Research Article

Molecularly Imprinted Porous Silica Particles for Molecular Recognition

Hao Gu[1,2], Katherine Ji[1], Rongji Dai[2], Yen Wei[1,3], and Hai-Feng Ji[1]*

[1]Department of Chemistry, Drexel University, USA

[2]School of Life Science, Beijing Institute of Technology, China

[3]Department of Chemistry, Tsinghua University, China

Abstract

Traditional molecularly imprinted polymer (MIP) prepared from bulky samples may lose its selectivity during the crushing procedure. In this work, we report a one-step approach to prepare MIP materials in the shape of mesoporous silica particles. The mesoporous silica particles were prepared in the presence of template molecules in order to gain selectivity for the template molecules. After thorough rinsing, re-absorption experiments showed that L-tyrosine templated silica particles PL-t absorbed more L-tyrosine than its enantiomer D-tyrosine, and serotonin-templated silica particles Ps absorbed more serotonin than its analogue, tryptophan. These results demonstrated that templated silica particles have the capability of selective absorption of the template molecules.

INTRODUCTION

A molecularly imprinted polymer (MIP) is a templated polymer that is designed to recognize specific molecules [1-3].The molecular imprinting technique usually includes a polymerization process in the presence of a template molecule that is extracted afterwards, which leaves cavities in the imprinted polymer matrix with affinity to the template molecule. The MIP artificial receptors offer significant advantages due to their low cost and freedom of molecular design. MIP polymers have been used in applications such as chemical separations, solid phase extraction, catalysis, drug release, chemical and biological sensors, etc. [4-9]. The imprinted molecules include sugars, amino acids, nucleic acids, alkaloids, vitamins, proteins, enzymes, antigens, drug molecules, pesticides, herbicides, dyes, etc.[10-15].

MIP was originally prepared based on "bulk" or solution polymerization. After polymerization, the polymeric block is crushed and sieved to obtain particles at micro-to nano-scale sizes in order to effectively remove the template form the MIP [1]. This method is the most common MIP technique due to its simplicity and versatility. However, one problem related to this process is the rupture of the cavity and its subsequent loss in selectivity of the MIP. Another challenge is the selection of appropriate monomers and cross-linkers in order to create adequate binding sites complementary to the functional groups and topological structures of the template molecules [2].

Several methods have been developed to improve the performance of MIP, such as Hierarchical method and the polymerization packed bed method for the recognition of small to large molecules such as protein [3-15]. However, one of the key issues that has limited the practical applications of MIPs is still the lack of facile and robust methods to make MIPs in the formats required by the industry.

In this work, we report a one-step approach to prepare MIP materials in the shape of mesoporous silica particles. The mesoporous silica particles were prepared with several small molecules as templates for selective recognition of these molecules for the proof-of-concept study.

EXPERIMENTAL

Materials

L-tyrosine, D-tyrosine, and tetraethyl orthosilicate (TEOS, 98%) were purchased from Sigma-Aldrich, Inc (Milwaukee, WI).Serotonin and L-tryptophan were obtained from Alfa Aesar (Reston, VA). D-fructose, Span 80, light mineral, oil and hydrochloric acid were purchased from Fisher Scientific (Waltham, MA). The structures of these molecules are shown in Figure (1).

Preparation of silica particle and gel: The silica particles with templates were prepared in water/oil system in acidic conditions according to an existing reported method [16]. In a

typical procedure, TEOS (5.2 g) and EtOH (5 ml) were mixed in a beaker under stirring and3 ml 0.375 g/ml serotonin or 0.18 g/mL L-tyrosine and 1.25 mL of 0.2 M HCl solution were added in the mixture. Then, light mineral oil (50 g) and Span 80 (20 g) were added in the solution. The reaction was heated up to 40 °C and proceeded for 3 days. The silica particles were separated from the mixture by centrifugation (centrifuge 5810R, Eppendorf, Germany) and washed with acetone and EtOH respectively. After synthesis of the particles, all of the templates were removed with water in a Soxhlet extractor for 3 days. Control experiments were conducted with non-porous silica gel powders purchased from Fisher Scientific.

Characterization: The surface areas and pore volumes were analyzed by using a nitrogen adsorption-desorption isotherm (ASAP model 2010, Micromeritics, America). Dry silica samples were degassed at 473 K and 1.33 Pa for 4hours.N_2 absorption-desorption isotherm measurement was carried out at 77 K in liquid nitrogen. Surface areas and pore volumes of the samples were calculated by the Brunauer-Emmett-Teller (BET) method and Barrett-Joyner-Halenda (BJH) method. Scanning Electron Microscopy (SEM) images of the silica particles were obtained on a Hitachi Tabletop SEM (TM-1000)**.**

Adsorption experiment

A certain amount of organic molecules were dissolved in deionized (DI) water. 10 mg of the rinsed silica particles or silica powders were suspended in 10 ml sample solution and the mixtures were shaken at 60 r/min (4°C) for 4 h. The amounts of the absorbed compounds were quantified by using ultraviolet spectrophotometer (UV-3600, Shimadzu, Japan).All assays were performed in parallel and repeated at least three times.

RESULTS AND DISCUSSION

Pang et al., reported [16], that when small molecules, acting as a template, are added during the gelation process, porous silicon gels are formed. Most of the following work in the porous silicon gels focused on the absorption capability of the gels. We hypothesize that when the templates are removed, these residual binding sites may be used for selective binding of template molecules.
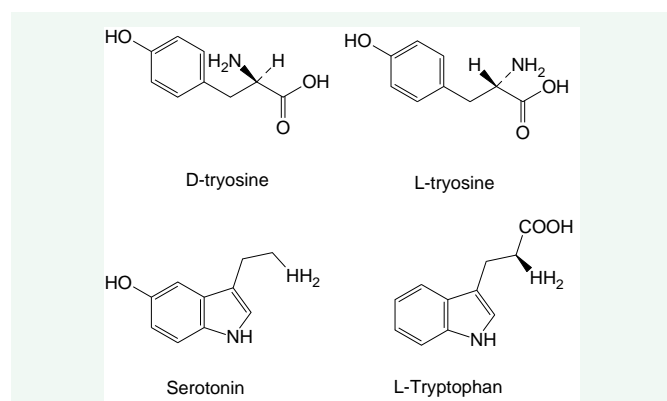
Figure 1 Structures of template and test molecules used in our experiments.
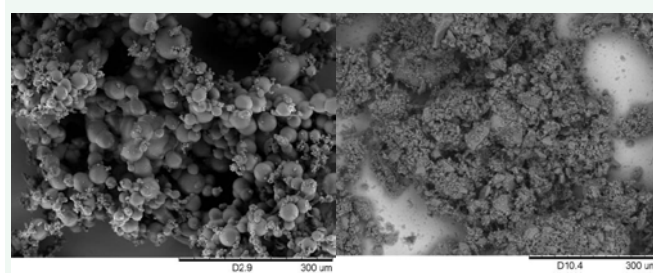
Figure 2 SEM images of the porous silica particles (left) and a silica gel material (right).

We prepared porous silica particles (in both micro- and nano scale) with L-tyrosine and serotonin as templates for two MIP silica particles, P_{L-t} and P_s, for selective recognition of L-tryosine and serotonin, respectively. L-tyrosine and D-tyrosine were used to verify whether the P_{L-t} can distinguish chiral amino acids. Serotonin and tryptophan were used to test whether P_s particles can recognize molecules with similar structures since the structure of serotonin and tryptophan are similar (Figure 1).

The SEM image of the porous silica particles P_s was shown in Figure (2), as compared to silica gel powders without pores. The silica particles were in the form of spheres with varying diameters from nano to micro size, while the silica gel powders showed irregular shapes.

We utilized the N_2 adsorption-desorption isotherms experiment to measure the surface area of synthesized silica particles. BET surface areas of the materials under different pressures (P/P_0, 0 ~ 1) were shown in Figure (3). The pore parameters of the silica particles and silica powders were summarized in Table (1). The results showed that the surface areas of both porous particles were significantly higher than those of silica powders without pores.
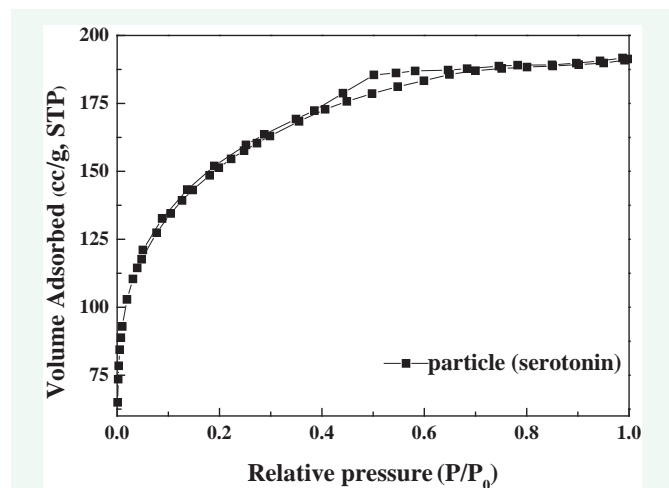
We compared the selective adsorption capability of these particles. UV spectra showed that the L-tyrosine templated silica particles P_{L-t} absorbed more L-tyrosine (31.8%) than D-tyrosine (25.9%) (Figure 4), demonstrating that the templated particles have the capability of selective absorption of the template molecules.

Similar behavior was observed for serotonin-templated silica particles, P_s. Table (2) shows P_s absorbed more serotonin (44.7%) than tryptophan (37.8%), which confirmed that templated silica particles have a preference to re-absorb the template molecule. Although the difference between these two numbers appears small, the molecular recognition capability of the P_s is more than it appears. In a control experiment, a porous silica particle (P_f) prepared in the same procedure with fructose was used as the template showed no absorption selectivity towards serotonin (36.4%) and tryptophan(36.9%), but these numbers are close to the 37.8% absorption of tryptophan by P_s (Table 2). This suggests that 37.8% of absorption of tryptophan by P_s was non-selective due to the large surface areas of P_s, and the extra 18.3%, i.e. (44.7%-37.8%)/37.8%, mainly comes from the specific recognition of serotonin beyond the nonselective absorption. In the control experiments, silica powders showed very low
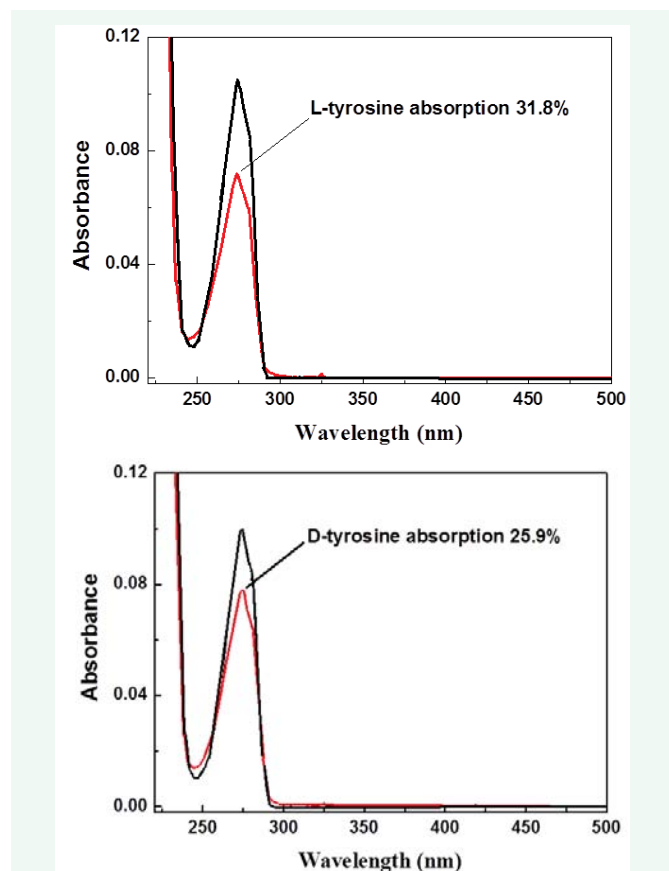
adsorbing capacity for both chemicals 0.3% for serotonin and 0.2% for tryptophan.

CONCLUSION

We developed a cost-effective molecularly imprinted polymer technique that may have applications in the fields of chemistry,

Table 1: Pore size and porosity of the porous silica particle and silica powders.

Sample	Template	BET surface area (m²/g)	Total pore volume (cm³/g)
powder	-	14	0.02
P$_{L-t}$	L-tyrosine	376	0.16
P$_s$	Serotonin	518	0.25

Table 2: Adsorption capacity of Ps for serotonin and tryptophan.

Sample	Template	Guest solution	Absorption change percentage%
P$_s$	Serotonin	Serotonin	44.7%
		Tryptophan	37.8%

biology and engineering, particularly as an affinity material for detection and separation of small molecules or solid phase extraction.

Figure 3 N$_2$ adsorption-desorption isotherms of the porous silica particle P$_s$.

Figure 4 UV absorption of an 8×10-5 M solution of tyrosine before (black line) and after (red line) addition of silica particle P$_{L-t}$.

REFERENCES

1. Lorenzo RA, Antonia MC, Carmen AL, Britt AC .To Remove or Not to Remove? The Challenge of Extracting the Template to Make the Cavities Available in Molecularly Imprinted Polymers (MIPs). Int J Mol Sci. 2011; 12: 4327-4347.

2. Yan H, Row KH. Characteristic and Synthetic Approach of Molecularly Imprinted Polymer. Int J Mol Sci. 2006; 7:155-178.

3. Nematollahzadeh A, Sun W, Aureliano CSA, Lütkemeyer D, Stute J, Abdekhodaie, MJ, et al. High capacity hierarchically imprinted polymer beads for protein recognition and capture. Angew Chem Int Ed. 2011; 50: 495-498.

4. Huang YP, Zheng C, Liu ZS. Molecularly Imprinted Polymers for the Separation of Organic Compounds in Capillary Electrochromatography. Curr Org Chem. 2011; 15:1863-1870.

5. Duan YP, Dai CM, Zhang YL, Chen L. Selective trace enrichment of acidic pharmaceuticals in real water and sediment samples based on solid-phase extraction using multi-templates molecularly imprinted polymers. Anal Chim Acta. 2013; 758: 93-100.

6. Zhang Y, Riduan SN. Functional porous organic polymers for heterogeneous catalysis. Chem Soc Rev. 2012; 41: 2083-2094.

7. Pernites R, Ponnapati R, Felipe MJ, Advincula R. Electropolymerization molecularly imprinted polymer (E-MIP) SPR sensing of drug molecules: Pre-polymerization complexed terthiophene and carbazole electroactive monomers. Biosens Bioelectron. 2011; 26: 2766-2771.

8. Lakshmi D, Bossi A, Whitcombe M, Chianella I, Fowler SA, Subrahmanyam S, et al. Electrochemical sensor for catechol and dopamine based on a catalytic molecularly imprinted polymer-conducting polymer hybrid recognition element. Anal Chem. 2009; 81: 3576-3584.

9. Moreira FTC, Freitas VAP, Sales MGF. Biomimetic norfloxacin sensors made of molecularly-imprinted materials for potentiometric transduction. Microchim acta. 2011; 172: 15-23.

10. Jia M, Qin L, He XW, Li WY. Preparation and application of lysozyme imprinted monolithic column with dopamine as the functional monomer. J Mater Chem. 2012; 22: 707-713.

11. Parmpi P, Kofinas P. Biomimetic glucose recognition using molecularly imprinted polymer hydrogels. Biomater. 2004; 25: 1969-1973.

12. 12. Zhu XL, Yang J, Su QD, Cai JB, Gao Y. Selective solid-phase extraction using molecularly imprinted polymer for the analysis of polar

SciMedCentral

organophosphorus pesticides in water and soil samples. J Chromatogr A. 2005; 1092: 161-169.

13. Djozan D, Ebrahimi B. Preparation of new solid phase micro extraction fiber on the basis of atrazine-molecular imprinted polymer: Application for GC and GC/MS screening of triazine herbicides in water, rice and onion. Anal Chim Acta. 2008; 616: 152-159.14. Kyzas GZ, Bikiaris DN, Lazaridis N. Selective separation of basic and reactive dyes by molecularly imprinted polymers (MIPs).Chem Eng J. 2009; 149: 263-272.

14.15. Li M, Lin X, Xie Z. Investigation of enantiomer recognition of molecularly imprinted polymeric monoliths in pressurized capillary electro chromatography screening the amino acids and their derivatives. J Chromatogr A. 2009; 1216: 5320-5326.

15.16. Pang JB, Qiu KY, Wei Y. Preparation of mesoporous silica materials with non-surfactant hydroxyl-carboxylic acid compounds as templates via sol-gel process. J Non-cryst Solids. 2001; 283: 101-108.

Cite this article

Gu H, Ji K, Dai R, Wei Y, Ji HF (2017) Molecularly Imprinted Porous Silica Particles for Molecular Recognition. JSM Nanotechnol Nanomed 5(1): 1045.