

Full Paper

Nanomolar Simultaneous Determination of Amlodipine and Uric acid at the Novel Carbon Paste Electrode Modified with Magnetic Carbon Nanotubes/Diatomite Earth Composite

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Abstract- In this work, we use synthesized magnetic carbon nanotubes/diatomite earth composite (CNTs/DE) to fabricate the novel modified carbon paste electrode (CNTs/DE/CPE). The modified electrode was developed and used as a sensitive electrochemical sensor for simultaneous determination of amlodipine (AML) and uric acid (UA). Cyclic voltammetry (CV), differential pulse voltammetry (DPV) and chronoamperometry (CA) methods were used for the measurements. The presence of the CNTs/DE in the electrode composite leads to rapid acceleration in electron transfer reaction of AML and UA at CNTs/DE/CPE. Under optimized conditions and using DPV method, the modified sensor provides a linear response versus UA and AML concentrations in the range of 0.02–250 and 0.04–140 μM and with a detection limit of 0.011 μM and 0.021 μM (S/N=3), respectively. The fabricated sensor offered numerous advantages such as excellent sensitivity, good stability and high selectivity toward UA and AML determination. The modified electrode was used for determination of UA and AML in human urine and serum with satisfactory results.

Keywords- Amlodipine, Uric acid, Carbon nanotubes/Diatomite earth composite, Carbon paste electrode

1. INTRODUCTION

There are a lot of reports on applications of the carbon nanotubes (CNTs) in various fields such as catalysis of redox reactions [1-3], nanoelectronics [4], electrochemical sensors [5, 6], due to their unique structures, high stabilities, high surface to volume ratios and low resistivity. Electrochemical sensors based on CNTs have received a lot of attention [7]. There are several methods for the synthesis of CNTs with different properties [8]. Arc discharge [9], laser vaporization [10] and chemical vapor deposition (CVD) are the common techniques for preparing the nanotubes. In addition, various substrate materials such as titana, alumina, nanoclay, diatomite earth (DE) etc. [11]. However, DE has many useful features. It is a naturally occurring, soft, siliceous sedimentary rock that could be easily crumbled into a fine powder with various sizes [12,13]. In addition it has a porous structure, low cost and readily available as a mineral material. Impregnation method was used for preparation of diatomite support by using aluminum nitrate and diatomite and then the CNTs were synthesized on the surface of diatomite as a substrate (CNTs/DE). We expect CNTs/DE provide high surface area and electrocatalytic activity. Therefore we used it to modify carbon paste electrode (CPE) to introduce the first application of CNTs/DE in electroanalytical purposes.

Amlodipine (AML, 3-ethyl 5-methyl 2-[(2-aminoethoxy) methyl]-4-(2-chlorophenyl)-6-methyl-1,4-dihydropyridine-3,5-dicarboxylate) is in a group of drugs called calcium channel blockers [14]. AML relaxes (widens) blood vessels and improves blood flow. AML is used to treat high blood pressure (hypertension) or chest pain (angina) and other conditions caused by coronary artery disease. Recent literature research reported numerous analytical methods for determination of the AML such as: high-performance liquid chromatography [15,16], electrophoresis [17], gas chromatography [18] and spectrophotometry [19-21]. However, these techniques may suffer from some disadvantages such as requirement for sample pretreatment, in some cases low sensitivity or selectivity, high costs and time-consuming analysis. Therefore electrochemical methods for determination of the AML or other analytes have received considerable interest because of the important advantages such as lower cost, good sensitivity and high speed [22-31].

Uric acid (UA, 2,6,8-tridroxypurine) is the primary product of purine metabolism in the human body and high levels of UA are symptoms of many diseases [32,33]. UA is present in saliva, urine, plasma and human blood serum [34]. Various methods like chemiluminescence [35], high-performance liquid chromatography [36], capillary electrophoresis [37] and electrochemical techniques [38,39] were used for determination of UA. Reducing levels of plasma UA can cause Schizophrenia and there is a correlation between sleep-disordered breathing and UA levels in peripheral blood [40,41]. However, AML can effect on UA levels as investigated by Hamo Mahmood [42]. It has been found that AML therapy produced a fall in serum UA level. In addition, UA could be present in human blood or urine. Therefore, it

would be useful development of a sensitive, rapid, and low cost analytical method for simultaneous determination of AML and UA.

To the best of our knowledge, no study has been reported so far on the electrochemical determinations of AML and UA simultaneously. CNTs/DE was prepared and used for modification of carbon paste electrode (CNTs/DE /CPE). In this work we introduce the first application of CNTs/DE /CPE for simultaneous determination of AML and UA. At optimum conditions, the modified electrode showed high sensitivity, low detection limits and a wide linear dynamic range. The analytical performance of the proposed modified electrode in quantification of UA and AML in human urine and blood serum is evaluated with satisfactory results, which suggest potential application of the proposed sensor in the real sample analysis.

2. EXPERIMENTAL

2.1. Reagents

All chemicals were analytical grade and were obtained mostly from Merck chemical company. DE sample was purchased from Kamel Abad (Tabriz, Iran). UA and AML were obtained from Sigma chemical company. All solutions were freshly prepared with triply distilled water.

Acetate buffer solutions (ABS) were prepared from stock solution of 0.1 M CH_3COOH and 0.1 M CH_3COONa . The pH adjustment was performed using concentrated CH_3COOH and CH_3COONa solutions. Electrochemical behavior of UA and AML were investigated in 0.1 M ABS at pH 6.0. Fresh urine and blood samples were available from Razi institute of vaccine and serum company (Tehran, Iran). The real samples were filtered and diluted 40 times using a 0.1 M ABS of pH 6.0.

2.2. Instrumentation

Autolab PGSTAT 30 Potentiostat Galvanostat (EcoChemie, The Netherlands) coupled with a 663 VA stand (Metrohm, Switzerland) was used for applying all electrochemical measurements. The modified carbon paste electrode (CNTs/DE/CPE) as the working electrode, Ag/AgCl 3 M KCl as the reference electrode and platinum wire as an auxiliary electrode were used for simultaneous determination of UA and AML. PH measurements were performed with a Metrohm 744 pH meter using a combination glass electrode. Field emission scanning electron microscopy (FESEM) images were obtained using Mira 3-XMU microscope.

2.3. Synthesis of CNTs/DE

The composite of the diatomite–alumina was prepared by aid of impregnation method as previously reported [43]. The substrate was loaded with Fe^{3+} ion (5%) to prepare substrate as

a catalyst. For synthesis of CNTs on the surface of substrate, a fixed bed flowed reactor was used. For the synthesis of CNTs, the methane was decomposed on the surface of diatomite–alumina substrate at 700 °C. Finally, the samples were collected and rinsed with nitric acid (3 mol L⁻¹) and water to remove any other impurities and then dried at 80 °C for 5 h.

2.4. Preparation of CNTs/DE/CPE

The results showed that the sensitivity of the modified electrode dependent to the ratio of CNTs/DE to graphite powder in the CPE. When the proportion by mass of CNTs/DE was increased from 2 to 10% and 2 to 8% for UA and AML respectively, the response of the electrode improved. However when the proportions were increased to more than 10% and 8% for UA and AML, respectively, the response slowly decreased (not shown). Therefore modified sensor was prepared by thoroughly mixing the optimum amount of graphite powder to CNTs/DE (%w/w, 90:10) in a mortar and then proper amount of paraffin oil was added to form a carbon paste. A glass tube (ca. 2 mm i.d. and 10 cm long) was firmly filled into one end with a portion of the carbon paste and a copper wire was inserted through the opposite end to establish an electrical contact. Prior to use the sensor, the CNTs/DE/CPE was polished on a piece of weighing paper and rinsed with double distilled water.

2.5. General Procedure

To obtain voltammograms, the general procedure was used as follows. Sample solutions (10 mL) containing 0.1 M ABS at pH 6.0 and appropriate amount of analytes were pipetted into a voltammetric cell. The voltammograms showed oxidation peak potentials about 0.4 and 0.8 V corresponding to UA and AML compounds, respectively. Before running electrochemical experiment, the solution underwent 100 seconds stirring.

EIS was performed in a solution containing 5mM of each of Fe (CN)₆³⁻ and Fe(CN)₆⁴⁻ and 0.1 M KCl at 0.24 V with the frequency swept from 10⁵ to 0.01 Hz.

3. RESULTS AND DISCUSSION

3.1. Characterization of CNTs/DE

The FE-SEM images of as prepared CNTs/DE and DE are shown in Fig. 1. As can be seen in Fig. 1a, DE is composed of plaque plate particles with spherical pores with diameters of about 40-60 nm. Figs. 1b, c and d show SEM image of CNTs/DE composite. The Figs. indicates CNTs retained into the cavities of the diatomite which lead to well dispersion of CNTs on the outer surfaces of the diatomite. The porosity of DE and well dispersion of CNTs on the surface of DE leads to high surface area of the CNTs/DE composite.

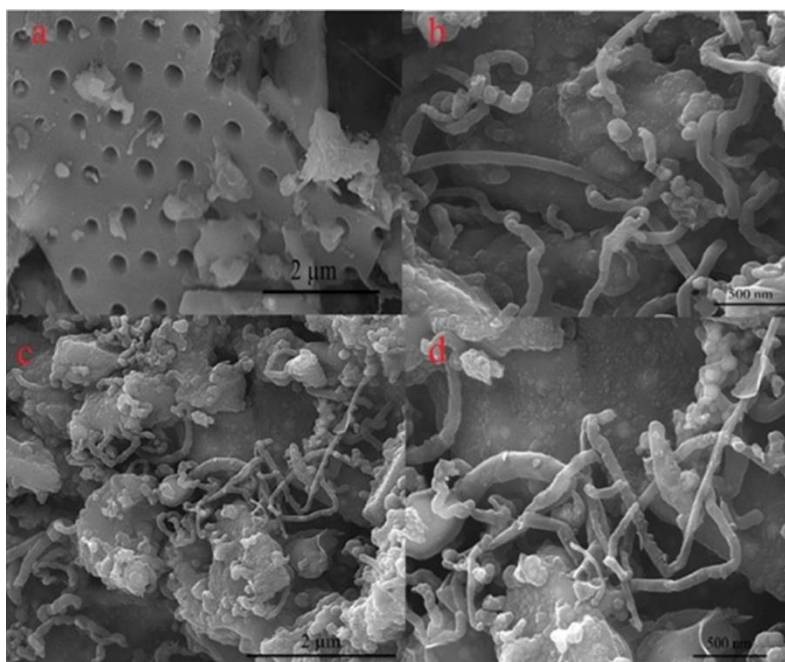


Fig. 1. FE-SEM images of the DE (a) and CNTs/DE (b, c and d)

3.2. Optimization of solution pH and accumulation time

The influence of the different type of electrolytes such as phosphate buffer solution, Britton-Robinson buffer solution, ammonia buffer solution and ABS at CNTs/DE/CPE on oxidation peak currents of UA and AML were investigated. The modified electrode showed the highest sensitivity towards UA and AML in ABS at pH 6.0.

The cyclic voltammetry (CV) method was used for investigation of the effect of solution pH on the responses of the sensor in simultaneous determination of 80 μM UA and 40 μM AML (Fig. 2). As can be seen from Fig. 2B, the oxidation peak currents of UA and AML were increased from pH=4 to pH=6. However at higher pH the corresponding oxidation peaks were decreased. Therefore the pH value of 6.0 was chosen as an optimum solution pH for further experiments.

Fig. 2C shows oxidation peak potential of UA and AML as a function of different pH values. The relationship between oxidation peak potentials of UA and AML are linear. The regression equations were as follows:

$$E_{\text{pa}} \text{ versus } \cdot\text{Ag/AgCl (V)} = 0.8014 - 0.058 \text{ pH} \quad (R^2 = 0.996) \quad \text{UA} \quad (1)$$

$$E_{\text{pa}} \text{ versus } \cdot\text{Ag/AgCl (V)} = 1.049 - 0.0298 \text{ pH} \quad (R^2 = 0.9778) \quad \text{AML} \quad (2)$$

The slope of the equation 1 is close to the Nernstian amounts which suggest an equal number of electron and proton transfers are involved in the electrochemical oxidation. However the slope of the equation 2 is close to the system which expected for a two electron and one proton electrode reaction, which is 0.0296 V/pH at 25 °C [44].

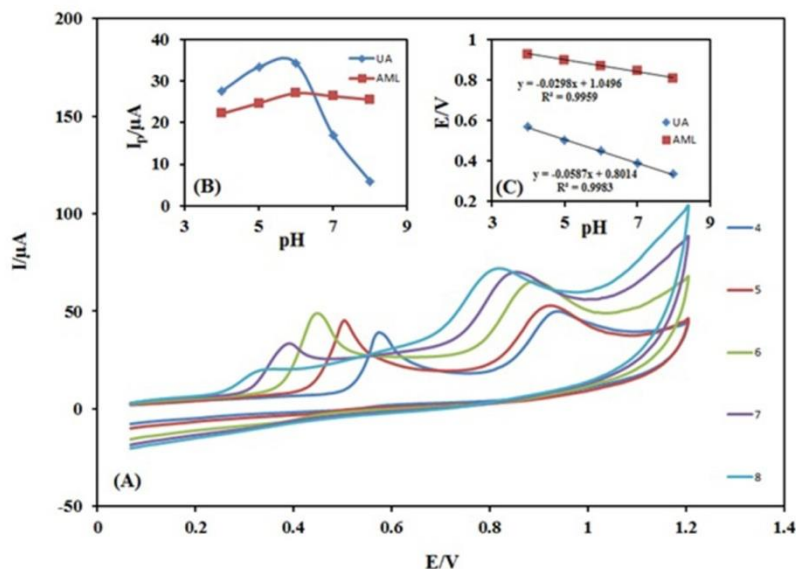


Fig. 2. (A) Cyclic voltammograms of 80 μM UA and 40 μM AML compounds at CNTs/DE/CPE in 0.1 M ABS at different pHs from 4 to 8. Insets; (B) Plot of anodic peak currents (I_{pa}) of UA and AML as a function of pH values; (C) Plot of potential values as a function of pH values

DPV voltammograms were recorded in ranged from 20 to 160 s for the simultaneous determination of 80 μM UA and 40 μM AML in ABS at pH 6.0 (not shown). The accumulation time influenced the responses of the sensor towards UA and AML. The oxidation peak currents of UA and AML were increased with accumulation time, but after 60 s for UA and after 100 s for AML remained almost stable then they level off, respectively. This may be due to saturation of the amount of UA and AML adsorbed at the CNTs/DE/CPE surface. Therefore, the value of 100 s was selected as optimum accumulation time to achieve the highest sensitivity in electrochemical simultaneous determination of UA and AML.

3.3. EIS Studies

The EIS measurement is useful method to investigate characterizations of modified electrodes. The Nyquist plots ($-z''$ vs. z') for (a) CPE, (b) CNTs/DE/CPE were shown in Fig. 3. Nyquist plots were recorded when the CPE and CNTs/DE/CPE were immersed in a 0.1 M KCl solution containing 5mM in both $\text{K}_3[\text{Fe}(\text{CN})_6]$ and $\text{K}_4[\text{Fe}(\text{CN})_6]$. The semicircle diameter in the Nyquist diagram is equal to charge transfer resistance of the electrode (R_{ct}). As can be seen in Fig. 3 the R_{ct} for the CNTs/DE/CPE is smaller than that of the unmodified CPE, which indicates the electron transfer resistance at the CNTs/DE/CPE is lower than CPE. The results suggest the CNTs/DE modification of the electrode provides significant acceleration for $[\text{Fe}(\text{CN})_6]^{3-/4-}$ redox reaction on the electrode surface.

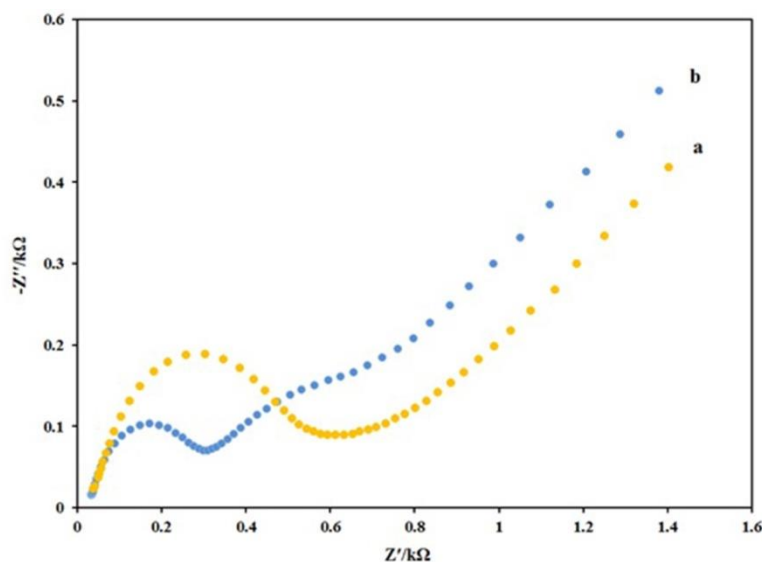


Fig. 3. Nyquist plots for CPE before (a) and after modification with CNTs/DE/CPE (b) when the electrodes immersed into solutions of 5 mM $K_3[Fe(CN)_6]/K_4[Fe(CN)_6]$ and 0.1 M KCl solution

3.4. Electrochemical Studies of UA and AML on CNTs/DE/CPE

Fig. 4 shows cyclic voltammograms of 100 μ M of UA and 50 μ M AML in ABS at bare CPE and CNTs/DE/CPE. The CNTs/DE/CPE shows higher oxidation peak currents with slight shifts to lower oxidation potentials for UA and AML.

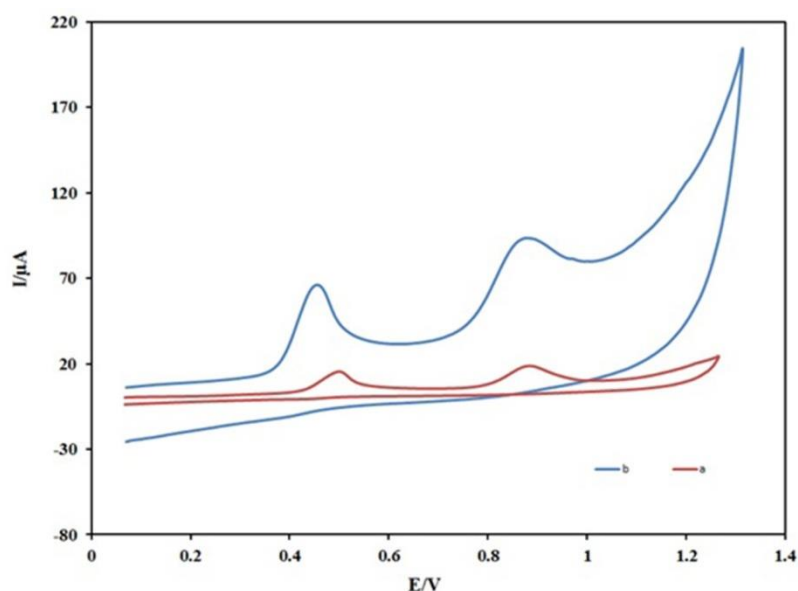


Fig. 4. The CV voltammograms of CPE (a) and CNTs/CPE (b) for 100 μ M UA and 50 μ M AML in 0.1 M ABS (pH 6.0) at scan rate of 100 $mV s^{-1}$

Presence of iron oxides as goethite (FeOOH) particles [43] on the substrate may cause electrocatalytic effect of CNTs/DE to oxidations of UA and AML. In addition presence of CNTs and porosity of DE at CNTs/DE can provide higher surface area which may lead to superior oxidation peak currents for UA and AML at CNTs/DE/CPE. . Therefore, it was concluded that CNTs/DE/CPE is a suitable sensor for simultaneous electrochemical determinations of UA and AML.

In order to investigate effect of variation of scan rate on the lelectrochemical behavior of UA and AML, the following experiments were carried out. Fig. 5 shows cyclic voltammograms of 100 μM of UA and 50 μM AML in ABS at pH 6.0 at various scan rates. The oxidation peak currents of UA and AML were increased with increasing the scan rate over the 10-160 mVs^{-1} and 10-320 mVs^{-1} ranges of scan rate at the modified electrode in 0.1M ABS (pH 6.0), respectively. The relationships between the oxidation peak currents and scan rates are linear and the regression equations were as follows:

$$I_{\text{pa}}(\mu\text{A})=369.66v(\text{V s}^{-1})+7.085 \quad (\text{R}^2=0.993) \quad \text{UA} \quad (3)$$

$$I_{\text{pa}}(\mu\text{A})=288.046v(\text{V s}^{-1})+7.357 \quad (\text{R}^2=0.996) \quad \text{AML} \quad (4)$$

The results prove that the redox reactions of two compounds are adsorption-controlled processes at such scan rates. The plot of currents versus scan rate deviate from linearity at scan rates more than 160 mVs^{-1} and 320 mVs^{-1} for UA and AML, respectively. However the corresponding oxidation peak currents at scan rate over the 180 to 1000 mVs^{-1} and 380 to 1000 mV.s^{-1} ranges of scan rate for UA and AML, respectively, relate linearly with the square root of scan rate ($v^{1/2}$) as follows:

$$I_{\text{pa}}(\mu\text{A})=209.91 v^{1/2}(\text{V s}^{-1})-17.70 \quad (\text{R}^2=0.995) \quad \text{UA} \quad (5)$$

$$I_{\text{pa}}(\mu\text{A})=268.17 v^{1/2}(\text{V s}^{-1})-54.004 \quad (\text{R}^2=0.998) \quad \text{AML} \quad (6)$$

The outcomes indicate the oxidation of UA and AML are diffusion control at such scan rates.

For an irreversible anodic reaction, the relationship between E_p and v describes by Laviron's theory [45] as follows:

$$E_p = E^0 - \left(\frac{RT}{\alpha_a nF}\right) \ln \left(\frac{RTk_s}{\alpha_a nF}\right) + \left(\frac{RT}{\alpha_a nF}\right) \ln v \quad (7)$$

According to the slope of the straight line of E_p against $\ln v$, the values of α_a were calculated to be 0.43 and 0.59 for UA and AML, respectively. The values of E^0 in Eq.(7) can be obtained from the intercept of E_p vs. v curves by extrapolating to the vertical axis at $v=0$ [46]. From E^0 of 0.449 for UA and 0.875 for AML and α_a values, the values of k_s were calculated equal to 3.58 s^{-1} and 1.43 s^{-1} for UA and AML, respectively.

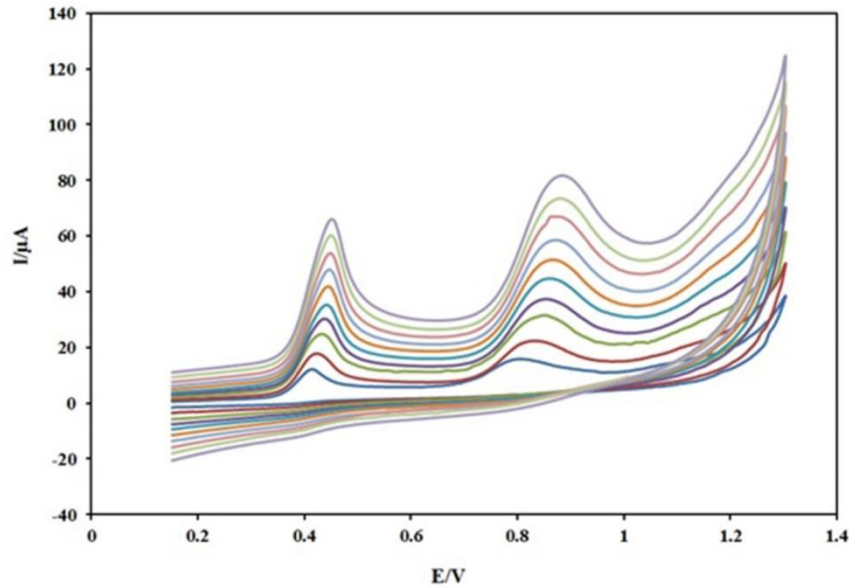


Fig. 5. CV voltammograms of 100 μM UA and 50 μM AML at different scan rates (from inner to outer) 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1 Vs^{-1}

The large values of the electron transfer rate constants shows the high ability of the modified electrode for promoting electron transfer between the UA, AML and the electrode surface.

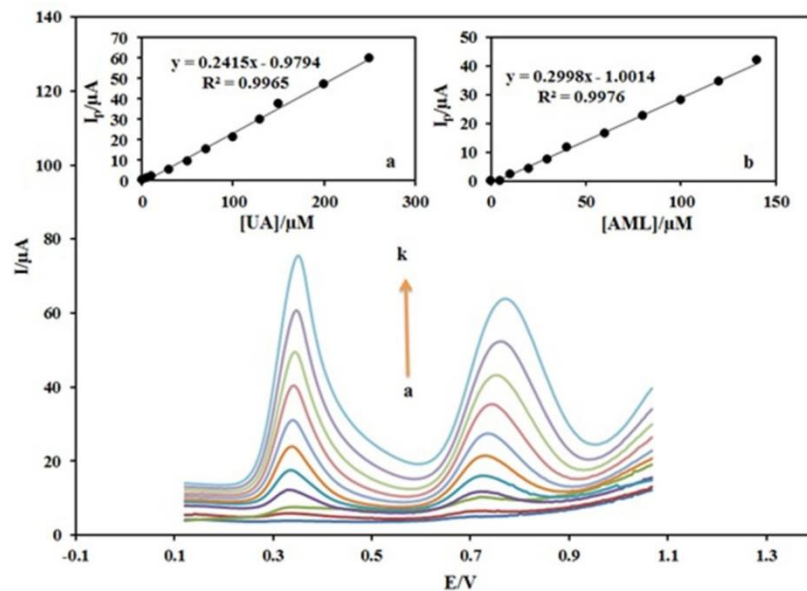


Fig. 6. DPV voltammograms for different concentrations of UA and AML mixture at scan rate of 10 mV s^{-1} as (a) 0.02+0.04, (b) 5+5, (c) 10+10, (d) 30+20, (e) 50+30, (f) 70+40, (g) 100+60, (h) 130+80, (i) 150+100, (j) 200+120 and (k) 250+140 respectively, in which the first value is the concentration of UA in μM and the second value is the concentration of AML in μM . Insets: (a) Plot of peak currents as a function of UA concentrations. (b) Plot of the peak currents as a function of AML concentrations

3.5. Calibration curves

DPV method was used to find out the relationship between the oxidation peak currents of UA and AML with their concentrations. Fig. 6 shows voltammetric responses for successive additions of UA and AML in 0.1 M ABS (pH 6.0) at the CNTs/DE/CPE. Fig. 6a and b shows the corresponding calibration curves of mixture of UA and AML respectively.

Table 1. Comparison of various electrochemical sensors for detection of UA and AML

Analyte	Electrode	pH	LDR (μM)	DL (μM)	Ref
UA	SnO ₂ /graphene nanocomposite /GCE	7.0	0.1-200	0.28	[48]
	graphene/SnO ₂ nanocomposite/GCE	6.8	3-21	3.0	[49]
	purine-based polymer/GCE	7.0	2-1600	0.06	[50]
	Au-nanoparticles/poly(E)-4-(p-tolyldiazenyl)benzene-1,2,3-triol film/GCE	3.0	5-820	0.1	[51]
	pristine graphene/GCE	7.0	5-710	2.0	[52]
	hemin functionalized graphene oxide sheets/GCE	6.0	8-90	0.5	[53]
	Activated graphene/MWCNT nanocomposite loaded Au nanoclusters/GCE	7.0	5-100	0.1	[54]
	CNTs/DE/CPE	6.0	0.02-250	0.011	This work
AML	boron-doped diamond electrode	5.0	0.2-6, 0.6-38	0.07	[44]
	GCE	5.0	1-35	0.31	[24]
	GCE	5.0	4-100	0.8	[23]
	GCE	5.5	8.1-41	0.017	[55]
	oxidized MWCNT/ AuE	11	24-34	4.2	[28]
	SWCNT/ edge plane pyrolytic graphite electrode	7.2	0.005-1	0.001	[27]
	MWCNT/GCE	13	0.017-0.52	0.009	[25]
	CNTs/DE/CPE	6.0	0.04-140	0.021	This work

The anodic peak currents of UA and AML were increased linearly with their concentrations in the ranges of 0.02–250 μM and 0.04–140 μM , respectively. The detection limits of 0.011 μM and 0.021 μM ($S/N=3$) were obtained for UA and AML, respectively. The electrochemical results of this work were compared with the individual analysis which reported in the other literatures and the results were listed in Table 1. As can be seen this modified electrode can provide wide linear range and low detection limit.

3.6. CA measurements

CA measurements were applied to determine the diffusion coefficients of UA and AML at CNTs/DE/CPE (Fig. 7). The working electrode potentials were recorded at 500 and 950 mV for UA and AML, respectively. The different concentrations for UA and AML (0.2, 0.3, 0.4 and 0.5 mM) were employed in this study. The diffusion coefficient of each analyte as calculated from slopes obtained from the plots of I vs. $t^{-1/2}$ (Fig. 7c and d) and using Cottrell equation [47]:

$$I = nFAD^{1/2}C_b\pi^{-1/2}t^{-1/2} \quad (8)$$

where D and C_b are regarded as diffusion coefficient ($\text{cm}^2 \text{s}^{-1}$) and bulk concentration (mol cm^{-3}), respectively. The values of D can be obtained from the mean values of the slopes that obtained from the plots of I vs. $t^{-1/2}$ (Fig. 7c and d). The mean values of D were found to be $172.6 \mu\text{m}^2 \text{s}^{-1}$ and $410.6 \mu\text{m}^2 \text{s}^{-1}$ for UA and AML respectively.

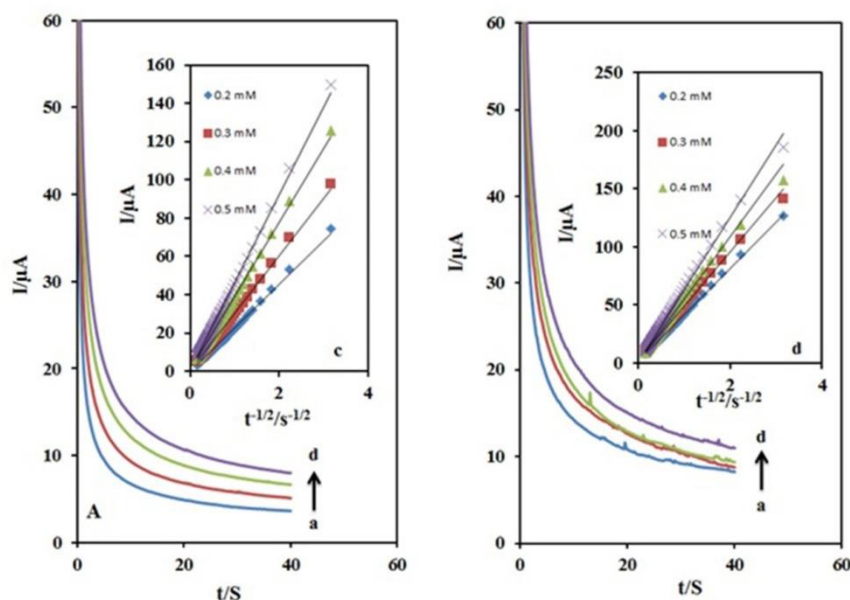


Fig. 7. (A) Chronoamperograms obtained in 0.1 M ABS (pH 6.0) in the presence of (a) 0.2, (b) 0.3, (c) 0.4 and (d) 0.5 mM of UA at CNTs/DE/CPE. (B) Chronoamperograms obtained in 0.1 M ABS (pH 6.0) in the presence of (a) 0.2, (b) 0.3, (c) 0.4 and (d) 0.5 mM of AML at

CNTs/DE/CPE. Insets: (c) Plots of I vs. $t^{-1/2}$ obtained from chronoamperograms in (A) for UA and (d) Plots of I vs. $t^{-1/2}$ obtained from chronoamperograms in (B) for AML

3.7. Stability and Repeatability of the modified electrode

The repeatability of the CNTs/DE/CPE was evaluated by measuring the peak currents of 150 μM UA and 100 μM AML in ABS (pH 6.0) by DPV method. Relative standard deviations of 3.6% and 4.8%, respectively, for UA and AML were obtained. The results showed that the modified electrode has a good repeatability and is not subject to surface fouling by the oxidation products.

The stability of prepared electrode was tested by determining of the decrease in voltammetric current during repetitive DPV measurements of UA and AML solutions with CNTs/DE/CPE stored in air or solution for certain period of time. As a results, in the determination of 150 μM UA and 100 μM AML in 0.1 M ABS (pH 6.0), when the modified electrode was subjected to an experiment, after 10h gave less than 9.6 and 9.5% decrease in the oxidation currents of UA and AML, respectively. In addition, when the modified electrode was stored in the air for 4 days, the responses of the electrode towards UA and AML in the solution were reduced less than 5.2 and 4.7%, respectively. The results showed good stability of the proposed modified electrode which suggests the potential of the proposed sensor for detection of these compounds in routine analysis.

3.8. Effect of Interferences and Analytical Applications

The effects of various foreign species in solutions of 100 μM UA and 50 μM AML were investigated at the optimum conditions.

Table 2. Maximum tolerable concentration of interfering species

<i>Interfering species</i>	<i>UA</i>	<i>AML</i>
Para aminophenol	200	250
L-glutamic acid	650	400
Epinephrine	450	350
Aspartic acid	700	650
Codeine	350	200
Ascorbic acid	400	550
L-Dopa	300	300
Dopamine	250	350
Fructose	600	500
Glucose	500	550
Methanol	650	700
Ethanol	550	500

C_{int} refers to interfering compound concentration

The tolerance limit is defined as the maximum concentration of the interferent, which caused an approximately 5% error in the determination of UA or AML. The results are given in Table 2. The data show that interferences are only significant at relatively high concentrations, confirming that the proposed method is expected to be free from interferences from common components of biological samples.

Table 3. Estimation of UA and AML in diluted (40-fold) urine

<i>Spiked (μM)</i>		<i>Found (μM)</i>		<i>^aR.S.D. (%)</i>		<i>Recovery</i>	
<i>UA</i>	<i>AML</i>	<i>UA</i>	<i>AML</i>	<i>UA</i>	<i>AML</i>	<i>UA</i>	<i>AML</i>
0	0	44.21	0	0	0	-	-
30	30	73.32	28.73	2.6	3.8	97.03	95.76
60	60	107.23	59.36	1.9	2.4	105.03	98.93

^a Average of five determinations at optimum conditions

UA and AML were determined in serum and urine samples in order to investigate the suitability of the proposed sensor for the determination of UA and AML in real sample analysis by DPV method. The results for the determination of UA and AML in human urine and serum are summarized in Table 3 and Table 4, respectively. The urine and serum samples were diluted 40 times before analysis and spiked with appropriate amounts of UA and AML. Standard additions method was used for calculation of the concentrations of UA and AML. The results show the proposed method is a reliable method for the direct simultaneous determination of UA and AML in biological fluids.

Table 4. Estimation of UA and AML in diluted (40-fold) serum

<i>Spiked (μM)</i>		<i>Found (μM)</i>		<i>^aR.S.D. (%)</i>		<i>Recovery</i>	
<i>UA</i>	<i>AML</i>	<i>UA</i>	<i>AML</i>	<i>UA</i>	<i>AML</i>	<i>UA</i>	<i>AML</i>
0	0	36.7	0	3.4	0	-	-
40	40	77.53	38.47	3.5	4.2	102.07	96.17
80	80	120.48	83.02	2.4	3.7	104.47	103.77

^a Average of five determinations at optimum conditions

4. CONCLUSION

In this paper CNTs/DE was prepared and used as a suitable modifier for fabrication of novel CNTs/DE/CPE. The modification of CPE with CNTs/DE leads to excellent electrocatalytic performance for the simultaneous determination of UA and AML. The electrode also shows high stability in repetitive experiments. The interfering study of some species showed no significant interference with determination of UA and AML. Application of the proposed sensor for the determination of UA and AML in some real samples gave satisfactory results, without the necessity of sample pretreatments or time-consuming extractions. The high speed, reproducibility, high stability, wide linear dynamic range, simplicity and low detection limit suggest that the proposed sensor is an attractive candidate for practical applications.

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