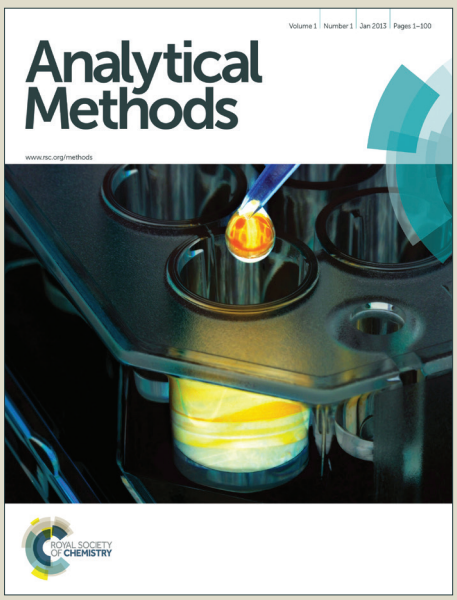
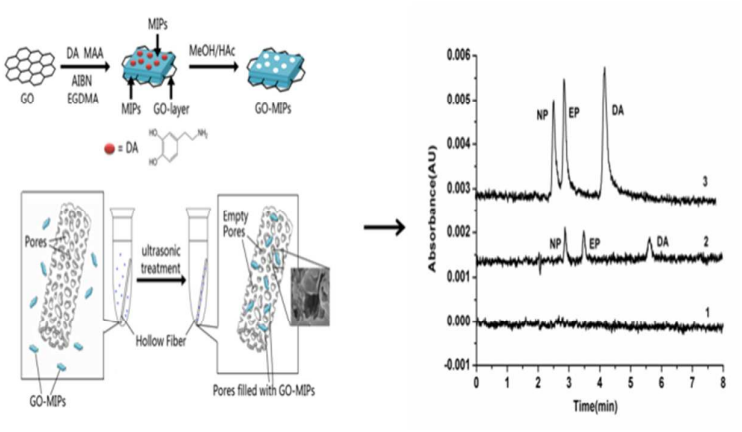
Analytical Methods

Accepted Manuscript



ROYAL SOCIETY OF CHEMISTRY

www.rsc.org/methods



A novel solid phase microextraction method with selectivity: Hollow fiber supported graphene oxide-molecularly imprinted polymers for determination of dopamine by HPLC-PDA

Hollow fiber-supported graphene oxide molecularly imprinted polymers for the determination of dopamine using HPLC-PDA

Nengsheng Ye*[,a], Ting Gao [a], Jian Li [a]

Abstract: Molecularly imprinted polymers (MIPs) of dopamine (DA) were constructed on the surface of graphene oxide (GO), and attached inside the pores of hollow fibers (HF) for the solid-phase microextraction (SPME) of DA. Scanning electron microscopy, thermo gravimetric analysis and Raman spectroscopy indicated that GO-MIPs composites were successfully synthesized and modified in the pores of HF via ultrasonication. Compared with common HF and HF modified with non-imprinted polymers (GO-NIPs/HF) using the same SPME procedures, the GO-MIPs/HF composite showed the best efficiency for the extraction of DA. The selectivity of GO-MIPs/HF was investigated based on the selectivity factor (*F*) using epinephrine and norepinephrine as the structural analogues of DA. The linear range of dopamine was 1.05×10^{-3}-5.27×10^{-3} μmol/mL using this process with a detection limit of 2.64×10^{-4} μmol/mL. The extraction procedure based on GO-MIPs/HF was successfully used for the determination of DA in human serum and its hydrochloride injection, showing average recoveries of 83-96%. GO-MIPs/HF was a good carrier for the selective adsorption of DA, and shows promise for the preconcentration of DA in real samples.

1 Introduction

Since their discovery in 2004, graphene and graphene-based materials have received tremendous attention because of their unique nanostructures and extraordinary properties, such as their large surface areas and good conductivities. These properties make graphene-based materials promising candidates for applications in biochemical and chemical sensing, [1, 2] sample preparation [3-5] and biomedical applications. [6-8] Because of their large surface areas, graphene and graphene-based materials provide ideal platforms for sample pretreatment via solid-phase extraction (SPE) and solid-phase microextraction (SPME). [4, 5] Despite their outstanding efficiency for the enrichment and cleanup of targets, graphene-based materials show low selectivity for the extraction of target analytes. To overcome this disadvantage, functional graphene-based composites have been designed using molecular imprinting techniques.

Molecular imprinting is a promising method for the preparation of extraction materials (termed molecularly imprinted polymers, MIPs) with high selectivity. The synthesis of MIPs involves the formation of a complex of a target molecule with functional monomers using covalent or non-covalent interactions, followed by a polymerization reaction with a cross-linking agent. Then the imprinted molecules are removed from the polymer. The advantages of MIPs, including stability, ease of preparation, and low cost, have resulted in wide use in chemical sensor and sample preparation.[9-13] Recently, a novel molecular imprinting technique on the surface of nanomaterial was applied for the preparation of

surface MIPs with favorable selectivity. For example, surface MIPs were synthesized on the surface of carbon nanotubes (CNTs) [14-18] and graphene, [19-27] and most of these composites were utilized to detect the target analytes. A novel composite of SiO_2-coated graphene oxide and molecularly imprinted polymers was synthesized for the electrochemical sensing of dopamine by Zeng *et al*..[19] However, only a few studies concern sample pretreatment using MIPs based on graphene oxide (GO).

Although graphene-based MIPs have a higher selectivity than traditional MIPs, some interference remains when studying large molecules in biological samples even though MIPs were designed using small molecules as the template. Based on liquid-phase microextraction using hollow fiber membranes (HF-LPME) for sample preparation, [28] the large molecules are prevented from entering the small pores of the fibers. To improve the extraction efficiency of HF-LPME, CNTs and graphene-reinforced hollow fiber microporous membrane liquid phase microextraction have been used. [29-31]

Herein, we proposed a novel imprinting route based on GO to prepare GO-MIP composites, which were attached to HF using ultrasonication. Dopamine (DA), an important neurotransmitter, was used as the template molecule in this work. This GO-MIPs/HF composite was used as the sorbent in SPME for the extraction of DA from real samples with satisfactory selectivity, and was analyzed using HPLC method.

2 Experimental

2.1 Reagents and material

Dopamine (DA), norepinephrine (NP), epinephrine (EP), ethylene glycol dimethacrylate (EGDMA) and methacrylic acid (MAA) were obtained from Sigma-Aldrich (Shanghai, China). Graphene oxide (GO) was purchased from XFNano Materials Tech. Co., Ltd. (Nanjing, China). *2, 2*-Azobisisobutyronitrile (AIBN) was supplied by Aladdin Reagent Co., Ltd. (Shanghai, China). Methylbenzene (MB), *N, N*-dimethyl formamide (DMF), acetic acid and acetone were purchased from Beijing Chemical Plant (Beijing, China). Chromatographic grade methanol was purchased from Merck Co. (Darmstadt, Germany). Accurel Q3/2 Polypropylene hollow fiber membranes (200-μm wall thickness, 600-μm i.d., 0.2-μm average pore size) were provided by Membrane (Wuppertal, Germany). Deionized water (18.2 MΩ) was purified using a Milli-Q system (Billerica, USA). All other reagents were of analytical grade and used without further purification. All solutions were filtered through 0.22 μm pore size filters (Tianjin, China).

The dopamine hydrochloride injections used in this work were purchased from a local drug store, and stored at 4 °C. Blood samples were collected from healthy volunteers in the morning. Three milliliters of blood was allowed to clot at room temperature for at least 1 hour, and then centrifuged (4,000 rpm) for 20 min at 4 °C. Then, the serum was collected, aliquoted, and stored at -80 °C until further processing.

2.2 Instrument

All separations were performed on a high performance liquid chromatography (HPLC, Waters 2695, Waters Technologies, USA) with a photodiode array detector (PDA, Waters 2998, Waters Technologies, USA) and the detection wavelength was set to 280 nm. An RP 18 column (5 μm, 150 mm × 4.6 mm i.d.) was used for the separation column. The data were acquired using Empower software (Waters Technologies, USA). The HPLC-PDA assay was performed using an 8-min isocratic elution with a flow rate of 0.8 mL/min. The volume of each injection was 5.0 μL. The mobile phase consisted of 100 mM of ammonium acetate (pH 5.0), acetonitrile and water (10:2:88). The mobile phase was filtered through a 0.22-μm pore size filter and degassed for 30 min before use.

Scanning electron microscope (SEM) images were taken using an S-4800 field scanning electron microscope (Hitachi, Japan) operating at 15 kV. Raman spectra were collected using a Raman spectrometer (Renishaw, UK) with a 633-nm excitation wavelength. Thermo gravimetric analysis (TGA) was conducted on an HCT-1 instrument (Beijing Henven Scientific Instrument Factory, Beijing) from room temperature to 800 $^{\circ}$C with a heating rate of 10 $^{\circ}$C/min under nitrogen flow.

2.3 Preparation of stock solutions and real samples

Stock solutions of DA, NP and EP were prepared in water and stored at 4 °C until use. All working solutions of different concentrations were freshly prepared through appropriate dilution of the stock solution with deionized water. The dopamine hydrochloride injections were filtered through a 0.22-μm pore filter before use, without any other pretreatment.

The frozen serum samples were defrosted on ice and centrifuged (10, 000 rpm) for 2 min at 4 °C. Then, 0.5 mL of ACN was added to the serum (100 μL) to precipitate the proteins. The sample solution was centrifuged for 5 min to remove the precipitates. The supernatant of the serum sample was purged with N_2 until dryness. The analytes in the residuals were redissolved in 1.5 mL of deionized water via ultrasonication for 10 min. After filtration through a 0.22-μm membrane filter, the sample solution was used for SPME.

2.4 Synthesis of GO-MIPs

First, 0.038 g of DA (template molecule) was added to a solution of 8.0 mL of DMF, 2.0 mL of MB and 0.17 mL of MAA. This mixture was ultrsonicated for 1 hrs. Then, 25 mL of a GO dispersion (4 mg/mL), 0.06 g of AIBN, and 0.38 mL of EGDMA were added to the mixture followed by ultrasonication for 15 min. Next, the temperature was held at 65 °C for 24 hrs to allow polymerization.

Polymerization occurred via non-covalent binding, such as π-π stacking. There was effective charge transfer between the monomers-template and graphene oxide, which agreed with the Raman spectral analysis. [21] Next, the composites were collected via centrifugation and washed twice with methanol to remove residual impurities. The imprinted template of DA was removed from the polymers using methanol and acetic acid (9:1, v/v) until no DA was detected in the eluent. Afterwards, the MIPs were dried under nitrogen gas. Non-imprinted polymers (NIPs) were synthesized using the same procedure without adding DA as the template during the polymerization process.

2.5 Procedure for GO-MIPs/HF preparation

A schematic diagram of the preparation of GO-MIPs/HF is shown in **Fig. 1**. Polypropylene HF was cut into 2-cm segments, and these segments were ultrasonicated in an acetone solution for 3 min to remove any contaminants from the fiber segments. Next, the HF segments were removed from the acetone solution, and the remaining acetone was allowed to completely evaporated. Each segment was then immersed into 0.60 mL of GO-MIPs dispersion (2 mg/mL in DMF) and ultrasonicated for 2 hrs. After ultrasonication, the segments were washed for three times with water to remove the excess composites. GO-NIPs/HF was prepared using GO-NIP composites using the same procedure as that for the GO-MIPs/HF.

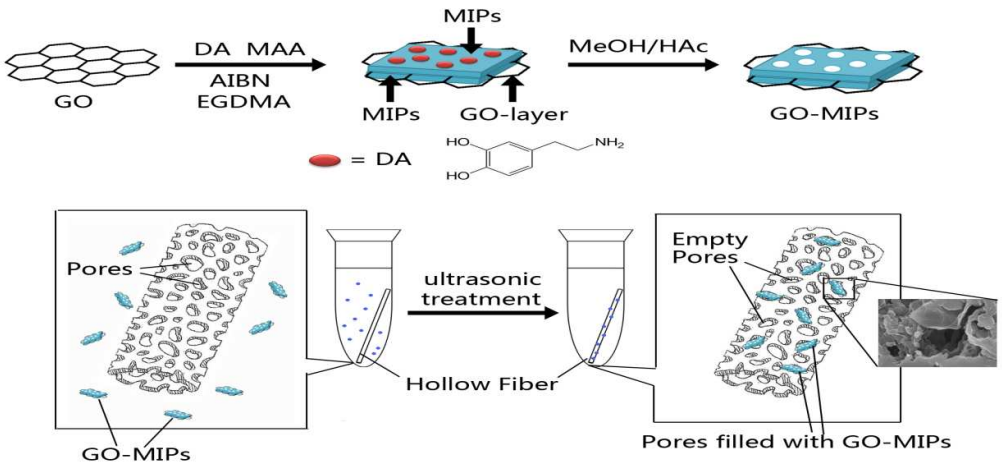


Fig. 1 A schematic illustration of the preparation of GO-MIPs/HF and the SEM image of GO-MIPs/HF (×10 000).

2.6 Solid-phase microextraction

The extraction and preconcentration procedures for the target analytes were as follows: 1.5 mL of a DA solution or pretreated sample solution was placed into a centrifuge tube, and a GO-MIPs/HF sample was then immersed in the solution. The solution was vortexed for 20 min on a rotator with a speed of 1,000 rpm. After extraction, the GO-MIPs/HF was removed and analytes were desorbed using 50 μL of a mixture methanol and acetic acid (9:1, v/v).

3 Results and discussion

3.1 Characterization of the GO/MIPs and GO/MIPs-HF

The SEM images of the GO, GO-NIPs and GO-MIPs are shown in **Fig. 2a-2c**. The GO sheets showed thin, wrinkled, smooth surfaces and layered structures (**Fig. 2a**) which are typical characteristics of GO. After polymerization, the surface of the GO-NIPs and GO-MIPs became rough and cross-linked, and new shapes appeared. Compared with the GO-NIP composites, GO-MIP composites showed a high degree of cross-linking because the target molecules provided sites for the polymerization. These results indicated that the GO-MIPs were successfully synthesized. The SEM image in **Fig. 1** shows that a number of holes on the wall of HF were filled with GO-MIP composites.

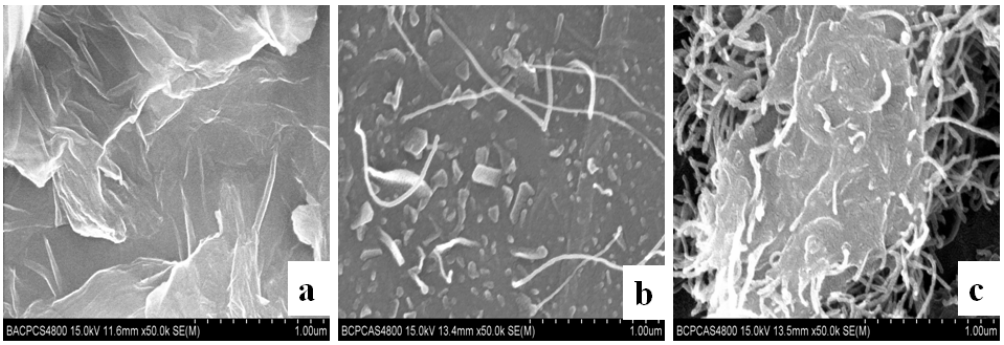


Fig. 2 SEM images of GO (a), GO-NIPs (b), GO-MIPs (c). Conditions: acceleration voltage, 15 kV; magnification, ×50 000.

Fig. 3a shows TGA weight loss curves for the GO and GO-MIPs, respectively. As shown in **Fig. 3a**, GO was not thermally stable. The weight of the GO declined

sharply between 100 ℃ and 200 ℃ due to the removal of functional groups (-OH and –COOH). [32] After the polymerization reaction, the MIP composites appeared to be effective at enhancing the thermal stability of GO sheets. A weight loss of 30% was observed between 550 ˚C and 700 ˚C, which might be due to decomposition of the polymer. [22] Based on the difference in thermal stability between GO and GO-MIPs, the TGA measurements indicated that the MIPs were successfully adhered onto the GO surface.

Raman spectroscopy is one of the most widely used techniques to characterize the structures and electronic states of carbon materials, including CNTs, graphene and GO. The Raman spectra of the GO, GO-NIPs, GO-MIPs, HF and GO-MIPs/HF are shown in **Fig. 3b**. The D band and G band represent disordered sp^3 carbon and ordered sp^2 crystalline graphite-like structures, respectively. [21] The Raman shifts of the GO-NIPs and GO-MIPs were different from the Raman shifts of GO due to the charge transfer between the GO and the other components in the GO-MIPs and GO-NIPs. The $I_{(D)}/I_{(G)}$ ratios of the GO-NIPs and GO-MIPs were higher than GO (0.906), which indicated increased disorder in the composites due to the polymer coating on the surface of GO, which resulted in increased disorder in the polymeric compounds [33]. Meanwhile, the peak intensities of the GO-NIPs were lower than the peak intensities of the GO-MIPs, possibly because a greater number of carbon atoms participated in the polymerization during the synthesis of the GO-MIPs. The HF exhibited no absorption peaks near the Raman shift of the GO-MIPs, while the G band and D band appeared in the GO-MIPs/HF spectra after decoration. The Raman

spectra indicated that the GO-MIPs composites were synthesized and combined with HF.

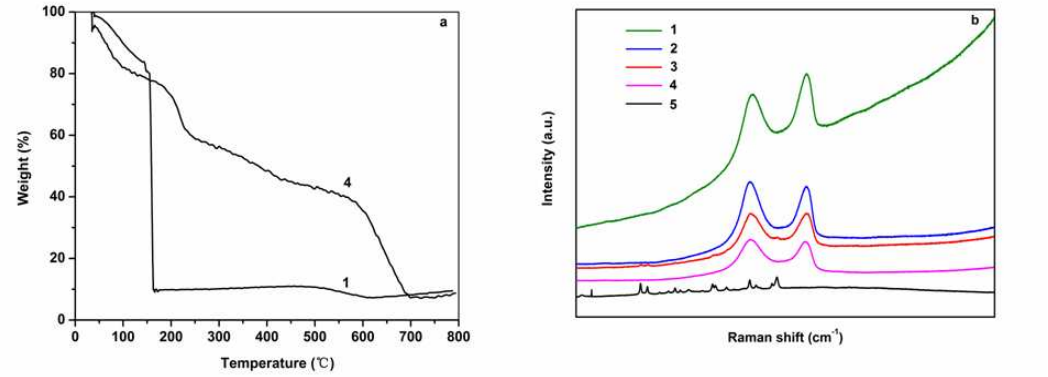


Fig. 3 The TGA curves and Raman spectra of the following compounds. (1) GO (D band: 1346, G band: 1601); (2) GO-NIPs (D band: 1335, G band: 1599); (3) GO-MIPs/HF (D band: 1331, G band: 1601); (4) GO-MIPs (D band: 1331, G band: 1594); (5) HF.

3.2 Optimization of SPME conditions

In the SPME method, maximum extraction of analytes is achieved at equilibrium. To obtain the highest extraction efficiency of DA, the extraction times from 10 to 60 min were investigated with a desorption time of 30 min. As shown in **Fig. 4a**, the peak areas of the target analytes increased from 10 to 20 min, While the peak areas decreased after 20 min. This phenomenon might result from analyte loss caused by the prolonged extraction time which would be disadvantageous for the contact between the analyte and the MIPs. Therefore, 20 min was selected as the optimal extraction time for the GO-MIPs/HF SPME method.

In this work, the extracted compounds were desorbed from the GO-MIPs/HF using 50 μL of methanol and acetic acid (9:1, v/v) and vortexing; the desorption time exerted a significant influence on the signal intensity of the extracted analytes. The effect of desorption times from 10-60 min on GO-MIPs/HF SPME was investigated, and the highest peak area of DA was achieved at 30 min (as shown in **Fig. 4b**). The desorption was incomplete when a shorter desorption time was used, and the peak area of DA decreased when the desorption was performed for longer than 30 min, which may have resulted because the desorbed analytes could be reabsorbed by the GO-MIPs/HF. Therefore, 30 min was chosen as the desorption time for the SPME method.

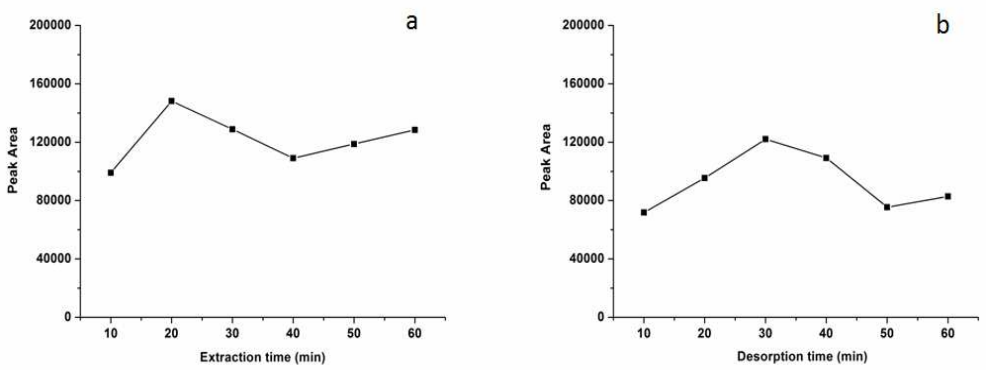


Fig. 4 Effect of extraction time (a) and desorption time (b).

3.3 Comparison between GO-MIPs/HF and HF on the extraction of DA, NP and EP

In this work, the unmodified HF was used to extract a mixed solution using the same procedure as the GO-MIPs/HF SPME, and the results are shown in **Fig.5**. As shown in the figure, the three target analytes (DA: 5.27×10^{-3} μmol/mL;

NP: 4.86×10^{-3} μmol/mL; EP: 4.55×10^{-3} μmol/mL) were slightly, but clearly, detected without any preparation (curve 2), but cannot be detected using the unmodified HF and the proposed SPME procedure (curve 1). After the GO-MIPs/HF SPME procedures, the peak area increased apparently and the GO-MIPs exhibited its advantages in the extraction process (curve 3). Compared with the unmodified HF, the presence of GO-MIPs composites increased the π-π interactions between the benzene rings of the analyte and the ring structures in the graphene oxide, which provided the specific adsorption sites for the cavities.

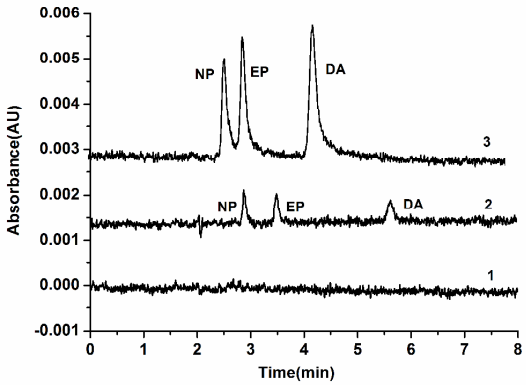


Fig. 5 Chromatograms of a mixed solution of DA, NP and EP without any pretreatment (2), treated with unmodified HF (1), and treated with GO-MIPs/HF (3).

3.4 Selectivity of GO-MIPs/HF

To evaluate the selectivity of GO-MIPs/HF towards the target molecule DA. NP and EP (DA: 5.27×10^{-3}μmol/mL; NP: 4.86×10^{-3} μmol/mL; EP: 4.55×10^{-3} μmol/mL) were chosen for the comparison due to their activities, structural

similarities and the coexistence with DA in real samples. The selectivity was calculated using the selectivity factor (*F*):

$$F = \frac{A_M}{A_N}$$

where A_M and A_N are the peak areas using GO-MIPs/HF treatment and GO-NIPs/HF treatments, respectively. Of three batches, GO-MIPs/HF exhibited the highest *F* for DA with an average value of 4.87 with RSD 6.2% (*n*=3), whereas the average *F* values of EP and NP were 1.42 (RSD11.4%, *n*=3) and 1.99 (RSD5.3%, *n*=3), respectively. For the comparison of selectivity of GO-MIPs/HF on these analytes, *t*-test on the selectivity factors was investigated. Between DA and NP with the confidence level at 90%, the value of *t* was 15.28, which was higher than 2.13 ($t_{0.10,\,4}$ of the standard values). So the selectivity between NP and EP had a significant difference. Between NP and EP with the confidence lever at 90%, the value of *t* was 0.70, which was lower than 2.13 ($t_{0.10,\,4}$ of the standard values). So the selectivity values between NP and EP had no significant difference. It meant that GO-MIPs/HF had showed a stable adsorption and an greater binding capacity for DA. This increased capacity maybe attributable to the perfect fit of the shapes of the cavities in the polymers for the unique molecular structure of DA. Thus, EP and NP cannot be adsorbed into the imprinted cavities via specific binding. Therefore, the GO-MIPs/HF showed good selectivity for the template molecule and its analogues.

3.5 Evaluation of analytical performance

Certain performance parameters including the relative standard deviations (RSDs), linearity, limit of detection (LOD) and limit of quantification (LOQ) were evaluated for the extraction of DA under the optimum extraction conditions. The precision of the developed method was assessed by performing intra-day and inter-day assays. The intra-day precision was measured for six parallel procedures in one day and the RSD of the peak area was 3.2%. The inter-day precision was calculated on three consecutive days and showed an RSD of 4.3%. These data indicated that the proposed method was stable for the extraction of DA. The LOD of DA was 2.64×10^{-4} μmol/mL, and the LOQ was 1.05×10^{-3} μmol/mL. Calibration standard solutions in the range of 1.05×10^{-3}-5.27×10^{-3} μmol/mL were extracted using the GO-MIPs/HF and GO-NIPs/HF SPME methods and analyzed using HPLC. The GO-MIPs composites have a better adsorption than GO-NIPs composites. According the results of GO-MIPs/HF SPME, The linear regression equation for DA was $y=2.59\times10^{7}x+3478$ with a correlation coefficient of 0.998. As shown in **Fig. 6**, as the concentrations increase beyond the linear range, the peak areas rise slowly. The material has clearly achieved saturation.

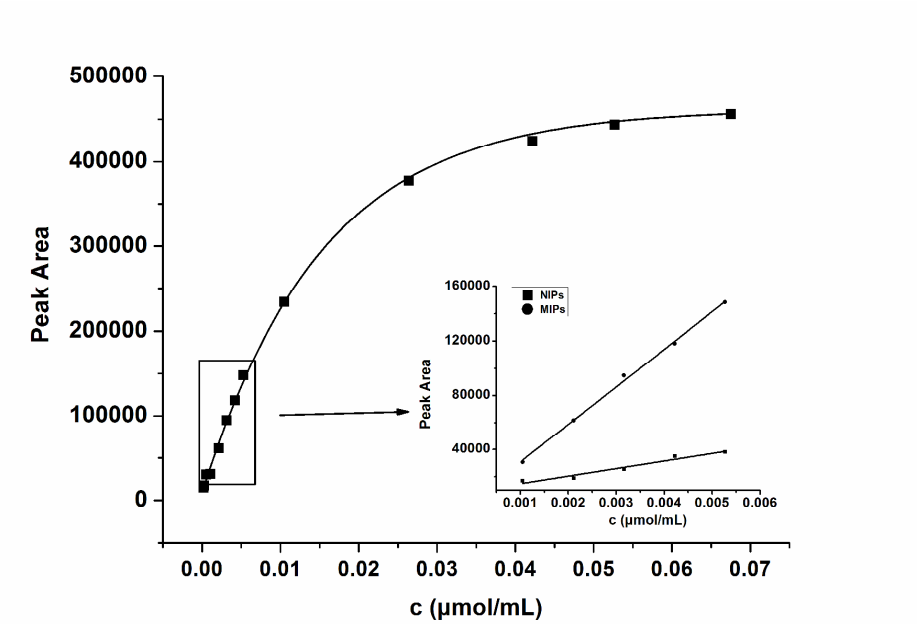


Fig. 6 Peak areas of different concentrations of DA and the linearity curve (inset).

3.6 Real samples

Real samples were analyzed using the standard addition method. To fit into the linear ranges, the DA standard solutions with different concentration levels (1.32×10^{-3} μmol/mL, 2.64×10^{-3} μmol/mL and 3.96×10^{-3}μmol/mL) were added into the serum and the DA hydrochloride injection. The results of the recovery test were shown in **Table 1** and **Table 2**. As shown in the **Table 1-2**, the recovery of the added DA had the potential to be quantitative and ranged between 83%-96%. The RSD values were 4.4%-5.9% for serum samples and 5.4%-7.7% for DA hydrochloride injection, respectively.

Table 1 Recovery results of DA in serum samples by using the SPME method with GO-MIPs/HF (n=5).

Sample No.	Found (μmol/mL)	Spiked (μmol/mL)	Total Found (μmol/mL)※	Recovery	RSD
1	-	1.32×10^{-3}	$(1.19\pm0.12)\times10^{-3}$	90%	5.9%
2	-	2.64×10^{-3}	$(2.20\pm0.16)\times10^{-3}$	83 %	4.4%
3	-	3.96×10^{-3}	$(3.55\pm0.32)\times10^{-3}$	89 %	5.5%

※Average±1.68×standard deviation with the confidence level at 90%

Table 2 Recovery results of DA in DA hydrochloride injection by using the SPME method with GO-MIPs/HF (n=5).

Sample No.	Found (μmol/mL)※	Spiked (μmol/mL)	Total Found (μmol/mL)※	Recovery	RSD
1	$(1.38\pm0.07)\times10^{-3}$	1.32×10^{-3}	$(2.65\pm0.20)\times10^{-3}$	96%	7.7%
2	$(1.35\pm0.08)\times10^{-3}$	2.64×10^{-3}	$(3.88\pm0.22)\times10^{-3}$	96%	5.4%
3	$(1.32\pm0.12)\times10^{-3}$	3.96×10^{-3}	$(5.01\pm0.39)\times10^{-3}$	93%	6.7%

※Average±1.68×standard deviation with the confidence level at 90%

3.7 Comparison of the proposed method with previous reports

As compared with the liquid-phase microextraction with hollow fiber,[34] the procedure based GO-MIPs/HF SPME was simple and eco-friendly without 1-octanol and the required equipment was inexpensive. Compared with

graphene reinforced hollow fiber liquid-phase microextraction,[31] the proposed GO-MIPs/HF SPME method showed satisfactory selectivity in the presence of coexist substances. The LOD, RSD and recoveries of the GO-MIPs/HF SPME method were comparable with imprinted electrochemical sensor for dopamine. [14, 15, 19] What's more, the proposed method showed better selectivity results than the electrochemical sensor. The developed SPME method was suitable for complex matrix samples without additional clean-up processes. These results show that the GO-MIPs/HF method is a sensitive, rapid and easy to handle technique for the pretreatment of target analyte from complex samples.

4 Conclusions

Composites of GO-MIPs were successfully synthesized for DA extraction using a novel imprinting route and an SPME method based on GO-MIPs/HF combined with HPLC was developed for the determination of DA in real samples. The proposed method shows a good selectivity for the extraction and enrichment of DA from real samples because of the combination of large surface area of graphene oxide, selectivity of MIPs and blocking interference of biomacromolecular by hollow fiber. Under the optimized conditions, this method demonstrated a low LOD and satisfactory repeatability. However, it also exhibited certain disadvantages, such as a narrow linear range, because the material reached maximum adsorption. The presence of GO-MIPs on the hollow fiber wall increased the effective surface area and the proposed method

may be a powerful and promising sample preparation technique for catecholamines in drugs and biological matrices.

Acknowledgements

The work was supported by the National Natural Science Foundation of China (No.21005050) and the Beijing Natural Science Foundation (No. 2133061).

All experiments were performed in compliance with relevant laws.

The authors declare that there are no conflicts of interest.

Notes and references

a. Department of Chemistry, Capital Normal University, Beijing, 100048, P.R. China; Tel: +8610 68902490; E-mail address: yensh@cnu.edu.cn.

References

1. S. Wu, Q. He, C. Tan, Y. Wang and H. Zhang, *Small* 2013, **9**, 1160-1172.
2. Y. Liu, X. Dong and P. Chen, *Chem. Soc. Rev.* 2012, **41**, 2283-2307.
3. Q. Liu, J. Shi and G. Jiang, *TrAC-Trends Anal. Chem.* 2012, **37**, 1-11.
4. J. Tian, J. Xu, F. Zhu, T. Lu, C. Su and G. Ouyang, *J. Chromatogr. A* 2013, **1300**, 2-16.
5. B. Zhang, X. Zheng, H. Li and J. Lin, *Anal. Chim. Acta* 2013, **784**,1-17.
6. C. Chung, Y.K. Kim, D. Shin, S.R. Ryoo, B. Hong and D. Min, *Accounts Chem. Res.* 2013, **46**, 2211-2224.
7. A.P. Pandey, K.P. Karande, M.P. More, S.G. Gattani and P.K. Deshmukh, *J. Biomed. Nanotechnol.* 2014, **10**, 179-204.
8. Y. Yang, A.M. Asiri, Z. Tang, D. Du and Y. Lin, *Mater. Today* 2013, **16**, 365-373.
9. Y. Fuchs, O. Soppera and K. Haupt, *Anal. Chim. Acta* 2012, **717**, 7-20.
10. M.J. Whitcombe, I. Chianella, L. Larcombe, S.A. Piletsky, J. Noble, R. Porter and A. Horgan, *Chem. Soc. Rev.* 2011, **40**, 1547-1571.
11. L. Chen and B. Li, *Anal. Methods 2012*, **4**, 2613-2621.
12. E. Turiel and A. Martin-Esteban, *Anal. Chim. Acta* 2010, **668**, 87-99.
13. M. Zhang, J. Zeng, Y. Wang and X. Chen, *J. Chromatogr. Sci.* 2013, **51**, 577-586.
14. X. Kan, Y. Zhao, Z. Geng, Z. Wang and J. Zhu, *J. Phys. Chem. C* 2008, **112**, 4849-4854.
15. X. Kan, H. Zhou, C. Li, A. Zhu, Z. Xing and Z. Zhao, *Electrochim. Acta* 2012, **63**, 69-75.
16. X. Yang, Z. Zhang, J. Li, X. Chen, M. Zhang, L. Luo and S. Yao, *Food Chem.* 2014, **145**, 687-693.
17. X. Chen, Z. Zhang, X. Yang, J. Li, Y. Liu, H. Chen, W. Rao and S. Yao, *Talanta* 2012, **99**, 959-965.
18. X. Zhang, Y. Zhang, X. Yin, B. Du, C. Zheng and H. Yang, *Talanta* 2013, **105**, 403-408.
19. Y. Zeng, Y. Zhou, L. Kong, T. Zhou, G. Shi, *Biosens. Bioelectron*. 2013, **45**, 25-33.

20. H. Qiu, C. Luo, M. Sun, F. Lu, L. Fan and X. Li, *Talanta* 2012, **98**, 226-230.

21. Y. Li , X. Li, C. Dong, J. Qi and X. Han, *Carbon* 2010, **48**, 3427-3433.

22. Y. Mao, Y. Bao, S. Gan, F. Li and L. Niu, *Biosens. Bioelectron*. 2011, **28**, 291-297.

23. Y. Yang, G. Fang, X. Wang, M. Pan, H. Qian, H. Liu and S. Wang, *Anal. Chim. Acta* 2014, **806**, 136-143.

24. H. Qiu, C. Luo, M. Sun, F. Lu, L. Fan and X. Li, *Anal. Chim. Acta* 2012, **744**, 75-81.

25. F. Duan, C. Chen, G. Wang, Y. Yang, X. Liu and Y. Qin, *RSC Adv*. 2014, **4**, 1469-1475.

26. H. Liu, G. Fang, H. Zhu, C. Li, C. Liu and S. Wang, *Biosens. Bioelectron.* 2013, **47**, 127-132.

27. W. Rao, R. Cai, X. Chen, Y. Liu, H. Chen, Z. Zhang and L. Nie, *Chem. J. Chine U.* 2013, **34**, 1353-1359.

28. M. Ghambarian, Y. Yamini and A. Esrafili, *Microchim. Acta* 2012, **177**, 271-294.

29. M. Fayazi, M. Ghanei-Motlagh and M. Taher, *Anal. Methods*, 2013, **5**, 1474-1480.

30. X. Song, Y. Shi and J. Chen, *Talanta* 2013, **116**, 188-194.

31. M. Sun, R. Tang, Q. Wu, C. Wang and Z. Wang, *Anal. Methods* 2013, **5**, 5694-5700.

32. H. A. Becerril, J. Mao, Z. Liu, R.M. Stoltenberg, Z. Bao and Y. Chen, *ACS Nano* 2008, **2**, 463-470.

33. J. Liu, S. Guo, L. Liu and E. Wang, *Talanta* 2012, **101**, 151-156.

34. X. Song, Y. Shi and J. Chen, *Talanta* 2012, **100**, 153-161.