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Electrochemical sensor for paracetamol recognition and detection based on catalytic and imprinted composite film

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ABSTRACT

A new strategy for a composite film based electrochemical sensor was developed in this work. A layer of conductive film of poly(*p*-aminobenzene sulfonic acid) (pABSA) was electropolymerized onto glassy carbon electrode surface and exhibited a high electrocatalytic active for paracetamol (PR) redox. The subsequent formation of a layer of molecular imprinted polymer (MIP) film on pABSA modified electrode endowed the sensor with plentiful imprinted cavities for PR specific adsorption. The advantages of the composite film made the prepared sensor display high sensitivity and good selectivity for PR detection and recognition. Under the optimal conditions, the sensor could recognize PR from its interferents. A linear ranging from 5.0×10^{-8} to 1.0×10^{-4} mol/L for PR detection was obtained with a detection limit of 4.3×10^{-8} mol/L. The sensor has been applied to analyze PR in tablets and human urine samples with satisfactory results. The simple, low cost, and efficient strategy reported here can be further used to prepare electrochemical sensors for other compounds recognition and detection.

1. Introduction

As a kind of synthetic material, molecular imprinting polymer (MIP) simulates the behavior of natural antibodies and exhibits greater stability than its natural counterparts, resulting in its wide applications in the field of chromatography separation, solid phase extraction, drug controlled release, and electrochemical sensor (Jin et al., 2013; Rossetti et al., 2014; Zeng et al., 2013). Traditional synthetic methods, such as UV and chemically initiated polymerizations, have been investigated and applied for lots of small molecules and biomacromolecules recognition (Wulff et al., 1973; Vlatkis et al., 1993). In electrochemical sensors, electropolymerization methods for MIP preparation exhibit many advantages, such as simple preparation procedures, easy control of the thickness of the film, and uniform polymer distribution on electrode surface. The modified MIP film on electrode surface acts as a molecular recognition element to improve the selectivity of the sensor due to its specific adsorption capacity. Generally, the electropolymerized MIP films are non electroactive, resulting in the lack of direct path for the conduction of electrons from the active sites to electrode (Whitcombe et al., 2011; Wang et al., 2014a; Li et al., 2012a,b). Even though the conductive polymers, such as polypyrrole and polyaniline, were involved, the overoxidation procedure was implemented before the determination also to restrain the non specific adsorption (Turco et al., 2015; Kan et al., 2012). Thus, the sensitivity of the MIP based electrochemical sensors would be seriously limited.

Due to the high surface-to-volume ratio, enhancement of the conductivity and acceleration of the electron transfer, various nanomaterials have been introduced into the MIP based electrochemical sensors preparation. Graphene, carbon nanotubes, gold nanoparticles et al. have been used to fabricate effective sensing platforms for electrochemical sensors. These nanomaterials based MIP electrochemical sensors exhibited improved sensitivity for template molecules detection (Riskin et al., 2008; Li et al., 2012a,b; Cai et al., 2010; Xie et al., 2010; Flavin and Resmini, 2009). Besides these nanomaterials, conductive polymers have been widely used in electrochemical sensors since they also can accelerate the electron transfer at the electrode–solution interface and significantly enhance the electrode reaction rate (Kong et al., 2014). Moreover, the advantages of stable coating on electrode and low cost make the conductive polymers perfect for electrochemical sensor preparation to improve the sensitivity in a sense. Yang et al. reported that a poly(malachite green) film-coated electrode displayed high electrocatalytic activity to dopamine (Wang et al., 2007). Cheng et al. investigated the electrocatalytic oxidation of cysteine at screen-printed electrode, which was modified with

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electrogenerated poly(3,4-ethylenediocythiophene) film. The prepared modified polymer film lowered the overpotentials and improved electrochemical behavior of cycteine oxidation (Su and Cheng, 2008). Thionine was used as a monomer for a poly(thionine) modified electrode preparation. Excellent catalytic activity and reversibility for the electrochemical redox reaction of both hydroquinone and catechol were achieved with a really low detection limit (Ahammad et al., 2011).

Among the conductive polymers synthesis, sulfonated polyaniline, as the first reported self-doped water-soluble conducting polyaniline derivative, is of interest because of its high stability and good conductivity in a broad pH range (Wei et al., 1996). *p*-Aminobenzene sulfonic acid (ABSA) is a kind of electroactive compound and has been successfully electropolymerized to form poly(*p*-aminobenzene sulfonic acid) (pABSA) film by many researchers under different conditions. Chen et al. electropolymerized a composite of pABSA and flavins on electrode surface, which showed excellent electrocatalytic activity for NADH redox (Kumar and Chen, 2007). A pABSA film modified electrode fabricated by electropolymerization showed an electrocatalytic activity for the oxidation of dopamine and ascorbic acid, resulting in the simultaneously determination of both compounds (Jin et al., 2005). It is of no doubt that the excellent conductivity and electrocatalysis of pABSA could provide a platform to facilitate the conduction of electrons. Hence, the combination of MIP and conductive polymers can be proposed for achieving good recognition capacity as well as high sensitivity of the electrochemical sensor.

Paracetamol (PR), as an antipyretic/analgesic, is rapidly and completely metabolized to form inactive metabolites, which would be eliminated in the urine in body (Markas, 1994). However, overdosing and the chronic use of PR produces toxic metabolite accumulation that will cause skin rashes and inflammation of the pancreas (Shiroma et al., 2012). An electrochemical sensor was prepared by modifying graphene on glassy carbon electrode surface for PR detection with a linear range of 1.0×10^{-7}–2.0×10^{-5} mol/L. A quasi-reversible redox process of PR at the modified electrode and the significant decrease of overpotential of PR were attributed to the electrocatalytic activity of graphene (Kang et al., 2010). A layer of MIP film was reported to be electropolymerized onto multiwalled carbon nanotubes modified electrode surface for PR detection and recognition. The sensor not only recognized PR from its possible interfering substances, but also sensitively detected PR with a linear range of 2.0×10^{-7}–4.0×10^{-5} mol/L (Peng et al., 2014). Electrochemical sensors based on multiwalled carbon nanotubes and dopamine nanospheres functionalized with gold nanoparticles (Liu et al., 2014), Pd/graphene oxide nanocomposite (J. Li et al., 2014a, Y. Li et al., 2014b), nanogolds (Goyal et al., 2005), have been reported for PR determined with some satisfactory results. These nanomaterials used for sensor preparation can improve the sensitivity of the sensor. Herein, two layers of polymer films were electrpolymerized on glassy carbon electrode (GCE) surface successively to fabricate a novel and facile electrochemical sensor. ABSA was chosen as a monomer to form the first layer of polymer, providing a conductive and catalytic platform for PR sensitive detection. And o-phenylenediamine (OPD) was chosen as a monomer for the second film preparation in the presence of PR to form MIP, endowing the sensor with good selective recognition capacity toward PR.

2. Experimental

2.1. Chemicals

Commercially available reagents were used without further purification. *p*-aminobenzene sulfonic acid (ABSA) and paracetamol (PR, $>99\%$) were ordered from Aladdin (Aladdin, China). *o*-phenylenediamine (OPD), 4-nitrophenol (4-NP), and ascorbic acid (AA) were purchased from Sinopharm Chemical Reagent Co. Ltd. (China). Uric acid (UA), dopamine (DA), and hydroquinone (HQ) were provided by Sigma (Sigma, USA). All other reagents were of at least analytical-reagent grade, and double-distilled deionized water was used for all solutions.

2.2. Apparatus

Electrochemical experiments, such as cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS) and differential pulse voltammetry (DPV) were performed on CHI 660C workstation (ChenHua Instruments Co., Shanghai, China) with a conventional three-electrode system. A bare or modified glassy carbon electrode (GCE) was served as a working electrode. A saturated calomel electrode and a platinum wire electrode were used as a reference electrode and a counter electrode, respectively. Field emission scanning electron microscope (FE-SEM) images were obtained on an S-4800 field emission scanning electron microanalyser (Hitachi, Japan). High-performance liquid chromatography (HPLC, Hitachi L-7100, UV-detector, $\lambda=214$ nm, VP-ODS C18 150 mm, $t=25$ °C, mobile phase 0.5% acetic acid in H_2O 10%: methanol 90%).

2.3. Preparation of pABSA modified GCE (pABSA/GCE)

Prior to the modification, the bare GCE were polished by 0.3 μm alumina slurry on micro-cloth pads and sonicated subsequently in water. Then the clean GCE was immersed into 5 mL phosphate buffer solution (PBS, 0.1 mol/L, pH 7.0) containing 2×10^{-4} mol/L ABSA. Then CV method was performed from -1.5 V to $+2.5$ V for 15 cycles at a scan rate of 100 mV/s, obtaining polymer film modified electrode (pABSA/GCE).

2.4. Fabrication of MIP modified pABSA/GCE (MIP/pABSA/GCE)

The prepared pABSA/GCE was immersed into PBS (0.1 mol/L, pH 5.0) containing 5.0×10^{-3} mol/L PR and 5.0×10^{-3} mol/L OPD. Then CV was performed from 0.0 V to $+0.8$ V for 35 cycles at a scan rate of 75 mV/s, obtaining polymer modified pABSA/GCE. Subsequently, the embedded PR molecules were extracted by incubating the modified electrode into ethanol for 20 min until no obvious oxidation peak of PR could be observed by DPV method, getting MIP modified pABSA/GCE (MIP/pABSA/GCE). The procedure of the fabrication of MIP/pABSA/GCE was depicted in Fig. 1A.

As a control, non-molecular imprinting polymer modified electrode (NIP/pABSA/GCE) was prepared and treated in exactly the same way except for the omitting of PR in the electropolymerization process. In order to investigate the electrocatalytic effect of pABSA, other two modified electrodes were prepared by direct electropolymerization of OPD on GCE surface in the presence and absence of PR, which were assigned as MIP/GCE and NIP/GCE, respectively.

2.5. Electrochemical properties measurements

Electrochemical measurements to characterize the prepared sensor were carried out in PBS by using CV, EIS, and DPV methods. AA, UA, DA, 4-NP, and HQ were selected as coexisted or structural similar compounds to evaluate the recognition capacity of the prepared sensor.