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Green synthesis of water-compatible and thermo-responsive molecularly imprinted nanoparticles

Xian-Hua Wang[a,*,1], Lei Tang[a,b,1], Fang-Fang Yang[a], Ling-Ling Ying[a], Yan-Ping Huang[a,*], Zhao-Sheng Liu[a]

[a] Tianjin Key Laboratory on Technologies Enabling Development of Clinical Therapeutics and Diagnostics (Theranostics), School of Pharmacy, Tianjin Medical University, Tianjin 300070, China
[b] Tianjin Binhai New Area Tanggu Obstetrical and Gynecological Hospital, Tianjin 300457, China

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ABSTRACT

Through precipitation polymerization, a novel water-compatible and positive thermo-responsive molecularly imprinted nanoparticle (MINP) was successfully synthesized in aqueous solution using acrylamide (AAm) and 2-acrylamide-2-methyl propanesulfonic acid (AMPS) as functional monomer, N,N′-methylenebis(acrylamide) (MBA) as cross-linker, and levofloxacin (LOFL) as template. The MINP was composed of LOFL imprinted matrix, which showed positively thermo-responsive interpolymer interaction between poly(AAm) and poly(AMPS). To obtain MINP with excellent molecular recognition ability, the composition and ratio of recipe were optimized in detail. The resultant MINP was characterized by transmission electron microscope, thermogravimetric analysis, nitrogen adsorption–desorption isotherms, and Fourier transform infrared spectra. The binding behavior demonstrated the zipper-like switchable molecular recognition ability for temperature. The low temperature could stabilize interpolymer interaction between poly(AAm) and poly(AMPS), thus the MINP demonstrated poor molecular recognition ability at 20 °C. In contrast, the high temperature resulted to the dissociation of poly(AAm)-poly(AMPS) complexes and promote the mass transfer of target in and out the MINP. Therefore, the MINP exhibited significant molecular recognition ability at 40 °C. In contrast to previously inverse thermo-responsive nanomaterials, this zipper-like thermo-responsive MINP is unique and has prospects in extensive application.

1. Introduction

In recent years, molecular imprinting technique (MIT) has attracted a lot of attention by reason of its capacity in the synthesis of antibody-mimetic polymers, also known as molecularly imprinted polymer (MIP). Compared with natural antibodies, the MIP possesses improved properties, including low-cost preparation, reusability, and robustness. Therefore, the MIP as molecular recognition element has been applied to many areas, such as drug delivery [1], enzyme catalysis [2], sensors [3], chiral resolution [4], solid-phase extraction [5] and chromatography stationary phase [6]. To fabricate MIP, the functional monomer and template are first mixed to form self-assembly complex. After adding cross-linker, polymerization is carried out to fix self-organised three-dimensional network. Next, imprinted template is removed from the polymeric network, which possesses imprinted sites complementary to the template.

* Corresponding authors at: Room 104, Building B for School of Pharmacy, Tianjin Medical University, 22 Qixiangtai Road, Heping District, Tianjin 300072, China.
E-mail addresses: xianhua.w@163.com (X.-H. Wang), huangyp100@163.com (Y.-P. Huang).
[1] Xian-Hua Wang and Lei Tang contributed equally to this work.

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Stimuli-responsive polymers are smart materials capable of responding to changes in external environment through transforming their properties [7]. The external environment trigger prior to response can be temperature, pH, light, ionic strength, oppositely charged polymer, electric, magnetic field, etc. [8]. The following responses were observed as changes in shape, solubility, surface characteristics, intricate molecular assembly, and other [9]. Combined with virtue of smart material, the smart MIP possesses stimulus-responsive molecular recognition ability, which is at the cutting-edge of MIT. According to the responsive element, the smart MIP includes pH-responsive [10], magnetic field-responsive [11], photo-responsive [12], molecule-responsive [13], salt-responsive [14], especially thermo-responsive MIP [15–22].

One classic case is N-isopropylacylamide (NIPAm)-based MIP [15,19–22], which mostly demonstrates negatively thermo-responsive molecular recognition ability [23,24]. The hydrophobicity of poly(NIPAm) increases with rising temperature. At low temperature, the NIPAm-based MIP exhibits excellent molecular recognition ability in water, because of the increase of hydrophilicity, which accelerates the mass transfer of template into and out of imprinted sites. On the contrary, the NIPAm-based MIP shrinks at elevated temperature, which results in reducing of molecular recognition [16,18]. Therefore, this negatively thermo-responsive molecular recognition ability limits pervasive application of the NIPAm-based MIP, mainly due to the slow kinetics at low temperature [24].

Recently, positively thermo-responsive MIP with zipper-like switchable ability was prepared on the base of acrylamide (AAm) and 2-acrylamide-2-methyl propanesulfonic acid (AMPS) [23,25]. At low temperature, the poly(AAm) and poly(AMPS) can form complexes, which result in shrinking of the polymer and restrict access of template to imprinted cavity. In contrast, great heat dissociates interpolymer interactions between poly(AAm) and poly(AMPS), which allows the template to reach the imprinted site so easily [23]. Thus, the positively thermo-responsive MIP shows excellent and inferior molecular recognition ability at high and low temperature, respectively. The ketoprofen imprinted thermo-responsive monolith has been prepared using AAm and AMPS as functional monomer by our group [26].

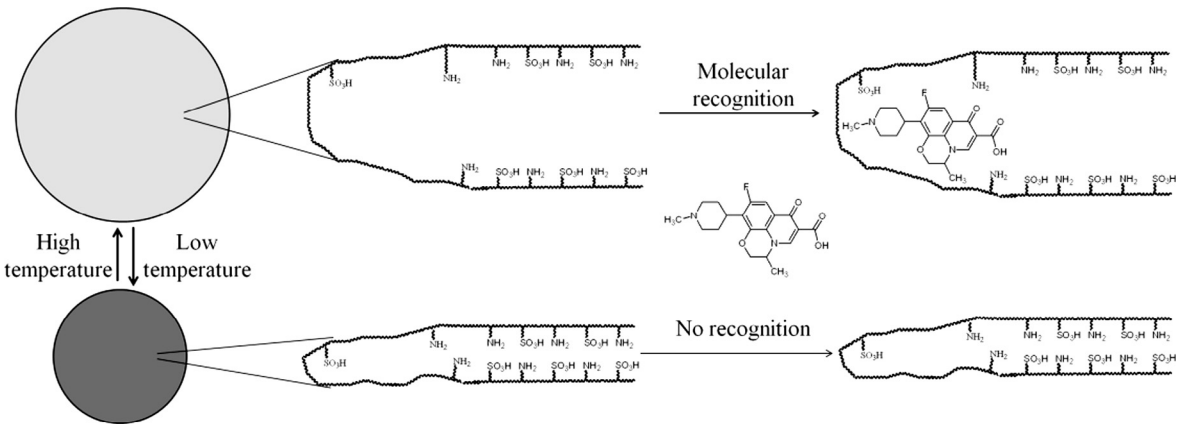
Many applications, including clinical diagnostics, food safety and environmental protection, require MIP capable of working in aqueous media, so water-compatible MIP was prepared by some strategies, for example, use of hydrophilic monomer, surface post-modification and interfacial Pickering emulsion polymerization [27]. However, organic solvent is the most commonly used porogen, which could stable the interactions between template and functional monomer, and the resultant MIP usually exhibits poor molecular recognition ability for the template in aqueous media [28]. In addition, the organic solvent would pollute the environment through volatilization into the air, as well as damage to operators due to the toxicity [29]. Therefore, it is essential to prepare water-compatible MIP in environment friendly solvent.

The attempt of this study is to seek to prepare novel water-compatible and positively thermo-responsive molecularly imprinted nanoparticle (MINP) using AAm and AMPS as functional monomer. Levofloxacin (LOFL), which is used to treat bacterial infections, was chose as template to prepare thermo-responsive MINP due to its compatibility with water. Thus, in aqueous solution, MINP with zipper-like switchable ability (Scheme 1) was synthesized by precipitation polymerization. The effect of the composition and ratio of recipe on the selectivity and morphology of MINP was investigated, and the resultant MINP was also characterized in detail. The binding behavior was used to demonstrate the positively thermo-responsive switchable recognition ability of MINP.

2. Experimental

2.1. Reagents and standards

Levofloxacin (LOFL), ciprofloxacin (CPFX) and gatifloxacin (GTFX) was purchased from Hengshuo Sci. & Tech. Corp. (Hubei, China). Acrylamide (AAm), 2-acrylamide-2-methyl propanesulfonic acid (AMPS), methyl methacrylate (MMA), butyl methacrylate (BMA), tetramethylethylenediamine (TEMED) and ammonium persulphate (APS) were obtained from Sigma-Aldrich (St. Louis, MO, USA). N,N′-methylenebis(acrylamide) (MBA), methanol and acetic acid were purchased from Tianjin Kermel Chemical Reagents Co.,



Scheme 1. Proposed mechanism of positively thermo-responsive molecularly imprinted nanoparticles (MINP).