pm$ 47	1201 $\pm$ 98
Sample number 3	227 $\pm$ 30	285 $\pm$ 51

There are no conflicts to declare.

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