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Review: Applications of chromatography in forensic sciences

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Abstract
This article reviews the use of different Chromatography techniques in the forensic science; Chromatographic technique is very sensitive and selective. Different types of chromatography techniques used were Liquid chromatography -mass spectrometry, Gas chromatography–mass spectrometry, Thin layer chromatography, HPTLC in investigating criminal cases of which chemical warfare's, terrorist attacks, smugglers, drug abuse, alcoholics. This techniques are promising to detect even pictogram or very less, with selectivity and sensitivity.
Keywords: Forensic science, LC-MS, GC-MS, HPTLC

1. Introduction

Recent years have seen the development of powerful technologies that have provided forensic scientists with new analytical capabilities, unimaginable only a few years ago. The term "forensic science" covers those professions which are involved in the application of the social and physical sciences to the criminal justice system. Forensic science (often shortened to forensics) is the practical application of science to matters of the law. In criminal law, forensics science can help prove the guilt or innocence of the defendant. In civil actions, forensics can help resolve a broad spectrum of legal issues through the identification, analysis and evaluation of physical evidence. Forensic experts are required to explain the smallest details of the methods used, to substantiate the choice of the applied technique and to give their unbiased conclusions-all under the critical and often mistrustful gaze of the servants of the justice, as well as the general public and the media. The final result of the work of the forensic scientist exerts a direct influence on the fate of a given individual. This burden is a most important stimulus, and one which determines the way of thinking and acting in forensic sciences. Consequently, the methods applied in forensic laboratories should assure a very high level of reliability and must be subjected to extensive quality assurance and rigid quality control programs. The legal system is based on the belief that the legal process results in justice. This has come under some question in recent years. Of course, the forensic scientist cannot change scepticism and mistrust singlehandedly. He or she can, however, contribute to restoring faith in the judicial processes by using science and technology in the search for facts in civil, criminal and regulatory matters. The purpose of this article is to review some of the most recent applications of LC–MS (/MS) to forensic analysis with special focus on the following; trace analysis, the use of alternative specimens for monitoring drugs of abuse, systematic toxicological analysis and high-throughput analysis.

2. Liquid chromatography–mass spectrometry

Recent years have seen the development of powerful technologies that have provided forensic scientists with new analytical capabilities which were unimaginable only a few years ago. The ability of mass spectrometry (MS) to extract chemical fingerprints from microscopic levels of analyte is invaluable in this quest, enabling the legally defensible identification and quantification of a wide range of compounds. Gas chromatography (GC)–MS, liquid chromatography (LC)–MS, isotope ratio (IR)- MS and inductively coupled plasma (ICP)-MS have become routine tools to enable detection and characterization of minute quantities in what can often be very complex matrices. In the case of LC–MS, the last two decades have seen some significant developments and improvements in instrumentation design. Particularly noteworthy has been the introduction of robust, user-friendly interfaces such as those based on atmospheric pressure ionisation techniques, e.g. electrospray (ESI) and atmospheric pressure chemical ionisation (APCI). Consequently, many analysts and laboratories are finally at the point where they are considering the acquisition of LC–MS capabilities.

According to Willoughby *et al*. [1] LC–MS has progressed from the "innovators" stage through the "early adaptors", to the "early majority" stage and is now open to specialists from a variety of disciplines, especially for those applications where in volatile, labile and/or high molecular weight compounds are being analyzed.

3. Trace chemicals

3.1 Chemical warfare agents

Determining the use of chemical warfare agents (CWAs) in times of war or in acts of terrorism requires rapid and reliable methods. The sarin gas attacks by a Japanese cult in Matsumoto city (1994) and the Tokyo subway system (1995) represented the first cases in which a CWA was indiscriminately released against a civilian population [2]. The latter incident resulted in the deaths of 12 people and led over 5000 to seek medical attention. Nerve agents are extremely potent organophosphorus compounds that cause biological effects by irreversibly inhibiting

the enzyme acetylcholinesterase (AChE). To confirm exposure, biological samples, e.g. urine, can be analysed for the agents themselves, their metabolites or their degradation products. Nerve agents are rather volatile compounds, thus analysis by GC–MS might be considered the obvious choice. However, in an aqueous environment, these agents readily hydrolyse to produce alkyl alkylphosphonates (RMPAs); these in turn can be further hydrolysed to methyl phosphonate (MPA). LC–MS is increasingly being used for this low molecular weight, highly polar compounds whilst exploiting the benefits over GC–MS, of reduced sample handling and no requirement for derivatisation [3–5]. Hayes *et al*. [6] recently developed LC–tandem MS (LC–MS/MS) methods for the analysis of the short-lived metabolites of several CWAs including; sulfur mustard, sarin, soman, cyclohexyl methylphosphonofluridate (GF) and O-ethyl S-2-diisopropylamino ethyl methylphosphonothioate (VX) in urine. These methods were also used to determine the feasibility of using saliva as a complementary or alternative matrix to urine; this could be a particularly valuable approach to assess the exposure of young children, where collection of a urine sample on demand is often difficult. VX comprises a mixture of two enantiomers which demonstrate significant differences in the rate of AChE inhibition and overall toxicity. Thus, the ability to distinguish between them is desirable for toxicological studies and for the development of antidotes. Smith [7] has used normal-phase LC in conjunction with MS detection for this purpose. LC–MS has also been used to investigate the longer-lived metabolites. Several groups have used LC–MS to determine the metabolites of sulfur mustard, i.e. the lyase metabolites in urine samples from human casualties after sulphur mustard poisoning [8,9].

In the case of large-scale attacks, analysis of the environment and other materials may also be required. Hancock and D'Agostino have developed a LC–ESI-MS (/MS) procedure which allows the identification of a munitions grade sample of tabun, sarin, soman, GF and the nerve agent stimulant triethyl phosphate (TEP) on manmade fibres [10]. Although this technique uses only minimal sample preparation the same group have more recently experimented to omit sample preparation completely and to allow the direct analysis of TEP collected on solid-phase microextraction (SPME) fibres [11]. The biotoxin ricin originates from the seeds (castor beans) of the *Ricinus communis* plant and is extremely toxic (human LD50 estimated at 3–30g/kg by inhalation or ingestion, respectively) [12]. It has the unique position of being the only protein listed under the Chemical Weapons Convention and is of forensic interest due to its potential for terrorist use or as a homicide agent [13]. Due to the high molecular weight of this compound (66 kDa) absolute structural elucidation of the intact protein is not possible using nominal mass analysis. However, several groups have used a preliminary enzymatic digestion to convert the protein into intermediate molecular weight peptides followed by LC–MS (/MS) using a hybrid quadrupole time-of-flight (QTOF) instrument [12,14]. The methods were used to characterize purified ricin from several different varieties of R. communis and also from crude castor bean extracts.

3.2 Explosives

The analysis of trace levels of explosives is critical in crime scene forensic investigations, homeland security and environmental analysis. LC–MS is a well-established technique for explosives in associated complex matrices such as post-blast residues and in environmental samples such as soil and plant material extracts [15,16]. Although these compounds have a low vapour pressure they tend to be heat labile and can degrade at the high temperatures typically used in GC injectors. Thus, LC–MS is particularly well-suited to the analysis of these relatively polar molecules, heat labile compounds. Many of the methods rely on the formation of cluster or adduct ions for identification. Gapeev *et al*. [17] studied the formation of cluster ions of 1,3,5-trinitro- 1,3,5-triazacyclohexane (RDX), one of the most commonly used military explosives in both ESI and APCI. Results showed that in ESI, self-decomposition of RDX did not play a role in adduct formation; the adducts were produced from impurities present in the mobile phase at ppm levels. In contrast, with APCI, part of the RDX molecule decomposes yielding a NO_2^- species; this in turn clusters with other RDX molecules. More recently, Mathis and McCord presented a comprehensive method to allow the screening of a panel of high explosives including; RDX, 2,4,6,-trinitrotoluene (TNT), pentaerythritol tetranitrate (PETN), 1,3,5,7-tetramethylene-2,4,6,8-tetranitramine (HMX), nitrogycerine (NG) and ethylene glycol dinitrate (EGDN). This method was based on the competitive formation of adducts following infusion of the high explosives with a mixture of four anions; chloride, formate, acetate and nitrate. Information relating to the relative extent of adduct formation (based on intensity ratios) in addition to adduct stability, was used to provide a multiplexed detection scheme [18]. Anti-personnel (AP) mines are currently in place in over seventy countries and are designed to maim or kill humans. In addition to the lives that are lost, the mere suspicion that they may be present, can prevent the use of large areas which could otherwise be utilised for agriculture or social infrastructure. Removal of landmines from such areas is known as humanitarian de-mining and relies on the accurate detection of the explosive. A potentially useful approach and one which is currently under investigation, is the detection of the chemical vapours which arise from the explosives and are transported into the surrounding atmosphere. High sensitivity is required since the concentration of molecules expected to reach the gas phase is low. Sanchez *et al*. [19] have developed a method for the sampling and identification of nitroaromatic explosives. Air was sampled at flow rates of up to 15 L/min using a holder fitted with a C18 solid-phase extraction (SPE) membrane. After sampling, trapped analytes were desorbed on-line and analysed by LC–MS/MS using an APCI interface. Storage stability studies indicated that the captured analytes were stable for 1 week or 3 weeks, when membranes were stored at room temperature or at −4 ◦C, respectively. The method allowed the identification and separation of most of the isomers of TNT and 2,4-dinitrotoluene (DNT); limits of detection were in the range of femtogram/L. The method is suitable for the chemical profiling of militarygrade explosives and is valuable for both forensic identification and for de-mining purposes.

3.3 Drugs of abuse in alternative matrices

For the detection of illicit drugs, plasma and urine are currently the most common matrices investigated. However, over the past few years there has been an increased interest in the use of more convenient, less invasive specimens, e.g. hair, oral fluid and sweat, to document drug use and exposure [20,21]. Indeed in April 2004, the US Department of Health and Human Services proposed new guidelines for the use of these alternative specimens as an adjunct to urine, for the testing of employees in a number of situations including; pre-employment, random, reasonable cause and post-accident testing [22]. For these samples, collection is relatively easy to perform and requires no special equipment or facilities. Furthermore, collection can be supervised, thus reducing the opportunity for sample adulteration. One of the main disadvantages however, of using these alternatives is that the volume or amount of sample is usually limited, consequently highly sensitive confirmatory techniques such as LC–MS/MS become a necessity.

3.4 Hair

In addition to the convenience of sample collection, any drugs and metabolites incorporated into hair, tend to persist much longer than in conventional specimens. Recently, hair has been used to document drug exposure in a variety of scenarios such as forensic and workplace testing [28–30], to monitor compliance to drug therapy [23,24] and particularly for investigating cases of drug-facilitated crimes (DFC) [25–35]. The availability of standard reference materials for drugs of abuse in hair is vital and enables those laboratories performing hair analysis to check the accuracy of their methods [36]. Over the last few years DFC, e.g. sexual assault and robbery, have been increasing; these crimes are often difficult to prove due to factors such as the low concentrations of drugs used, or their rapid clearance from the body. In addition, many victims of DFC do not report an incident until several days later, often due to the amnesia caused by the drug. Hence, conventional specimens such as blood or urine may have limited value. Hair samples have been successfully used to document cases of DFC involving a variety of drugs including; benzodiazepines and the hypnotics (zolpidem and zopiclone), methadone and buprenorphine [25-35]. Kintz and co-workers concluded that due to

the extremely low concentrations of drugs typically encountered in hair analysis (low pg/mg) the "sensitivity of LC–MS/MS appears to be a pre-requisite to document any case involving drug-facilitated sexual assault". However, they also added the caveat that hair analysis should not simply be considered as an alternative to blood and urine testing but as a complementary technique where possible. The importance of this was revealed in a controlled study to investigate the window of detection for lorazepam in urine, oral fluid and hair [37]. Following a single (2.5 mg) dose, the drug could be still be detected in urine and oral fluid for 144 and 8 h, respectively, after dosing. However, they were unable to detect lorazepam in hair samples collected 4 weeks after administration. Cheze *et al*. [38] used LC–MS/MS to conduct a survey into the drugs most commonly used to commit DFC in Paris over the period from June 2003 to May 2004. Out of the total of 128 cases investigated, 18% were proven DFC cases and they found a high prevalence of zolpidem and clonazepam, followed by bromazepam, nordazepam and midazolam. Laloup *et al*. [39] recently reported a LC–MS/MS method for the simultaneous analysis of 26 benzodiazepines and metabolites, zolpidem and zopiclone in blood, urine and hair. The method was applied to authentic samples from both clinical and forensic cases, including the analysis of hair from a woman who claimed to have been drugged and sexually abused over a period of several years. Thirty-three centimetre lengths of hair were submitted for analysis and cut into 1–3 cm sections; all segments were found to be positive for more than one benzodiazepine, indicating multiple drug exposure, with higher concentrations closer to the root. These results demonstrated the utility of hair to provide a long-term drug history.

3.5 Oral fluid

The use of oral fluid as an alternative specimen is also increasing in popularity especially for monitoring recent drug use within the workplace, at the roadside, in prisons and to check compliance to medication. Concheiro *et al*. [26] developed a method for the quantification of the active constituent of cannabis, i.e. 9- tetrahydrocannabinol (9-THC) in oral fluid. Samples were collected by spitting into polypropylene tubes. Two hundred microlitres of sample was processed using liquid/liquid extraction (LLE) with hexane followed by analysis using LC–MS. Limits of detection of 2 g/L were achieved. Wood *et al*. [41] reported a validated method for the simultaneous analysis of six amphetamines in oral fluid (also collected by expectoration). The procedure required only 50 L of sample to achieve limits of detection of 2 g/L or better and comprised rapid and simple sample preparation, i.e. protein precipitation (PPT) using methanol followed by LC–MS/MS. Dams *et al*. [42] described a method for methadone and multiple illicit drugs in addition to their metabolites in oral fluid. Their method also involved PPT using acetonitrile followed by LC–MS/MS analysis. The method proved useful for determining methadone concentrations in pregnant opiate and/or cocaine addicts. Although the methods referenced above utilized oral fluid that has been collected by expectoration, it should be noted that the increased interest in oral fluid has also been accompanied by an increase in the availability of specialized collection devices; these promise a simplified, more controllable collection and sample stability. The final choice of oral fluid collection system, however, has been shown to have serious implications on drug analysis [43–45]. The Intercept is a US Food and Drugs Administration (FDA) approved sampling device that is used on a large scale in the USA for workplace drug testing and is one of the devices currently under investigation in a joint roadside study between the EU and the USA to detect driving under the influence of drugs [46]. The collection system contains additives which can cause problems, e.g. ion suppression during LC–MS/MS analysis in the absence of a suitable cleanup method. Several groups have employed LLE (with hexane) to prepare the so-called 'preserved oral fluid' specimen prior to analysis; drugs of interest have included 9-THC, benzodiazepines and hypnotics [47,48]. A SPE method has also been developed, which is combined with LC–MS/MS to allow the simultaneous determination of a panel of common basic illicit drugs [50]. Work is underway to extend the current panel of analytes to include 9-THC [49].

3.6 Gas chromatography–mass spectrometry

A sensitive method for the simultaneous quantification of quazepam and its metabolites (2-oxoquazepam and 3-hydroxy-2-oxoquazepam) in human urine was developed using an Rtx-5MS capillary column and GC/MS. [50].

Hair

Determination of methamphetamine and amphetamine in hair was performed by gas chromatography/mass spectrometry using stable isotope-labeled internal standards, 2-methylamino-1-phenylpropane-2,3,3,3-d4 and 2-amino-1-phenylpropane-2,3,3,3-d4. Extraction of hair with methanol/5M hydrochloric acid (20:1) using ultrasonication was chosen as the standard method. The calibration curves for amphetamines in the hair were linear from 1 to 100 ng/mg (r greater than 0.99). The detection limit was 0.5 ng/mg at the 95% confidence level. The coefficients of variation (CV) (n = 8) of analysis using the spiked hair with methamphetamine were from 0.7 to 6%. The CV (n = 8) of analysis of the methamphetamine abuser's hair was 17.5%. Sectional analysis of monkey and human hair after methamphetamine ingestion suggested a good correlation between the duration of drug use and drug distribution in the hair. [51].

Drugs-

A procedure is presented for the simultaneous identification and quantification of morphine (MOR), codeine (COD), ethylmorphine (EM), 6-monoacetylmorphine (6-MAM), cocaine (COC), benzoylecgonine (BZE), ecgonine methylester (EME) and cocaethylene (CE), contained in the hair of opiates and cocaine addicts. The method involves decontamination in dichloromethane, pulverization in a ball mill, heat-acid hydrolysis, addition of deuterated internal standards, liquid-liquid extraction and gas chromatography/mass spectrometry (GC/MS) after silylation. [52].

Thin layer chromatography-

The ink spot was extracted from the document using methanol and separated by TLC using plastic sheet silica gel 60 without fluorescent indicator, and a mixture of ethyl acetate, ethanol, and water (70:35:30, v/v/v) as mobile phase. To discriminate between different pen inks, new software was designed on the basis of intensity profile of red, green, and blue (RGB) characteristic. In practice, after development of chromatogram, the chromatograms were scanned by ordinary office scanner, intensity profiles of RGB characteristics on the development straight of each sample were produced and compared with the mentioned software. RGB profiles of ballpoint inks from various manufacturers showed that the patterns in most cases were distinctly different from each other. [53].

HPTLC-

A quality assurance process for analysing, digitally acquiring and storing the chemical profile of ink samples was proposed. This process aims at processing ink samples with improved objectivity, reliability and efficiency. It includes the use of standard ladders of dyes, which are eluted simultaneously with the ink samples, the digital capture of the ink samples using a TLC scanner, the calibration of ink samples using the dye ladder and the computerised storage of the ink dye profiles.

During this study, the benefits of the proposed process, in terms of the increased reproducibility of the analytical process, were demonstrated. It was observed that the use of a standard dye ladder contributes doubly to the quality assurance process of the forensic analysis of ink: During the analytical stage, the correct elution of HPTLC plates can be controlled by monitoring the elution of the standard ladders. The use of ladders allows for a more accurate calibration and comparison of ink samples analysed, which were analysed on separate HPTLC plates. [54].

Conclusion

By using various chromatographic techniques such as gas chromatography, thin layer chromatography, HPTLC and other techniques solve the forensic science problems. In forensic science, it's normally used for analysis of body fluids for the presence of illegal substances, testing of fibber and blood from a crime scene and to detect residue from explosives. Also chromatography is useful for hair analysis which is helpful for crime cases. Chromatography is used in forensics to match DNA or any other substance or compound. Detect alcohol levels in a patient's blood stream. It can be used in crime scene investigations. Also environmental agencies use to determine the level of pollutants in water supplies. So, chromatography plays an important role or as a most useful technique in forensic science

Reference

[1]. R.Willoughby, E. Sheehan, S. Mitrovich, A Global View of LC/MS, Global View Publications, Pittsburg, 1998.
[2]. White Paper on Police 1994 and 1995, National Police Agency, Government of Japan.
[3]. D. Noort, A.G. Hulst, D.H.J.M. Platenburg, M. Polhuijs, H.P. Benschop, Arch. Toxicol. 72 (1998) 671.
[4]. E.W.J. Hooijschuur, C.E. Kientz, U.A.Th. Brinkmann, J. Chromatogr. A 982 (2002) 177.
[5]. J.R. Smith, M.L. Shih, J. Appl. Toxicol. 21 (Suppl.) (2001) 27.
[6]. T.L. Hayes, D.V. Kenny, L. Hernon-Kenny, J. Med. Chem. Def. 2 (2004).
[7]. J.R. Smith, J. Anal. Toxicol. 28 (2004) 390.
[8]. R.W. Read, R.M. Black, J. Anal. Toxicol. 28 (2004) 346.
[9]. M.-L. Rapinoja, M.-L.Kuitunen, H. Bjork, K. Rosendahl, P.Vanninen, Presented at the 3rd Conference on Mass Spectrometry Applied to Chemical and Biological Warfare Agents, Noordwijkerhout, The Netherlands, 17–20 April 2005.
[10]. J.R. Hancock, P.A. D'Agostino, C.L. Chenier, Presented at the 3rd Conference on Mass Spectrometry Applied to Chemical and Biological Warfare Agents, Noordwijkerhout, The Netherlands, 17–20 April 2005.
[11]. J.R. Hancock, P.A. D'Agostino, C.L. Chenier, C.R. Jackson Lapage, Presented at the 3rd Conference on Mass Spectrometry Applied to Chemical and BiologicalWarfare Agents, Noordwijkerhout, The Netherlands, 17–20 April 2005.
[12]. S.-A. Fredriksson, A.G. Hulst, E. Artursson, A.L. DeJong, C. Nilsson, B.L.M. Van Baar, Anal. Chem. 77 (2005) 1545.
[13]. Definition of Chemical Weapons on the website of the Organisation for the Prohibition of Chemical Weapons, http://www.opcw.org/, accessed 29 March 2006.
[14]. Y. Seto, M. Kanamori-Kataoka, J. Health Sci. 51 (2005) 519.
[15]. J. Yinon, J.E. McClellan, R.A. Yost, Rapid Commun. Mass Spectrom. 11 (1997) 1961.
[16]. R.Q. Thompson, D.D. Fetterolf, M.L. Miller, R.F.Mothershead II, J. Forensic Sci. 44 (1999) 795.
[17]. A. Gapeev, M. Sigman, J. Yinon, Rapid Commun. Mass Spectrom. 17 (2003) 943.
[18]. J.A. Mathis, B.R. McCord, Rapid Commun. Mass Spectrom. 19 (2005) 99.
[19]. C. Sanchez, H. Carlsson, A. Colmsjo, C. Crescenzi, R. Batlle, Anal. Chem. 75 (2003) 4639.
[20]. P. Kintz, N. Samyn, in: M. Bogusz (Ed.), Handbook of Analytical Separation, Forensic Science, Elsevier, Amsterdam, 2000.
[21]. Y.H. Caplan, B.A. Goldberger, J. Anal. Toxicol. 25 (2001) 396.
[22]. Department of Health and Human Services, Substance Abuse and Mental Health Administration, Proposed revisions to Mandatory Guidelines for Federal Workplace drug testing programs, Federal Register Part III, 69, No. 71, 13 April 2004, pp. 19673–19677.
[23]. T. Kelly, P. Doble, M. Dawson, J. Chromatogr. B 814 (2005) 315.
[24]. B.K. Charles, J.E. Day, D.E. Rollins, D. Andrenyak, W. Ling, D.G. Wilkins, J. Anal. Toxicol. 27 (2003) 412.
[25]. M. Villain, M. Concheiro, V. Cirimele, P. Kintz, J. Chromatogr. B 825 (2005) 72.
[26]. M. Concheiro, M. Villain, S. Bouchet, B. Ludes, M. Lopez-Rivadulla, P. Kintz, Ther. Drug Monitor. 27 (2005) 565.
[27]. P. Kintz, M. Villain, V. Dumestre-Toulet, B. Ludes, J. Clin. Forensic Med.1 (2005) 36.
[28]. R. Kronstrand, I. Nystrom, J. Strandberg, H. Druid, Forensic Sci. Int. 145 (2004) 183.
[29]. K.B. Scheidweiler, M.A. Huestis, Anal. Chem. 76 (2004) 4358.
[30]. T. Cairns, V. Hill, M. Schaffer, W. Thistle, Forensic Sci. Int. 145 (2004) 137.
[31]. M. Villain, M. Cheze, A. Tracqui, B. Ludes, P. Kintz, Forensic Sci. Int. 145 (2004) 117.
[32]. P. Kintz, M. Villain, M. Cheze, G. Pepin, Forensic Sci. Int. 153 (2005) 222.
[33]. M. Villain, M. Cheze, V. Dumestre, B. Ludes, P. Kintz, J. Anal. Toxicol. 28 (2004) 516.
[34]. P. Kintz, M. Villain, V. Cirimele, G. Pepin, B. Ludes, Forensic Sci. Int. 145 (2004) 131.
[35]. P. Kintz, M. Villain, V. Dumestre-Toulet, B. Capolaghi, V. Cirimele, Ther. Drug Monitor. 27 (2005) 741.
[36]. P. Kintz, M. Villain, A. Traqui, V. Cirimele, B. Ludes, J. Anal. Toxicol. 27
[37]. M. Cheze, G. Duffort, M. Deveaux, G. Pepin, Forensic Sci. Int. 153 (2005) 3.
[38]. M. Laloup, M. Ramirez Fernandez, G. De Boeck, M. Wood, V. Maes, N. Samyn, J. Anal. Toxicol. 29 (2005) 616.
[39]. M.J.Welch, L.T. Sniegoski, S. Tai, Anal. Bioanal. Chem. 376 (2003) 1205.
[40]. M.Wood, G. De Boeck, N. Samyn, M. Morris, D.P. Cooper, R.A.A. Maes, E.A. de Bruijn, J. Anal. Toxicol. 27 (2002) 78.
[41]. R. Dams, C.M. Murphy, R.E. Choo, W. Lambert, A.P. De Leenheer, M.A. Huestis, Anal. Chem. 75 (2003) 798.
[42]. N. Samyn, G. De Boeck, A. Verstraete, J. Forensic Sci. 47 (2002) 1380.
[43]. H. Teixeira, P. Proenca, A. Verstraete, F. Corte-Real, D.N. Vieira, Forensic Sci. Int. 150 (2005) 205.
[44]. M. Wood, M. Laloup, M. Ramirez Fernandez, K.M. Jenkins, M.S. Young, J.G. Ramaekers, G. De Boeck, N. Samyn, Forensic Sci. Int. 150 (2004) 227.
[45]. A.G. Verstraete, Forensic Sci. Int. 150 (2005) 143.
[46]. M. Laloup, M. Ramirez Fernandez, M. Wood, G. De Boeck, C. Henquet, V. Maes, N. Samyn, J. Chromatogr. A 1082 (2005) 15.
[47]. P. Kintz, M. Villain, M. Concheiro, V. Cirimele, Forensic Sci. Int. 150 (2005) 213.
[48]. M. Wood, M. Laloup, G. De Boeck, Personal communication, September 2005.
[49]. M. Terada, T. Shinozuka, C. Hasegawa, E. Tanaka, M. Hayashida ,Y. Ohno, K. Kurosaki Forensic Sci. Int. 227 (2013) 95–99
[50]. Y Nakahara, K Takahashi, M Shimamine , Y Takeda, Journal of Forensic Sciences 36(1) (1991), 70-78.
[51]. P. Kintz, P. Mangin, Forensic Sci. Int. (73) 2, 1995, 93–100.
[52]. D. Djozan, T. Baheri, G. Karimian, M. Shahidi, Forensic Sci. Int. 179 (2008) 199–205.
[53]. C. Neumann, P. Margot Forensic Sci. Int. 185 (2009) 29–37.