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Full Paper

A Sensitive Simultaneous Determination of Uric Acid, Norepinephrine and Indomethacin using a Cadmium Sulfide Nanoparticles/Multi-Walled Carbon Nanotubes Modified Gold Electrode

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Abstract- In this study a novel method was developed to fabricate cadmium sulfide nanoparticles/multiwalled carbon nanotubes composite modified gold electrode (CdSNPs/MWCNTS/AuE) to measure trace amounts of norepinephrine(NE), indomethacin (IND), and uric acid (UA) simultaneously. Electrochemical investigations were carried out using cyclic voltammetry (CV), differential pulse voltammetry (DPV) and chronoamprometery (CA) methods. Using DPV method under optimum condition, the NE anodic peak current represented a linear relationship in the two concentration ranges of 0.3 to 100.0 µM and 100.0 to 500.0 µM. For UA, the corresponding anodic peak current showed linear ranges from 0.5 to 100.0 µM and from 100.0 to 350.0 µM, and IND the corresponding linear range was between 2.0 to 80.0 µM, respectively. Detection limits have been calculated equal to 0.16 µM for NE, 0.09 µM for UA, and 0.46 µM for IND, respectively. The modified electrode has been applied for the determination of NE, UA and IND in human urine and blood serum with satisfactory results.

Keywords- Uric acid; Norepinephrine; Indomethacin; Multi-walled carbon nanotubes; Cadmium sulfide nanoparticles; Modified electrode

1. INTRODUCTION

Norepinephrine (NE) is a hormone secreted from the adrenal medulla following the command of the brain. It is one of the catecholamines of the sympathetic system, which acts as both mediators of the nervous system (neurotransmitter) and the hormone [1]. Several analytical techniques reported for the determination of NE in pharmaceutical preparations or biological samples, including spectrophotometry [2], high performance liquid chromatography [3], capillary electrophoresis [4], and fluorimetry [5]. NE is a compound which can be oxidized electrochemically and therefore several articles on electrochemical determination of NE have been reported [6, 7].

Indomethacin (IND) is a non-narcotic analgesic and a nonsteroidal anti-inflammatory drug. It is used for the relief of moderate to severe arthritis. An adverse effects caused by this drug is observed in 30-60% of consumers. Often side effects of this drug are dose-dependent. Most common side effects are gastrointestinal and neurological side effects indomethacin [8]. Variety of techniques including gas chromatography [9, 10], mass spectrometry [11], high performance liquid chromatography [12], and high performance liquid chromatography- mass spectrometry [13] have been reported in the literature for the determination of IND.

Uric acid (UA) is the primary product of purine metabolism in the human body and high levels of UA are symptoms of many diseases [14]. UA is present in saliva, urine, plasma and human blood serum [15]. Various methods like chemiluminescence [16], high-performance liquid chromatography [17], capillary electrophoresis [18] and electrochemical techniques [19] were used for determination of UA.

Some of analytical methods which have been used for determination of NE, IND and UA have disadvantages such as high costs, long analysis time and required sample pretreatments. Therefore developing an analytical method that is simple, inexpensive, sensitive and accurate for the determination of these analytes is important. The electrochemical methods due to simplicity, speed, sensitivity, and pretreatment of sample provide more attentions.

NE is able to increase blood pressure in human body, so it was often used as a medicine to treat people with very low blood pressure. Previous report indicates that intake IND as a medicine can also increase blood pressure in people [20]. Therefore usage of both NE and IND for people could have side effect of dangerous high blood pressure. In addition as it was described earlier, UA is presented in human body and it may cause various diseases in high doses. Therefore fabrication of a method for simultaneous determination of NE, IND and UA would be useful.

Carbon nanotubes (CNTs) have become an important subject of research in various fields of nanotechnology over the past decade due to the unique properties of other carbonaceous materials and nanoparticles [21]. Both forms of CNTs, i.e. single-walled CNTs (SWCNTs) and multi-walled CNTs (MWCNTs), have shown specific properties such as functional surfaces, good conductivity, small dimensions, great chemical stability, modifiable sidewall

and great mechanical strength [22-24]. Due to these unique properties, they are being used in widespread areas, including nano-electronics [25], catalysis of redox reactions [26,27], and electrochemical sensors [28, 29].

Cadmium sulfide nanoparticles (CdSNPs) have been extensively studied due to their unique photocatalytic and electrocatalytical properties [30,31]. Different methods are available for the preparation of CdSNPs namely evaporation [32], spray pyrolysis [33], sputtering [34], chemical method [35], metal organic chemical vapor deposition [36], and sol-gel spin coating [37]. Among these methods, chemical precipitation method is considered to be the most appropriate due to its ease, simplicity, inexpensive and single step method [38].

In this study, we report the use of new gold electrode modified with CdSNPs/MWCNTS composite as a sensitive sensor for simultaneous measurement of NE, IND and UA. To the best of our knowledge this the first report on electrochemical determination of NE, IND and UA. The modified electrode showed good electrochemical responses under the optimum conditions, with high sensitivity, low detection limit, and wide linear dynamic range. In addition, the proposed sensor was successfully used for simultaneous determination of NE, IND and UA in real samples.

2. EXPERIMENTAL

2.1. Chemicals and reagents

All reagents in the electrochemical measurements and analysis were of analytical grade and they were used as received. NE, UA and IND were purchased from Sigma-Aldrich chemical company. MWCNTs (purity > 95%) with average number of walls of 3–15, and tube length of 1–10 μm were purchased from Plasma Chem GmbH Company. The stock standard solutions of 10 mM IND, 10 mM UA and 10 mM NE were freshly prepared in 0.1 M phosphate buffer solutions (PBS) with pH of 7. The most of electrochemical experiments on NE, UA and IND were carried out in the 0.1 M PBS, otherwise is stated. All solutions were prepared by triply distilled water. Fresh human serum samples were obtained from Razi Institute of Vaccine and Serum Company (Tehran, Iran). The human serum and urine samples were filtered and diluted 50 times using a 0.1 M PBS) pH=7)and used for the determination of the analytes in the matrix by spiking with NE, UA and IND compounds.

2.2. Apparatus

All electrochemical experiments were carried out using an AUTOLAB 30V devices Potentiostat / Galvanvastat (manufactured by ECO CHEMIE) that was connected to Metrohm Stand VA 663. Electrochemical data were recorded and analyzed using GPES software version 4.9. All electrochemical potentials have been reported relative to the Ag / AgCl reference electrode. The pH meter of Metrhom 744 was used to adjust pH of solution after

precise calibration.

2.3. Synthesis of CdSNPs

Initially 1 g of $Cd(CH_3COO)_2$,0.25g SDS dissolved in 100 ml distilled water. Subsequently 0.28g of thiourea was dissolved in 100 ml of distilled water and then it was added to the previous solution. Afterward solution of NaOH (1 M) was slowly added to the solution to obtain pH of 10 in solution. The solution was treated under microwave radiation (680 W) for 7 min. The orange precipitate is centrifuged and then it was washed several times with distilled water during filtration. Finally the product was dried in oven for 24 h to obtain CdSNPs.

2.4. Preparation of CdSNPs/MWCNTS/AuE

Prior to modification, the AuE was first polished with 0.3 and 0.05 μm aluminum oxide aqueous slurry on polishing cloth and then it was rinsed thoroughly with triply distilled water. The AuE was then cleaned by sonication for 5 min, first in ethanol and then distilled water, and then dried under nitrogen gas flow. A stock suspension solution of CdSNPs/MWCNTs in DMF was prepared by dispersing weighed amounts of MWCNTs (1mg/ml) and CdSNPs (1mg/ml) suspensions in weight ratio percent of 85:15 in 1 mL DMF using an ultrasonic bath. Then 30 μL of the prepared homogeneous suspension was cast on the gold electrode with a microsyringe. The electrode was then dried at room temperature to obtain the modified electrode. The fabricated CdSNPs/ MWCNT/ AuE was placed in the electrochemical cell containing 0.1 mol L^{-1} PBS (pH=7) and then several cycles in the potential windows of -0.1 to 1 V were performed using the cyclic voltammetry method to obtain stable responses.

2.5. General Procedure

The general procedure used to obtain voltammograms was as follows: 10 ml sample solution including 0.1 M PBS with pH of 7.0 and appropriate amount of NE, IND and UA was transferred into a voltammetric cell and electrochemical experiments were carried out.

The electrochemical oxidations of NE, UA and IND were performed in the range of -1.0 to 0.9 V at CdSNPs/ MWCNT/ AuE. The oxidative peak potential of NE appeared about 0.1 V and the oxidation peak potentials of UA and IND appeared about 0.25 V and 0.7 V, respectively.

The concentrations of species were measured using their corresponding oxidation peak currents. The electrode was regenerated by successive washing with triply distilled water, and then 0.5% sodium hydroxide solution. The electrode was finally rinsed carefully with distilled water to remove all adsorbates from the electrode surface and to provide a fresh surface before running subsequent experiments.

3. RESULTS AND DISCUSSION

3.1. Characterization of CdSNPs/ MWCNT/ Au

Figs. 1A and 1B show the FESEM images of the CdSNPs and MWCNTs, respectively. As can be seen in Fig. 1A, CdSNPs are approximately 20- 30 nm in diameter and clearly agglomerated. Fig. 1C shows an image of the CdSNPs/MWCNTs nanocomposite. It can be seen that the CdSNPs are well distributed on MWCNTs. Therefore, the modified electrode is expected to exhibit higher electrical conductivity. Fig. 1D shows the EDX analysis results of CdSNPs which confirm the presence of Cd and S.

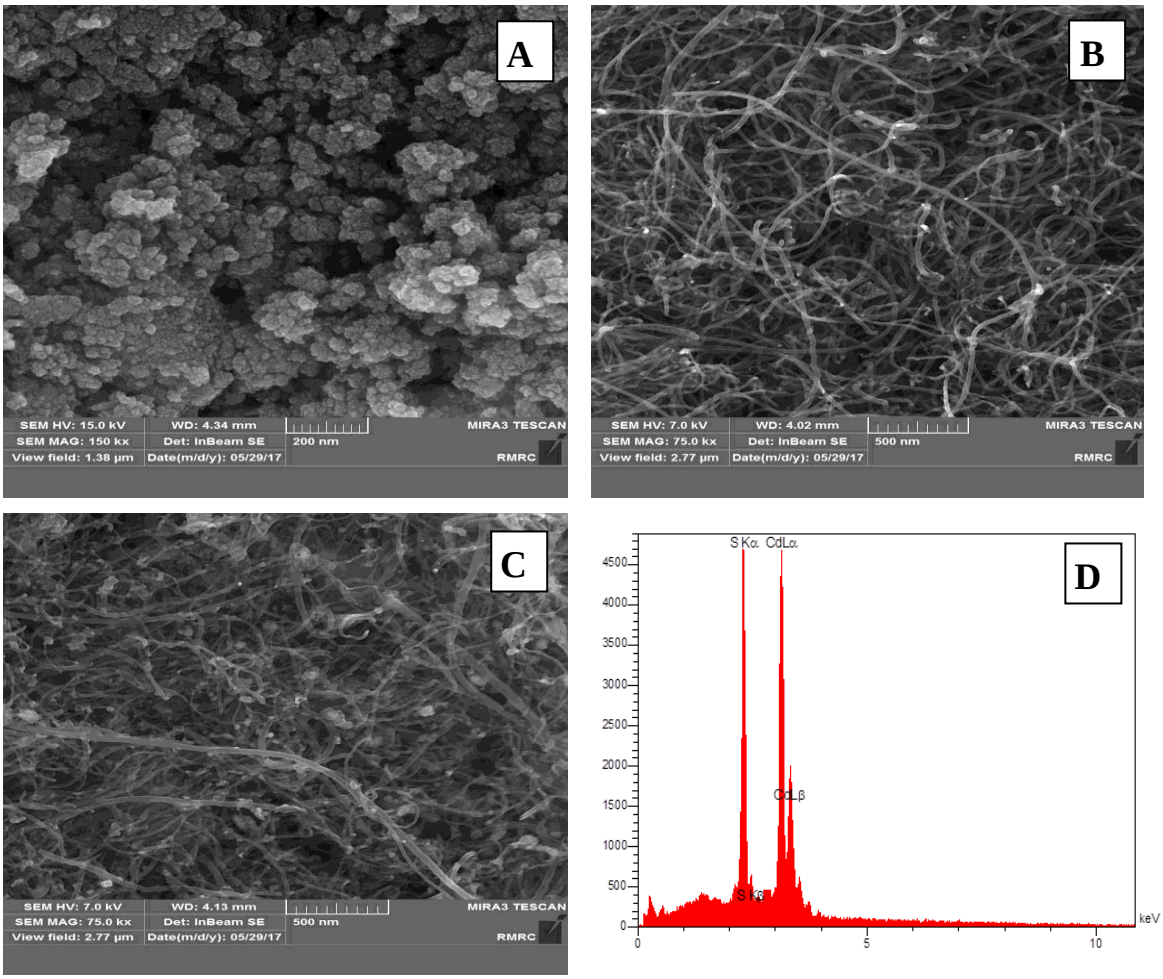

Fig. 1. FESEM images of (A) CdSNPs, (B) MWCNTs, (C) CdSNPs/MWCNTs and (D) EDX results of CdSNPs

Fig. 2 shows XRD pattern of CdSNPs. Peaks were observed at 27°, 44° and 52° with the corresponding *h k l* values of 0 0 2, 1 1 0 and 1 1 2, which are matched well with those in the JCPDS card (File No. 41-1049, CdS) [39]. The XRD results can be indexed as hexagonal wurtzite structure of CdS with prominent peaks corresponding to the reflections at (111), (220) and (311) planes. The broadened peaks are showing that the sizes of the particles are in

nanorange [40].

The effect of modification of the electrode on active surface area was characterized by cyclic voltammetry using CdSNPs/ MWCNTs/AuE, MWCNTs/ AuE, and AuE (not shown). For this purpose, both modified and unmodified electrodes were immersed subsequently in 4.0 mM potassium hexacyanoferrate(II) with PBS (pH=7.0) and voltammograms were recorded at various scan rates. The cyclic voltammograms showed that $K_4[Fe(CN)_6]$ exhibited a pair of reversible redox peaks at the bare and modified AuE, however the redox peaks for the modified electrodes are larger than unmodified AuE. The results showed that under the same conditions, the corresponding peak currents versus the square root of the sweep rate for all types of modified and unmodified AuEs, are linear. These outcomes indicate that the electrode process is controlled by diffusion at all types of gold electrodes. Therefore they follow with Randles-Sevcik equation (Eq. 1) [41]:

$$i_p = (2.69 \times 10^5)\, n^{3/2} A C_o D^{1/2} \nu^{1/2} \quad (1)$$

According to Randles-Sevcik equation and slopes of the equations for all types of AuEs, the surface area of MWCNTs/AuE and CdSNPs/MWCNTS/AuE were estimated to be 19.2 and 22.7 times larger than the unmodified AuE approximately. It can be concluded that using of a CdSNPs/MWCNTS leads to higher electrochemically active surface area than MWCNTs alone.

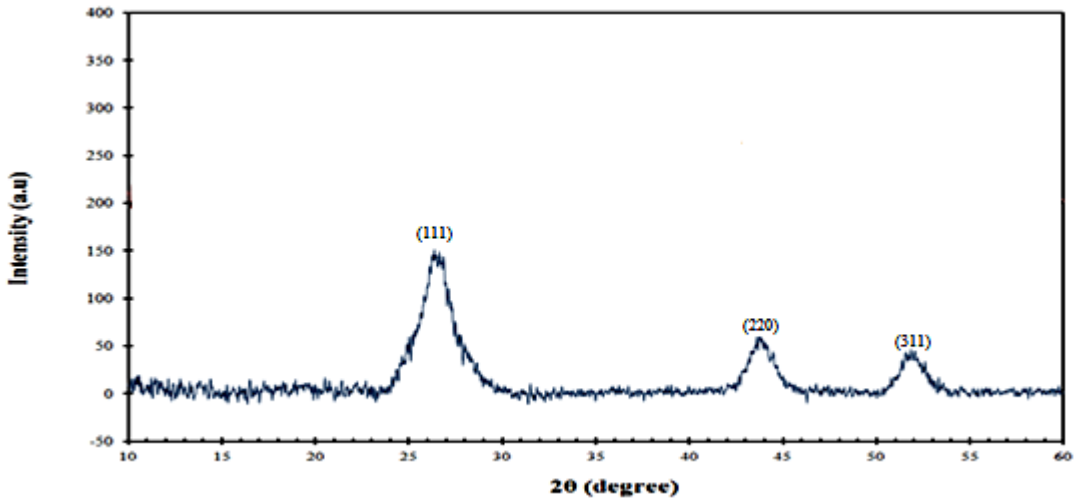

Fig. 2 The XRD patterns of the synthesized CdSNPs

3.2. Optimization of Operational Parameters

3.2.1. Type of buffer solution

The amount of anodic peak currents of analytes were measured in different solutions, including phosphate buffer, Britton–Robinson buffer, ammonia buffer and acetate buffer

solutions at pH = 7.0 and concentration 0.1 M of the buffer solutions (not shown). Comparison of the analytes anodic peak currents of the solutions with DPV method represented that the best sensitivity for NE, IND and UA was appeared in PBS. Therefore, PBS was chosen for further experiments.

3.2.2 pH effects

DPV results showed that corresponding oxidation peak currents and peak potential of the analytes are depended to the pH of sample. The effect of the pH values on the voltammetric behavior of analytes at the CdSNPs/MWCNTS/AuE were carefully investigated in the pH range of 4.0 to10.0 and concentration of 0.1 M of PBS as shown in Figure 3. The results of experiments represented that NE oxidation peak current increased gradually from pH = 4.0 to 7.0 and then decreased with pH change from 7.0 to 10.0 (Fig. 3A). The peak currents of NE and UA were increased from 4.0 to 7.0 and they reached to maximum amount at pH = 7.0 and then decreased at pH > 7.0. In case of IND, peak current decreased with changing pH ranging from 4.0 to 10.0 with slight increase at pH of 7. So, the phosphate buffer with a pH of 7.0, which is close to biological pH value, was selected as the optimum electrolyte for the simultaneous determination of analytes in the mixture samples.

Fig. 3B showed that the relationships between the oxidation peak potentials of analytes and the pH of samples were linear, and the regression equations were as follows:

NE:

E_{pa} *vs.* Ag/AgCl (V) = 0.6002 – 0.0667 pH (R^2 = 0.993) (2)

IND:

E_{pa} *vs.* Ag/AgCl (V) = 0.8874 – 0.0233pH (R^2 = 0.990) (3)

UA:

E_{pa} *vs.* Ag/AgCl (V) = 0.6691 – 0.0566pH (R^2 = 0.996) (4)

For NE and UA the slopes of the equations are close to the Nernstian amounts (0.0592 m/n) which suggest that n and m are equal to the number of electron and proton transferred that are involved in the electrochemical oxidation, respectively. These results are in accordance with previous report on electrochemical oxidations of NE [42] and UA [43] with two electrons and two protons mechanisms. However, the slope of oxidation potential versus pH for IND is equal 0.0233. The results suggest that the number of electron and proton transferred are not equal and for every two electron, one proton is transferred [44].

3.2.3. Effects of accumulation time

The accumulation time is an influential parameter affecting the response of the CdSNPs/MWCNTS/AuE towards oxidation of NE, IND and UA. In order to study effect of

accumulation time, differential pulse voltammetry (DPV) experiments in solution of 30 µM NE, 50 µM IND and 70 µM UA were carried out in PBS (pH=7) (Fig. 4).

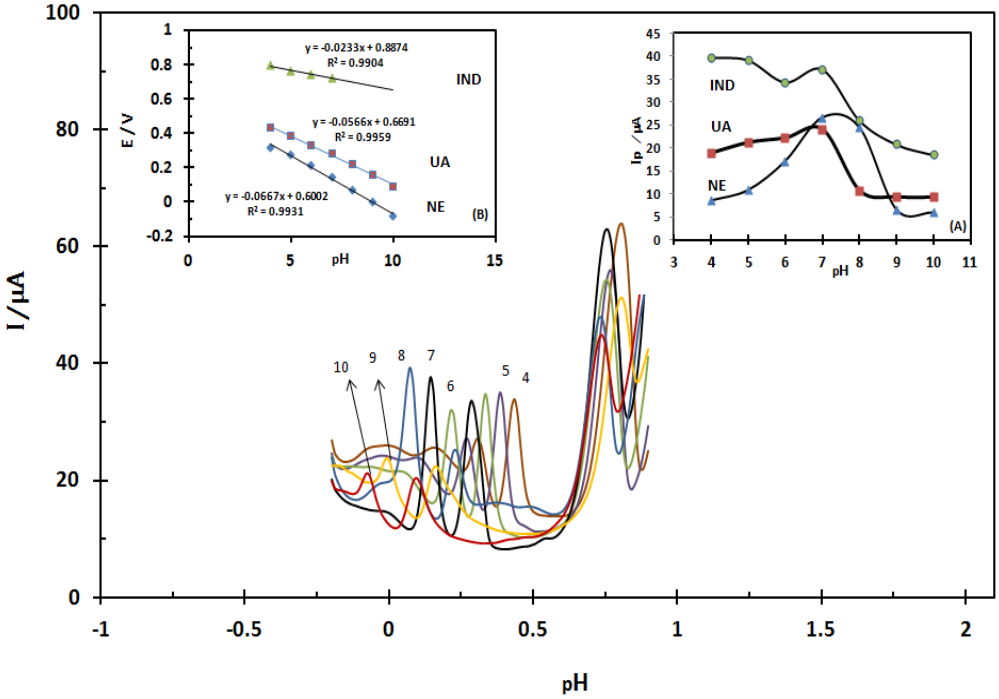

Fig. 3. Effect of pH on the differential pulse voltammograms of 50 µM NE, 30 µM IND and 50 µM UA compounds at CdSNPs/MWCNTs/AuE in 0.1M PBS. Insets: (A) Plot of peak potentials of NE, IND and UA as a function of pH of buffer solutions. (B) Plots of the corresponding oxidation peak currents of the analytes as a function of pH of buffer solutions

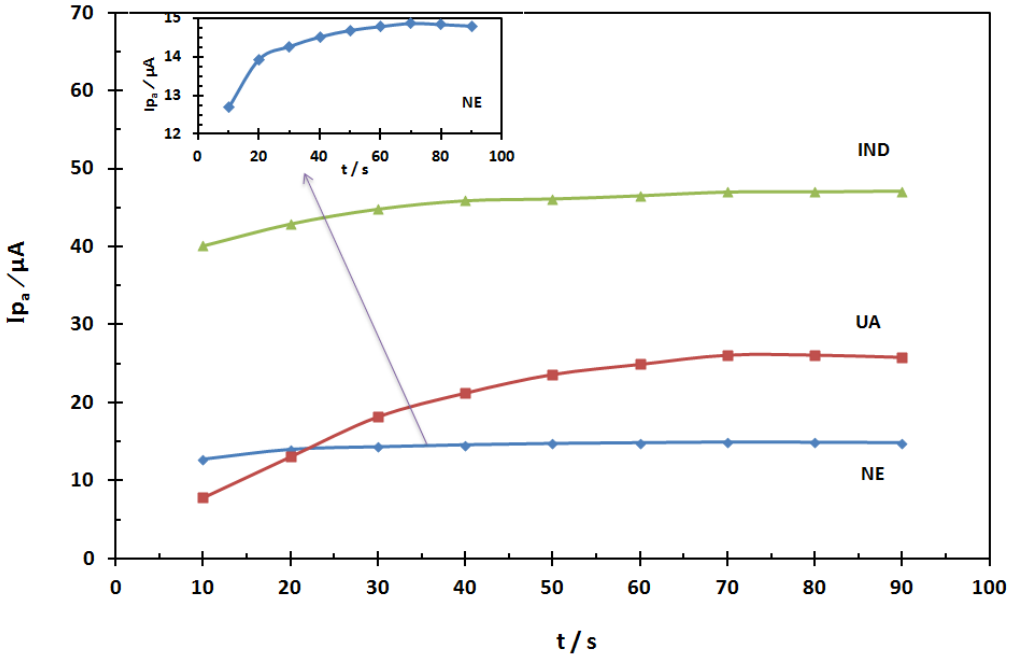

Fig. 4. Effects of accumulation time on oxidation peak currents of 30 µM NE, 70 µM UA and 50 µM IND in 0.1 M PBS (pH= 7.0) at CdSNPs/MWCNTs/AuE

The results showed that the oxidation peak currents the analytes increased sharply up to 70 s and then they leveled off at longer time. Therefore, the accumulation time of 70 s was chosen as the optimum time for further experiments.

3.3. Electrochemical Studies of NE, UA and IND on CdSNPs/MWCNTS/AuE

The electrochemical behaviors of a mixture of 250.0 µM of NE, 200 µM of UA and 80 µM IND were studied using DPV at bare AuE, MWCNTs/AuE and CdSNPs/MWCNTS /AuE in 0.1 M PBS and pH of 7.0 at accumulation time of 70 s (Fig. 5). Differential pulse voltammograms a, b, and c displays the analytes data at the AuE, MWCNTs/AuE, and CdSNPs/MWCNTS/AuE, respectively. It is obvious that the CdSNPs/MWCNTS /AuE represents enhanced electrocatalytic oxidation with higher peak current for the oxidation of the analytes in comparison to the both two bare AuE and MWCNTs/AuE. So, it is concluded that the CdSNPs/MWCNTS /AuE can be used for a highly sensitive electrochemical determination of NE, UA and IND, simultaneously.

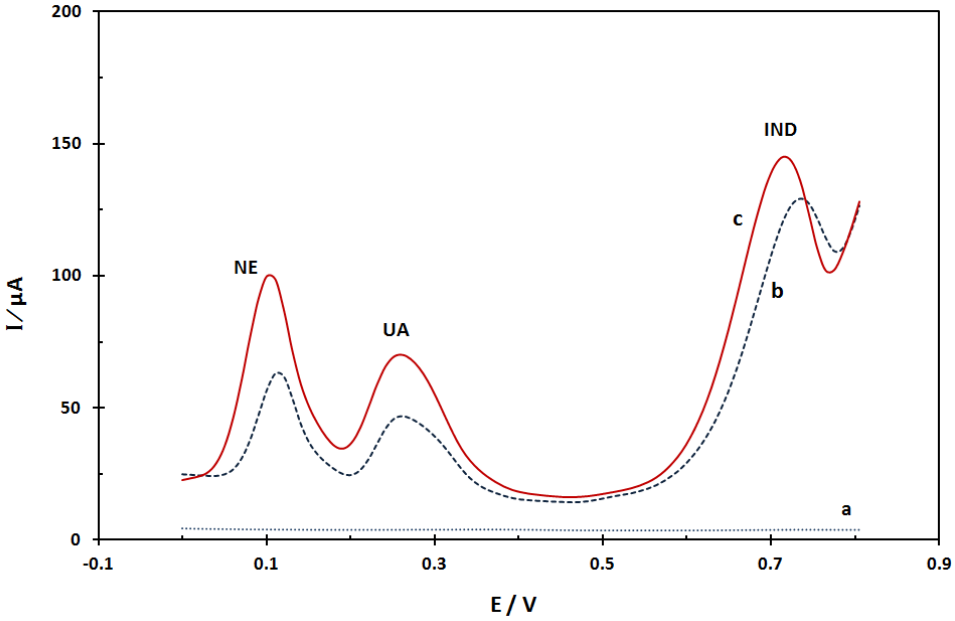

Fig. 5. Differential pulse voltammograms of 250 µM NE, 200 µM UA and 80 µM IND at (a) AuE, (b) MWCNTs/AuE and (c) CdSNPs/MWCNTs/AuE in 0.1 M PBS (pH= 7.0) at accumulation time of 70 s

To study the influence of the scan rate on the oxidation peak potential (Ep_a) and peak current of NE, UA and IND at the CdSNPs/MWCNTS /AuE in 0.1 M PBS (pH = 7.0), cyclic voltammetry experiments with various scan rates were carried out (Fig. 6). The results showed that corresponding Ep_a of the analytes were shifted to more positive potentials with increasing scan rate (ν), confirming the kinetic limitation of the electrochemical reaction. The plot of anodic peak current of 50.0 µM of NE was proportional to the scan rate over the range

of 10.0 to 160.0 mVs^{-1}. However, the plot of anodic peak currents for 25.0 µM of UA and IND were linear over the range of 10.0 to 180.0 mVs^{-1} in the PBS. The corresponding linear regression equations were as follow:

NE:

$I_{(\mu A)} = 419.77\ \nu + 7.5895$ $R^2 = 0.9916$ (5)

UA:

$I_{(\mu A)} = 108.3\ \nu + 6.7352$ $R^2 = 0.9939$ (6)

IND:

$I_{(\mu A)} = 563.87\ \nu + 0.2554$ $R^2 = 0.9988$ (7)

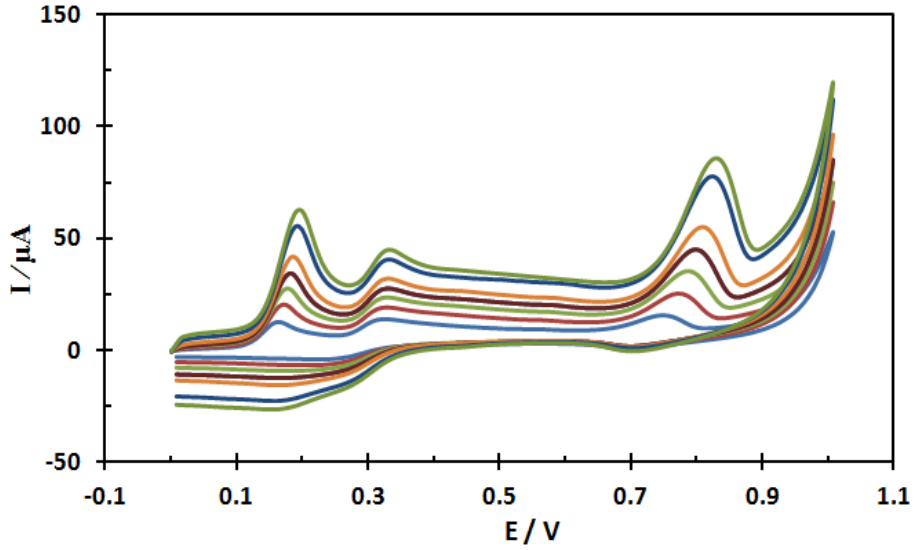

Fig. 6. Cyclic voltammograms of 50 µM NE and 25 µM UA and 25 µM IND in 0.1 M phosphate buffer solution (pH = 7.0) at different scan rates (from inner to outer) 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, $V.s^{-1}$

The results confirmed that electrochemical oxidation of NE, UA and IND are adsorption control at such scan rates. However, for NE at scan rate ranges from 160.0-500.0 mVs^{-1} and for UA, from 180.0 to 400.0 mVs^{-1} and for IND, from 180.0-600.0 mVs^{-1}, the plot of currents versus scan rate deviates from linearity and the peak currents relate linearly with the square root of the scan rate ($\nu^{1/2}$). These results indicate that diffusion controlled mechanisms of the reactions at those scan rate ranges. The linear regression equations for the analytes are as follows:

NE:

$I_{(\mu A)} = 239.41\ \nu^{1/2} - 26.078$ $R^2 = 0.9946$ (8)

UA:

$I_{(\mu A)} = 92.02\ \nu^{1/2} - 14.545$ $R^2 = 0.9896$ (9)

IND:

$$I_{(\mu A)} = 414.83\ \nu^{1/2} - 76.215 \qquad R^2 = 0.9981 \qquad (10)$$

3.4. Linear dynamic range and detection limit of the method

The differential pulse voltammograms (DPVs) of NE, UA and IND were obtained in various concentrations at CdSNPs/MWCNTS /AuE in PBS under optimum conditions to obtain corresponding calibration curves (Fig. 7).

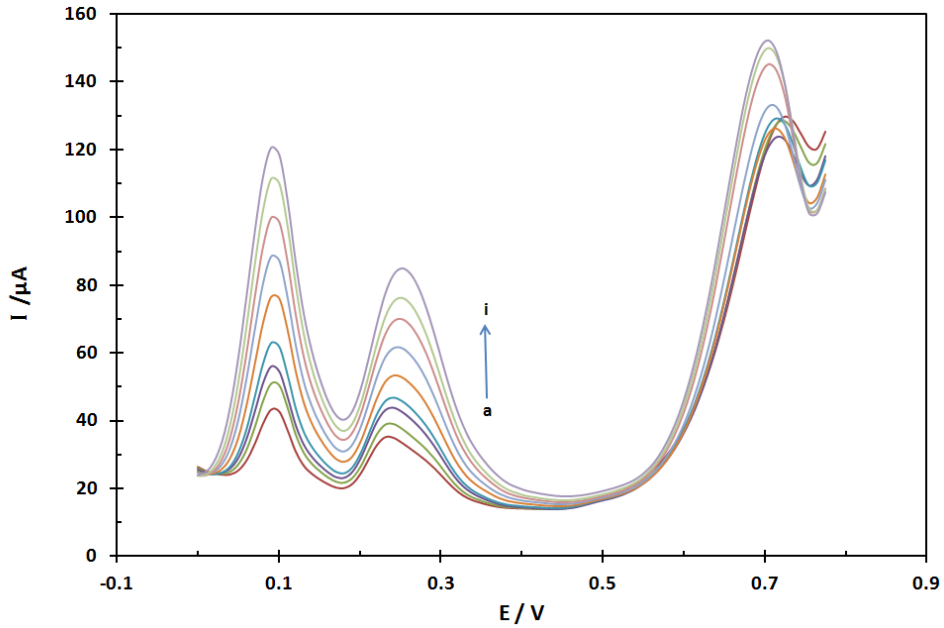

Fig. 7. Differential pulse voltammograms for different concentrations of the mixture of analytes with concentrations of (a) 60,60,35 (b) 40,70,80, (c) 80,100,50 (d) 100,150,60 (e) 150,200,70 (f) 200,250,80 (g) 250,300,90 (h) 300,350,100 (i) 350,400,120 µM of NE, UA and IND respectively, in 0.1 M PBS (pH = 7.0) under optimum conditions

The anodic peak currents of NE were proportional to the concentration in two concentration ranges of 0.3–100.0 µM with a linear regression equation I_p (µA) = 0.474 C (µM) + 0.900 (R^2 = 0.994) and 100.0-500.0 µM with a linear regression equation I_p (µA) = 0.128 C (µM) +37.77 (R^2 = 0.990). Linearity relationship anodic peak currents versus concentration was also obtained in two concentration ranges of 0.5-100.0 µM with a linear regression equation I_p (µA) = 0.3489 C (µM) +1.2354 (R^2 = 0.996) and 100.0-350.0 µM with a linear regression equation I_p (µA) = 0.0856 c (µM) +27.75 (R^2 = 0.987) for UA. The anodic peak current of IND was proportional to the concentration in the range of 2.0-80.0 µM with a linear regression equation I_p (µA) = 0.8732 C (µM) +3.2953 (R^2 = 0.993). The detection limit was obtained 0.16 µM, 0.09 µM and 0.46 µM for NE, UA and IND based on the signal-to-noise ratio (S/N) of 3, respectively.

To obtain calibration curves of NE, UA and IND at CdSNPs/MWCNTS /AuE the chronoamperometry method was employed (Fig. 8). The results showed that the peak

currents of NE were proportional to concentration between 1.0 to 580.0 µM with regression equation of I (µA)=0.3094 C (µM)+2.3664 and a correlation coefficient of R^2=0.9943. The calibration plots of UA were linear between two ranges of 1.0-96.0 µM with regression equation of I (µA) = 0.181 C (µM)+0.4743 (R^2=0.994) and the range of 96.0-384.0 µM with regression equation of I (µA)=0.0995 C (µM)+8.1 (R^2=0.989). The currents of IND were proportional to the concentration between 1.0-96.0 µM with regression equation of I (µA)=0.1536 C (µM)+0.4255 (R^2=0.998). The corresponding detection limits were obtained 0.21, 0.35 and 0.41 µM for NE, UA and IND, respectively.

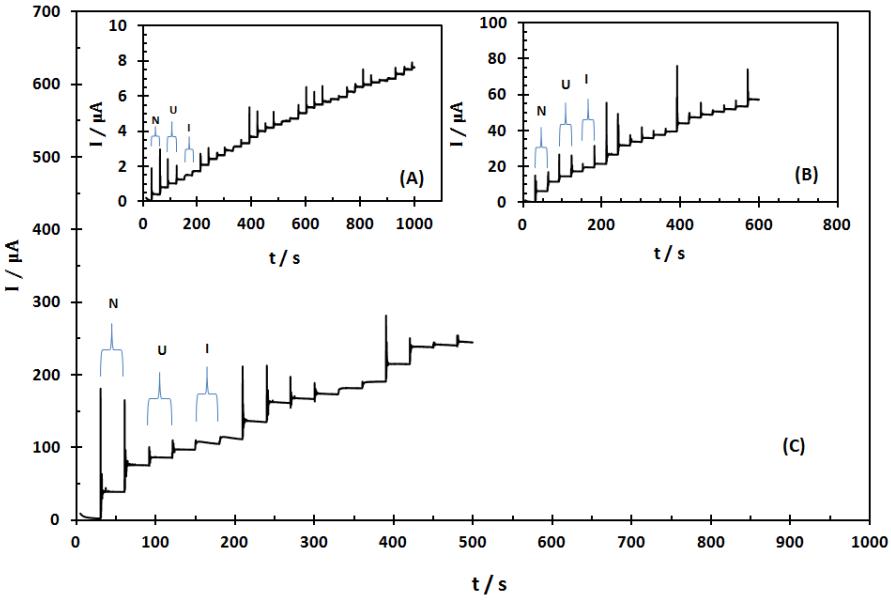

Fig. 8. Chronoamperometric responses at rotating CdSNPs/MWCNTs/AuE (rotating speed 2500 rpm) held at 0.7 V in phosphate buffer solution (pH = 7.0) for simultaneous determination of NE (N), IND (I) and UA(U)by successive additions of (A) 1 µM of NE, UA and IND; (B) (c) 12 µM of three analytes; (C) 96 µM of the analytes.

3.5. Stability and repeatability of the CdSNPs/MWCNTS /AuE

Stability of the CdSNPs/MWCNTS /AuE was assessed, in and out of the solution in a special time period, by determining the reduction of peak currents during repetitive DPV measurements of three analytes after storing the electrode in 0.1 M PBS at pH of 7.0. To evaluate the stability of the CdSNPs/MWCNTS /AuE in wet condition, the peak currents of successive measurements by DPV in the mixture solution of 100 µM NE and UA and 50 µM IND, were determined. After ten hours, the results showed the relative standard deviation (RSD) of 6.9%, 7.8% and 6.3% for NE, UA and IND, respectively. These results signified that the CdSNPs/MWCNTS /AuE had a good Stability in the solution. However, storing the CdSNPs/MWCNTS /AuE in air for 10 days reflected only about 5.6%, 7.2% and 8.5%

current reduction for NE, UA and IND, respectively. The results proved that the CdSNPs/MWCNTS /AuE had a very good stability and it has potential for practical applications.

To evaluate the repeatability of the CdSNPs/MWCNTS /AuE, DPV measurements were repeated in the series of determinations in the mixture of 70 µM of NE, 50 µM UA and 50 µM IND. The results of eight successive measurements represented good repeatability with relative standard deviation (RSD) equal to 0.81% for NE, 0.51% for UA and 0.42% for IND. The small amounts of the RSD for CdSNPs/MWCNTS /AuE, confirmed that the electrode had a high stability during continuous voltammetric measurements, and therefore the sensor was not affected by surface contaminations.

3.6. Effect of Interferences and Analytical Applications

To investigate the effects of common interfering species, the solutions of 50 µM NE, 50 µM UA, and 25 µM IND were used. The tolerance limit for each potential interfering, which is defined as the concentration of the interfering that gives an error less than 5% in determination of all three analytes before and after added interfering compounds, are listed in Table 1. According to the results, it seems that the proposed method is free from interference from the common interferant.

Table 1. Maximum tolerable concentration of interfering species, under optimum conditions

Interfering species	NE	UA	INd
	$C_{in\ t}$(µM)	C_{int} (µM)	C_{int} (µM)
Tyrosine	500	350	200
Aspirin	1000	600	600
L - Glutamic Acid	300	450	800
Ascorbic acid	250	150	200
Aspartic acid	750	650	500

The proposed method was successfully applied to the simultaneous determination of NE, UA and IND in human urine (Table 2) and human blood serum (Table3) in PBS at pH of 7.0 using DPV method. The samples were diluted 20 times before analysis and spiked with appropriate amounts of each analytes. In order to prevent any matrix effect the concentrations of analytes were calculated using standard additions method. The good recoveries which was obtained from spiked samples, providing more evidence, that the proposed method is a

reliable for the simultaneous and direct determination of NE, UA and IND in biological fluids.

Table 2. Determination of NE, UA and IND in diluted human urine samples, under optimum conditions

Samples	Analytes	Added (μM)	Found[a] (μM)	RR (%)	RSD (%) (n = 5)
Sample 1	NE	0	<LOD	-	-
	UA	0	31.7	-	1.4
	IND	0	<LOD	-	-
Sample 2	NE	25	26.46	105.8	1.8
	UA	10	44.09	105.7	1.8
	IND	25	27.04	108.2	1.2
Sample 3	NE	150	145.31	96.87	1.5
	UA	150	185.42	102.05	1.9
	IND	70	68.76	98.23	1.9

[a] Concentration of NE, UA and IND in spiked samples that was found by the proposed method

Table 3. Determination of NE, UA and IND in diluted human blood serum samples, under optimum conditions

Samples	Analytes	Added (μM)	Found[a] (μM)	RR (%)	RSD (%) (n = 5)
Sample 1	NE	0	<LOD	-	-
	UA	0	22.18	-	1.8
	IND	0	<LOD	-	-
Sample 2	NE	20	21.06	105.3	1.7
	UA	10	31.59	98.2	2.5
	IND	20	21.11	105.6	2.1
Sample 3	NE	150	146.4	97.6	1.4
	UA	150	176.51	102.05	2.0
	IND	70	68.32	97.6	1.8

[a] Concentration of NE, UA and IND in spiked samples that was found by the proposed method

4. CONCLUSION

In this work a modified CdSNPs/MWCNTS /AuE was introduced as a novel sensor for simultaneous determination of NE, UA and IND. The proposed modified electrode showed very high sensitivity for the simultaneous determination of the analytes under the optimum conditions. This improvement in sensitivity can be due to the excellent electro-catalytic performance and high electro-active surface area of the composite. Rapid determinations of NE, UA and IND in biological samples were realized through real sample analysis without any time consuming pretreatments. The interfering studies of some species showed no significant interference in determination of the analytes. The simple fabrication procedure,

wide linear range, low detection limit and high stability are benefits of the modified electrode. The results showed that the modified electrode have great potential for analytical applications in simultaneous determinations of NE, UA and IND.

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