Iranian Journal of Analytical Chemistry
Volume 11, Issue 2, September 2024 (223-229) Original Research Article

مجله ایرانی شیمی تجزیه
دوره ۱۱، شماره ۲، مهر۱۴۰۳ (۲۲۹-۲۲۳)

Electrochemical determination of epinine by using modified Screen-Printed electrode

Sayed Zia Mohammadi[1*], Elina Bani-assadi[1], Somayeh Tajik[2]

[1]Department of Chemistry, Payame Noor University, *P.O. Box* 19395-4697, Tehran, Iran
[2]*Research Center of Tropical and Infectious Diseases, Kerman University of Medical Sciences, P.O. Box 76169-13555, Kerman, Iran*

Received: 10 July 2024 **Accepted:** 22August 2024
DOI: 10.30473/ijac.2026.77132.1337

Abstract
In the present work, we designed a disposable voltammetric sensor utilizing manganese ferrite nanoparticles -modified screen-printed electrode (MF/SPE) for epinine determination. The electrochemical behavior of EP at the MF/SPE was examined using differential pulse voltammetry (DPV), cyclic voltammetry (CV), and chronoamperometry techniques. The MF/SPE exhibited outstanding electro-catalytic activity for the voltammetric detection of EP. Under optimized conditions, the peak current showed a linear dependence with the concentration of EP in the range of 0.1 to 600.0 µM, and a detection limit (LOD) of 0.02 µM was determined. In addition, the MF/SPE sensor has advantages including repeatability, reproducibility, stability, inexpensiveness, and practical application. Finally, the MF/SPE -based sensor was utilized for the determination of EP in the real urine samples and the satisfactory results were obtained.

Keywords
Disposable sensor; Manganese ferrite nanoparticles; Electrochemical sensor; Epinie.

1. INTRODUCTION

Catecholamines are the main category of drugs with wide applications in biological systems and clinical investigations [1,2]. The catecholamines constitute the main branch of sympathomimetic drugs, suggested for the treatment of blood pressure and cardiac arrest[3–5]. Epinine (EP) or deoxyepinephrine is a natural catecholamine drug found in some plants and insects. It has similar effects to epinephrine. EP is suggested for the treatment of congestive heart failure due to its ability to serve as a breakdown product of the prodrug ibopamine [6]. On the other hand, EP can cause an elevation in blood pressure according to the report of Barger and Dale [7]. In addition, EP is suggested as a substitute for epinephrine. An overdose of EP can be harmful to the human body and the use of this drug must be controlled in patients. According to our knowledge, only the high performance liquid chromatography (HPLC) method has been used for the determination of EP in biological samples [8-11]. Although, the HPLC method showed good ability in the analysis of a wide range of drugs at a low level [12-14], but need expensive devices and accessories such as isolation system, temperature control; and they are time-consuming and costly. On the other hand, electrochemical methods are more advantageous due to their lower detection limits, higher sensitivity, higher selectivity, lower costs, simplicity, and the possibility direct measurement in biological media at shorter time intervals. Therefore, electrochemical methods based on anodic oxidation seem reasonable to determine drug concentrations. Due to the importance of measuring EP, analysts are looking to develop a simple, rapid, and sensitive method for measuring epinine. The screen-printed electrodes (SPEs) have been designed especially for miniaturization of electrochemical analytical systems [15]. SPEs are highly-versatile, easy to use, cost-effective analytical tools, also suitable to miniaturization [16]. Furthermore, a screen printed electrode avoids the cleaning process, unlike conventional electrodes such as a glassy carbon electrode (GCE) [17].Today, it has been proven that by modifying

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* Corresponding author:

Sayed Zia Mohammadi, Email: szmohammadi@pnu.ac.ir, szmohammadi@yahoo.com

the surface of various electrodes, we can measure analytes with better sensitivity and also at lower potentials. Therefore, modified electrochemical sensors were suggested as convenient alternative tools for analysis of drugs and biological compounds instead of the HPLC method [18-20].

Nanoparticles with different varieties, fantastic features [21], and especially high surface area and good electrical conductivity are suitable choices for the modification of electrochemical sensors [22-23].

Metal NPs have some distinct advantagessuch as higher mass transport, lower influence of thesolution resistance, low detection limit, and better signal-tonoise ratio over the conventional electrodes [24]. Metals in the nanometer range provide three importantfunctions for electroanalysis: the roughening of theconductive sensing interface, catalytic properties, andconductivity properties [24]. From both fundamental andindustrial points of view, many different syntheticprocedures have been developed for the preparation ofmetal nanoparticles (NPs).

In the present work, we synthesized magnetic coreshell manganese ferrite nanoparticles (MF) [25] andscreen printed electrodes were modified withMF. To the best of our knowledge, no study has beenreported so far on the determination of epinine byusing MF/SPE.

2.EXPERIMENTAL

2.1.Reagents and Instruments

All reagents were obtained in their highest general purity and employed as received, without additional purification. The phosphate-buffered (PB) were prepared using ortho-phosphoric acid (0.1 M) and pH adjustment of the solutions within the range of pH 2.0 to pH 9.0 was performed using NaOH solution. They were employed as the supporting electrolyte.

CV, chronoamperometry and DPV experiments were conducted using the PGSTAT302N electrochemical workstation (Metrohm, Herisau, Switzerland). Electrochemical investigations were conducted using disposable screen-printed electrodes (SPEs) from Dropsens, which include carbon working electrode (DRP-110) along with a carbon counter electrode and a silver-pseudo reference electrode. Solutions were prepared using deionized water from Millipore, Direct-Q 8UV (Darmstadt, Germany).

2.2.Synthesis ofmagnetic coreshell manganese ferrite NPs

With minor adjustments, the MF NPs were synthesized in accordance with the previously published article [25]. For this purpose, 70 mL distilled water containing 4.2 g NaOH and 3.0 mL ethylene diamine was transferred to an Erlenmeyer and $Fe(NO_3)_3$ (13.4 g) and $Mn(NO_3)_2$ (4.9 g) were added to it. This combination was heated to 85 °C and maintained there for one hour. The black product was centrifuged and extensively cleaned with distilled water to get rid of any unreacted materials once it had cooled to room temperature. Ultimately, the material was calcined for 60 minutes at 500 °C in an alumina crucible to produce MF NPs.

2.3. Modification Process of SPE

For the modification of SPE, an aqueous suspension was prepared through dispersing 1 mg of MF NPs in 1.0 mL of deionized water. The suspension was then ultra-sonicated for 30 min to achieve uniform dispersion of the nanostructure powder. The SPE was modified by applying 5 µL of the resulting suspension and allowing them to dry at ambient temperature.

2.4. Preparation of urine samples

The collected urine samples were immediately centrifuged at 2500 rpm for 10 min. Then, the supernatant was filtered by using 0.45-µm filter and then a portion 10.0 mL was poured into a 25-mL volumetric flask and diluted to mark with PBS 0.1 M (pH = 7). It should be noted that prior to centrifugation and filtration, an aliquot of standard epinine was spiked to the collected urine. The accuracy of determinations was enhanced by analyzing the epinine levels according to the proposed protocol based on the standard addition method.

3. RESULTS AND DISCUSSION

3.1. Electrochemical Behavior of EP at the MF/SPE

The effect of pH on the electro-catalytic activity of EP at the MF/SPE was investigated in diverse pH solutions ranging from 2 to 9, each containing 300.0 µM EP. It was observed that the reduction signals of EP increased as the pH values rose from 3 to 7, followed by a slight decrease with further increases in pH. The highest peak current was achieved at pH = 7, which was subsequently used in this study.

Figure 1 displays the comparative CV responses of the bare SPE, and MF/SPE recorded in PB (0.1 M with a pH of 7.0) containing 300.0 µM EP, at a fixed scan rate of 50 mV/s. From CV studies, we can observe that bare SPE exhibits a poor response to EP with a low reduction peak current (Ip = −2.9 µA) (CV a). From cyclic voltammogram b, the reduction peak of EP exhibits a higher peak current (Ip= −9.9 µA) at the surface of the MF modified SPE in comparison with the bare SPE, indicating the beneficial effect of MF NPs in improving the efficiency of bare SPE.

DOI: 10.30473/ijac.2026.77132.1337

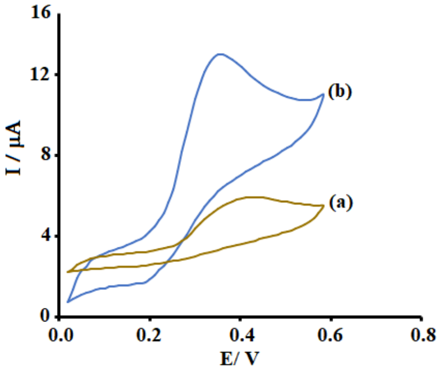

Figure 1. CVs of bare SPE (a) and MF/SPE in PB: 0.1 M, pH 7.0 (containing 300.0 µM EP), (scan rate: 50 mV/s).

3.2. Influence of Scan Rate

Figure 2 exhibits the influence of the potential scan rate on the CV responses of the MF/SPE towards the reduction process of EP (200.0 µM). The cyclic voltammograms at various scan rates demonstrate that increasing the scan rate causes an increase in the Ip. At the same time, by increasing the scan rate, the peak potential (Ep) shifts slightly towards more negative values. Based on a detailed analysis of the cyclic voltammograms, a linear plot of Ip as a function of the square root of the scan rate ($\upsilon^{1/2}$) is observed (Figure2(Inset)). This linear relationship demonstrates a typical diffusion-controlled electrochemical process of EP.

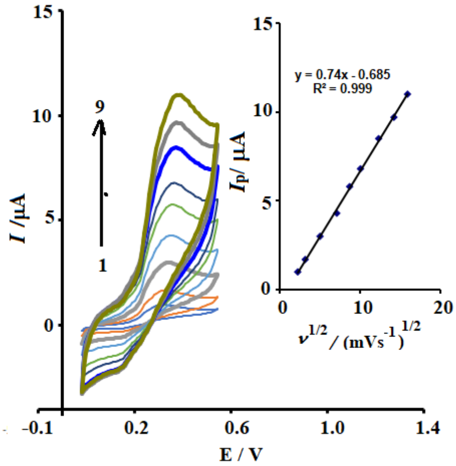

Figure 2. CVs of MF/SPE in 0.1 M PB (pH: 7.0) containing 200.0 µM EP at diverse scan rates from 5 to 250 mVs^{-1}(CVs of 1 to 9 correspond to 5, 10, 25, 50, 75, 100, 150, 200 and 250 mVs^{-1}). Inset: plot of Ip vs. $\upsilon^{1/2}$.

3.3. Chronoamperometric Studies

Given that the reduction peak of EP is a diffusion-controlled process, we employed the chronoamperometry approach to assess the diffusion coefficient (D) of EP at the MF/SPE. Figure 3 displays chronoamperograms of various solutions containing concentrations of EP, ranging from 0.1 to 2.0 mM, in PBS (pH = 7.0) at the MF/SPE surface (chronoamperograms were recorded at potential step = −400 mV). For an electro-active analyte (such as EP) with a diffusion coefficient of D, the electrochemical reaction current is described by the Cottrell equation (Eq. 1).

$I = nFACD^{1/2}\pi^{-1/2}t^{-1/2}$ Eq. 1

(I: current (µA), n: number of electrons participating in the electrochemical process of the target compound, F: Faraday’s constant (96485 C/mol), A: the surface area of the working electrode (cm^2), C: the concentration of the target compound (mol/cm^3), D: diffusion coefficient (cm^2/s), and t: time (s)).
According to the Cottrell equation (under diffusion-limited transport), a plot of I vs. $t^{-1/2}$ is linear. We plotted the variation in I as a function of $t^{-1/2}$ for different chronoamperograms (Figure 3a). Then, we plotted the slopes of Cottrell plots in Inset A vs. concentrations of EP(Figure 3b). Therefore, based on the Cottrell equation and using the obtained slope in Inset down, the diffusion coefficient of EP was found to be 1.96×10^{-6} cm^2/s.

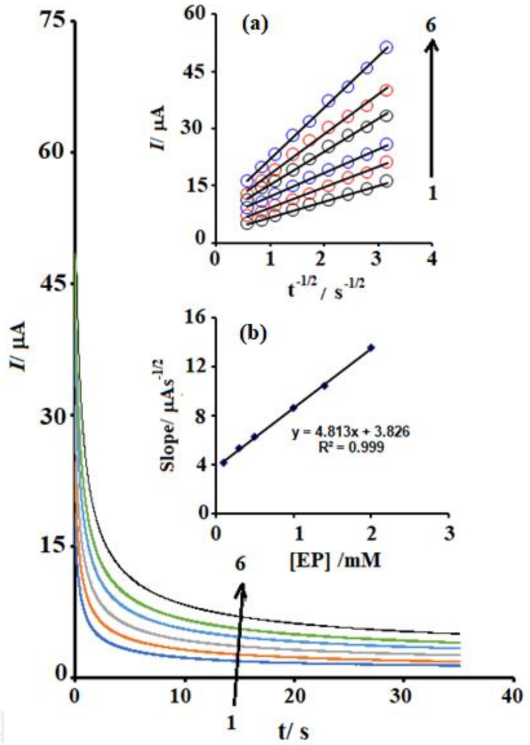

Figure 3. Chronoamperograms recorded at the MF/SPE in 0.1 M PB (pH = 7.0) for various concentrations of EP from 0.1 mM to 2.0 mM (potential step at −400 mV). Inset (a): Plots of I vs. $t^{-1/2}$ based on the observed chronoamperograms. Inset (b): A linear plot of the slopes for the straight lines in Inset A vs. the concentration of EP.

3.4. Analytical Performance of MF/SPE

DOI: 10.30473/ijac.2026.77132.1337

The DPV method was employed to quantify EP in 0.1 M PB at the MF/SPE. Figure 4 shows the DPVs of EP obtained through DPV for different concentrations ranging from 0.1 to 600.0 µM. The peak currents of EP increased with rising concentrations. The peak current of EP is plotted versus its concentration in the inset of Figure 4. It demonstrates linearity from 0.1 to 600.0 µM. The limit of detection (LOD) was calculated based on the equation LOD = $3S_b/m$, where S_b is the standard deviation of measurements of the blank sample, and m is the slope of the calibration curve. Based on the above equation, it was found that the value of LOD was 0.02 µM.

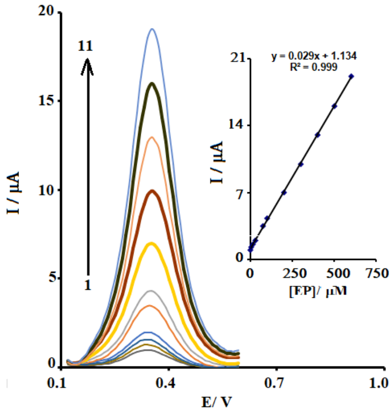

Figure 4. DPVs of MF/SPE in diverse concentrations of EP ranging from 0.1 to 600.0 µM in 0.1 M PB at pH = 7.0. Inset: Plot of Ip vs. concentration for EP determination.

3.5. The Repeatability, Reproducibility and stability of the MF/SPE Sensor

The fabricated electrode (MF/SPE) demonstrated significant repeatability, exhibiting a relative standard deviation (RSD) of 3.8% across six successive measurements conducted with a single electrode. Furthermore, the sensor showed satisfactory reproducibility, with an RSD of 4.3% across six independent measurements performed on six distinct electrodes. The findings indicate that the MF/SPE sensor has satisfactory levels of repeatability and reproducibility in measuring EP.

The stability of the developed sensor (MF/SPE) was studied by keeping the MF/SPE sensor at room temperature for 21 day and detecting EP. After this timeframe, the sensor demonstrated a retention rate of 95.8% of its initial response, thereby suggesting a good level of storage stability for the MF/SPE.

3.6. Selectivity of the MF/SPE Sensor

Selectivity demonstrates the performance of a designed sensor in terms of the response to a specific compound in the presence of other compounds. Therefore, we investigated the sensor's selectivity in response to EP. DPV was conducted using the MF/SPE to detect 50.0 µM of EP in the presence of various potential interferents in 0.1 M PB (pH = 7). The results demonstrated that 250-fold K^+,Ca^{2+}, Na^+, Mg^{2+}, Zn^{2+}, Br^-, and NO_3^-, 200-fold tartaric acid, glucose, sucrose and citric acid, and 50-fold urea, ascorbic acid and uric acid had no interference in sensing of EP.

3.7. Practical Application of the MF/SPE Sensor for EP Detection

To illustrate the suitability and potential of the MF/SPE for practical specimen analysis, the suggested method was employed to quantify EP in urine samples. The investigation of EP content in the real specimens was conducted using the DPV technique along with the standard addition approach. The results for the real specimens are presented in Table 1. The recoveries of the spiked specimens ranged from 96.0% to 104.3%, indicating that the MF/SPE is practical and could be applied for EP determination in real water specimens.

Table 1. Applicability of MF/SPE sensor in the determination of EP (n = 4).

Sample	Spiked (µM)	Found (µM)	Recovery (%)	RSD (%)
Urine	0.0	---	---	---
	5.0	5.12	102.4	3.2
	10.0	9.78	97.8	2.9
	15.0	14.66	97.7	3.1
	20.0	20.93	104.6	3.4

4. Conclusions

In this work, we reported the design of a MF nanocomposite-modified SPE and its utilization for the voltammetric determination of EP. The developed sensor (MF/SPE) demonstrated strong electrical performance and delivered an amplified response for the determination of EP. Additionally, the voltammetric determination of EP was assessed using the MF/SPE, with a linear concentration range from 0.1 to 600.0 µM and an LOD of 0.02 µM. The MF/SPE sensor has good stability, reproducibility, repeatability, and selectivity for the determination of EP. Furthermore, the MF/SPE has the potential to be utilized for EP determination in urine samples, positioning the developed electrode as a promising option for practical applications.

DOI: 10.30473/ijac.2026.77132.1337

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DOI: 10.30473/ijac.2026.77132.1337

تعیین الکتروشیمیایی اپی نین با استفاده از الکترود صفحه چاپی اصلاح شده

سید ضیا محمدی*[۱]، الینا بنی اسدی[۱]، سمیه تاجیک[۲]

[۱]بخش شیمی، دانشگاه پیام نور، تهران، ایران

[۲]مرکز تحقیقات بیماریهای مغز و اعصاب، پژوهشکده نوروفارماکولوژی، دانشگاه علوم پزشکی کرمان، صندوق پستی ۷۶۱۶۹-۱۳۵۵۵، کرمان، ایران

* E-mail: szmohammadi@pnu.ac.ir, szmohammadi@yahoo.com

تاریخ دریافت: ۲۰ تیرماه ۱۴۰۳ **تاریخ پذیرش:**۱شهریور ماه ۱۴۰۳

چکیده

در کار حاضر، یک حسگر ولتامتری یکبار مصرف با استفاده از الکترود صفحه چاپی اصلاح شده با نانوذرات فریت منگنز (MF/SPE) برای تعیین اپی‌نین(EP) طراحی گردید.رفتار الکتروشیمیایی EP در سطح MF/SPE با استفاده از تکنیک‌های ولتامتری پالس تفاضلی(DPV) ، ولتامتری چرخه‌ای (CV)و کرونوآمپرومتری بررسی شد.الکترود MF/SPE فعالیت الکتروکاتالیستی برجسته‌ای را برای تعیین ولتامتری EP نشان داد. تحت شرایط بهینه، جریان پیک وابستگی خطی با غلظت EP در محدوده ۰/۱ تا۶۰۰/۰ میکرومولار نشان داد و حد تشخیص (LOD) ۰/۰۲میکرومولار تعیین شد.علاوه بر این، حسگر MF/SPE مزایایی از جمله تکرارپذیری، تکثیرپذیری، پایداری، ارزان بودن و قابلت کاربردهای عملی را دارد. در پایان، حسگر مبتنی بر MF/SPEبرای تعیین EP در نمونه‌های ادرار مورد استفاده قرار گرقت و نتایج رضایت بخشی بدست آمد.

کلید واژه ها

حسگر یکبار مصرف؛نانوذرات فریت منگنز؛حسگر الکتروشیمیایی؛اپی‌نین.

DOI: 10.30473/ijac.2026.77132.1337